An overview of Flavor Physics (II)

J. Martin Camalich

XLVIII International Meeting on Fundamental Physics In Benasque

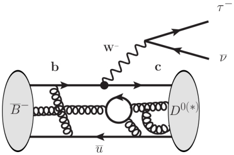
September 7 2021

Outline of the talks

1. **1st talk: September 7th**
   - Introduction to flavor and "Why to investigate on Flavor Physics in the XXI c.?"
   - Quick status CKM metrology and Cabibbo-angle Anomaly
   - The R_K lepton-flavor universality anomalies
2. **2nd talk: September 8th**
   - The R_D lepton-flavor universality anomalies
   - The LHC flavor-physics program
   - A view on dark-flavor sectors

The $b \to c\tau\nu$ lepton-universality anomalies

Another lepton-flavor universality anomaly: The $b \to c\tau\nu$ decays

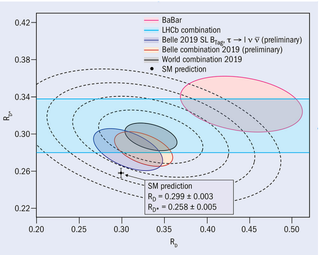


$$R_{D^{(*)}} = \frac{\mathcal{B}(\bar{B}\to D^{(*)}\tau^-\bar{\nu})}{\mathcal{B}(\bar{B}\to D^{(*)}\ell^-\bar{\nu})} \quad \text{where} \quad \ell = e, \mu$$

- **Babar**, **Belle** and **LHCb** are independently in tension with SM!

Obs.	Current World Av./Data	Current SM Prediction	Significance	
$\mathcal{R}(D)$	$\mathbf{0.337 \pm 0.030}$	0.299 ± 0.003	1.3σ	$\mathbf{3.6\sigma}$
$\mathcal{R}(D^*)$	$\mathbf{0.298 \pm 0.014}$	0.258 ± 0.005	2.5σ	
$P_\tau(D^*)$	$-0.38 \pm 0.51^{+0.21}_{-0.16}$	-0.501 ± 0.011	0.2σ	
$F_{L,\tau}(D^*)$	$0.60 \pm 0.08 \pm 0.04$	0.455 ± 0.006	1.6σ	
$\mathcal{R}(J/\psi)$	$0.71 \pm 0.17 \pm 0.18$	0.2582 ± 0.0038	1.8σ	
$\mathcal{R}(\pi)$	1.05 ± 0.51	0.641 ± 0.016	0.8σ	

Bernlochner *et al.*, arXiv:2101.08326
Bernlochner talk @ EPS-HEP 2021

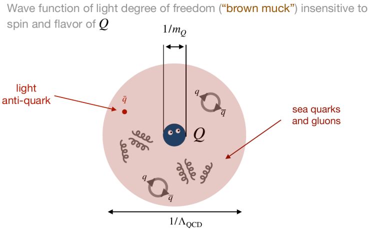


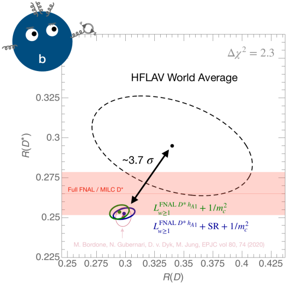
1. **Independent LFUV in B decays** (to 2$^{\rm nd}$-generation quarks)
2. **Large effect in CCs** (10%): $\Lambda_{\rm NP} \sim 3$ TeV
3. **Hint towards NP addressing flavor puzzle?** (τ vs. μ)

Hadronic matrix elements in $B \to D^{(*)}$ transitions

- **Fit Form Factors to experimental $B \to D^{(*)}(\mu, e)\nu$ data**

  Boyd, Grinstein & Lebed '96, Caprini, Lellouch & Neubert'98
  - Important kinematic effects! ($m_\tau \gg m_\ell$)
- **There are LQCD calculations of the FFs** (Na *et al.* PRD92(2015)no.5,054510, Bailey *et al.* PRD92,034506)...
- **Prediction relies on HQET**





Bernlochner talk @ EPS-HEP 2021

- Includes "constrained" $\mathcal{O}(\Lambda_{\rm QCD}/m_{c,b})^2$ and $\mathcal{O}(\alpha_s)$ corrections
- Nonperturbative (subleading) inputs from **LQCD** and **QCD sum rules**

Hadronic uncertainties cannot explain the $R_{D^{(*)}}$ anomalies

Analysis in terms of EFT of NP

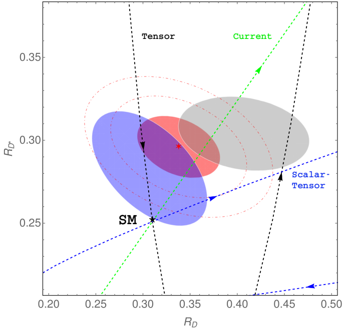
Low-Energy EFT Lagrangian

$$\mathcal{L}_{\rm eff} \supset -\frac{G_F V_{cb}}{\sqrt{2}}[(1+\epsilon_L^\ell)(\bar{\ell}\nu_\ell)_{\mathbf{V-A}}\cdot(\bar{c}b)_{\mathbf{V-A}}+\epsilon_{S_L}^\ell(\bar{\ell}\nu_\ell)_{\mathbf{S-P}}\cdot(\bar{c}b)_{\mathbf{S-P}}+\epsilon_{S_R}^\ell(\bar{\ell}\nu_\ell)_{\mathbf{S-P}}(\cdot\bar{c}b)_{\mathbf{S+P}}+\epsilon_T^\ell(\bar{\ell}\nu_\ell)_{\mathbf{T}}\cdot(\bar{c}b)_{\mathbf{T}}]+\text{h.c.}$$

- Add RH ν's N_R (See e.g. Robinson, Shakya & Zupan, JHEP 1902 (2019) 11)

$$\mathcal{L}_{\rm eff}\supset -\frac{G_F V_{cb}}{\sqrt{2}}\tilde{\epsilon}_R^\ell\ \bar{\ell}\gamma_\mu N_R\ \bar{c}\gamma^\mu(1+\gamma_5)b$$

- The SM + 5 New-Physics operators



Post-Moriond 2019		
	Best fit	$\text{Pull}_{\rm SM}$
ϵ_L^τ	0.07(2)	3.43
$\tilde{\epsilon}_R^\tau$	0.39(5)	3.43
ϵ_T^τ	$-0.03(1)$	3.30

- **"Current-current" scenarios** best

$\Lambda_{\rm NP} \simeq 4.6$ TeV

Shi *et al.* JHEP 1912 (2019) 065, Murgui *et al.* JHEP 09 (2019) 103, ...

Beyond the $R_{D^{(*)}}$ ratios

❶ New R_X and/or q^2 spectrum

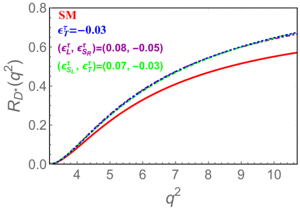
- Baryonic modes ($\Lambda_b \to \Lambda_c^{(*)} \tau\nu$), B_c decays ($B_c \to J/\psi \tau\nu$), B_s decays ($B_s \to D_s^{(*)} \tau\nu$)
- Limited additional info?

$$\frac{\mathcal{R}(\Lambda_c)}{\mathcal{R}_{\rm SM}(\Lambda_c)} = 0.262\frac{\mathcal{R}(D)}{\mathcal{R}_{\rm SM}(D)} + 0.738\frac{\mathcal{R}(D^*)}{\mathcal{R}_{\rm SM}(D^*)} - x$$

Blanke *et al.* PRD99(2019)7,075006

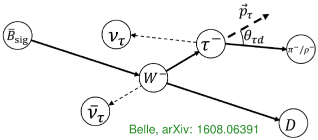
- **Consistency tests** of NP!

- **Spectrum:** Not very informative



❷ Measure new (angular) observables

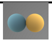
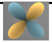
- τ decays "promptly"



Belle, arXiv: 1608.06391

$$\cos\theta_{\tau d} = \frac{2E_\pi E_\tau - m_\pi^2 - m_\tau^2}{2|\vec{p}_\pi||\vec{p}_\tau|}$$

- Access to polarization properties of the τ!

Polarization		Angular	
			
1	Γ	A_{FB}	A_Q
L	P_L	Z_L	Z_Q
$\perp$	$P_\perp$	$Z_\perp$	✗
T	P_T	Z_T	✗

* Z stands for *zweifach*.

Asadi *et al.* PRD102(2020)9,095028, Peñalva *et al.* JHEP06(2021)118, Bhattacharya *et al.* JHEP07(2020)07,194 ...

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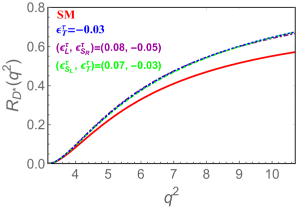

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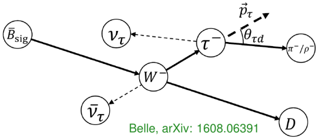
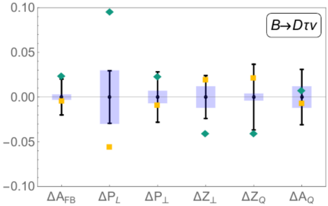


Belle, arXiv: 1608.06391

$$\cos\theta_{\tau d} = \frac{2E_\pi E_\tau - m_\pi^2 - m_\tau^2}{2|\vec{p}_\pi||\vec{p}_\tau|}$$

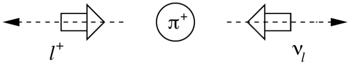
- **Discrimination between NPs at Belle II**



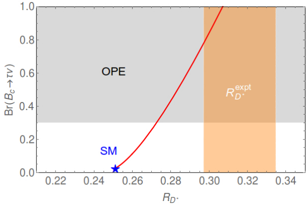
Asadi *et al.* PRD102(2020)9,095028, Peñalva *et al.* JHEP06(2021)118, Bhattacharya *et al.* JHEP07(2020)07,194 ...

The special case of $B_c \to \tau\nu$

- $B_c \to \tau\nu$ **very sensitive to "scalar currents"** (e.g. charged Higgses)
  - Axial (SM) – "Chiral suppression": m_τ / m_{B_c}



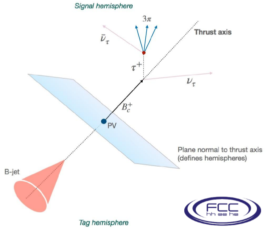
$$A : \bar{e}_L \gamma^\mu \nu_L \,, \quad P : \bar{e}_R \nu_L$$

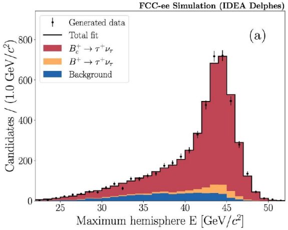


  - ***B_c's lifetime disfavors charged scalars!***

See though Aebischer talk @ PANIC2021

- **Flavor-physics case for FCC-ee** C. Halsen's talk @ EPS-HEP 2021
  - 5×10^{12} Z^0 (7.6×10^{10}) $b\bar{b}$ pairs





$\sim$ 4% precision

Combined explanations of R_{D^*} and R_{K^*} anomalies

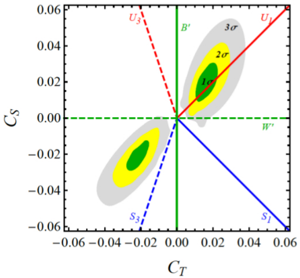
Same structure and generations as in $b \to s\mu\mu$

SMEFT operators: $Q^{(1)}_{\ell q(ijkl)} = \frac{1}{\Lambda^2}(\bar{Q}_L^{\,i}\gamma^\mu Q_L^{\,j})(\bar{L}_L^{\,k}\gamma_\mu L_L^{\,l})$, $\quad Q^{(3)}_{\ell q(ijkl)} = \frac{1}{\Lambda^2}(\bar{Q}_L^{\,i}\gamma^\mu \vec{\tau} Q_L^{\,j})\cdot(\bar{L}_L^{\,k}\gamma_\mu \vec{\tau} L_L^{\,l})$

- Suggestive of a combined explanation* Bhattacharya et al. '14, Alonso et al. '15, Greljo et al. '15, ...
  1. **Can be probed at LHC:** Reduces scale of NP to ∼TeV
  2. **Addressing flavor puzzle?** Effect **larger** for **heavier** leptons and quarks

Three main options
(*for the combined explanation*):

	$SU(2)_L$ singlet	$SU(2)_L$ triplet
Vector LQ:	U_1	U_3
Scalar LQ:	S_1	S_3
Colorless vector:	B'	W'

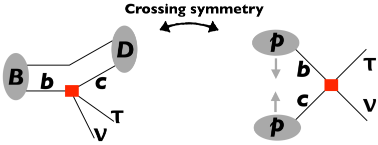


Vector leptoquarks are the (almost) unique choice

- **A lot of activity in model building** A. Teixeira's talk @ EPS-HEP 2021, G. Isidori's talk @ PANIC2021

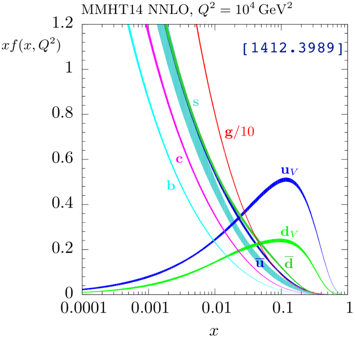
The LHC Flavor Physics Program

The LHC flavor program: Collider probes of the R_{D^*} anomalies



Greljo, JMC & Ruiz-Álvarez, PRL122, 131803

- **The proton is flavored. . .**



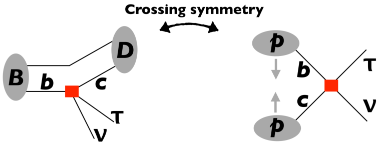
- Cross-section at $s \gg m_W^2$

$$\frac{\sigma_{\rm NP}}{\sigma_{\rm SM}} \sim \frac{\sum_i \mathcal{L}_{ib} \otimes |V_{ib}|^2 \frac{s}{v^4} \left(\alpha_\Gamma |\epsilon_\Gamma^\tau|^2\right)}{\mathcal{L}_{ud} \otimes |V_{ud}|^2 \frac{s}{v^4} \left(\frac{M_W^2}{s}\right)^2}$$

- NP **suppressed** by CKM and PDF's
- NP **enhanced** by s^2/M_W^4
- NP sensitivity is **quadratic**

Search excess in tails of $pp \to \tau +$ MET!

The LHC flavor program: Collider probes of the R_{D^*} anomalies



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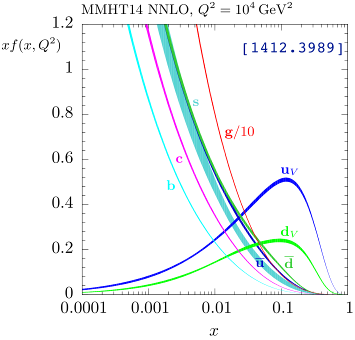
- **The proton is flavored…**



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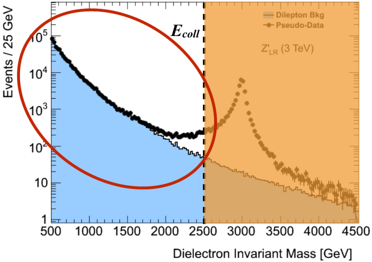


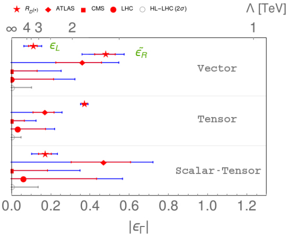
LHC bounds and HL-LHC prospects

- **We could (should?) discover the mediators at the HL-LHC**

  - **The LHC is sensitive to the relevant NP!**
    - ★ **Current LHC data:** Exclude RHCs
    - ★ **HL-LHC:** Sensitivity to all scenarios
  - ***b*-tagging:** Improve bounds ($\sim 30\%$)

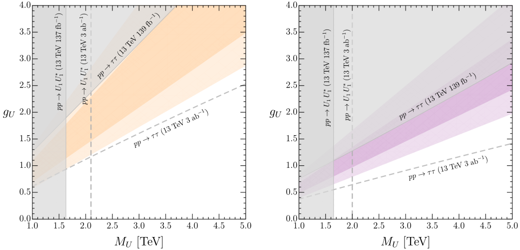
    Marzocca *et al.*, JHEP 12 (2020) 035

No-loose theorem for colliders!



Greljo, JMC & Ruiz-Álvarez, PRL122, 131803

- **Tauonic Drell-Yan $pp \to \tau\tau$ more relevant for many models**
  - U_1-leptoquark mostly coupled to 3rd generation Cornella *et al.*, 2103.16558, G. Isidori's talk @ PANIC2021

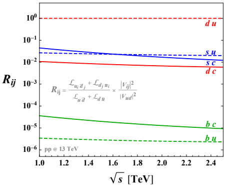


The LHC as a quark-flavor collider

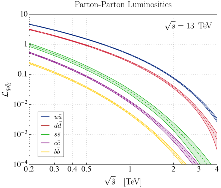
- **Partonic luminosities at LHC** Angelescu *et al.*, EPJC80(2020)7,641, Fuentes-Martin *et al.*, JHEP11(2020)080

$$\mathcal{L}_{q_i\bar{q}_j}(\tau,\mu_F) = \int_\tau^1 \frac{dx}{x} f_{q_i}(x,\mu_F) f_{\bar{q}_j}(\tau/x,\mu_F)$$

  - Off-diagonal



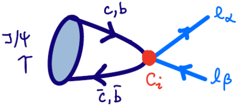
  - Diagonal

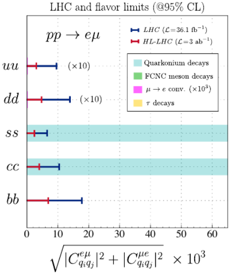


- **Some searches of NP more sensitive than low energies!**

- **LHC much more sensitive to LFV than quarkonium!**

Angelescu *et al.* EPJC80(2020)7,641



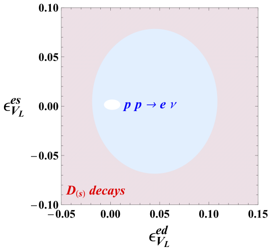


  - Quarkonium mainly decays electromagnetically

Charming NP at the LHC

- **Charged current decays:** $c \to d\ell\nu$ and $c \to s\ell\nu$

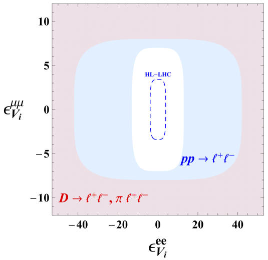
Channel	Statistics [fb^{-1}]	Experiment
$\tau\nu$	36	CMS
	36	ATLAS
$e\nu, \mu\nu$	139	ATLAS
	36	ATLAS
	36	CMS



LHC much stronger than low-E

- **FCNC decay:** $c \to u\ell\nu$

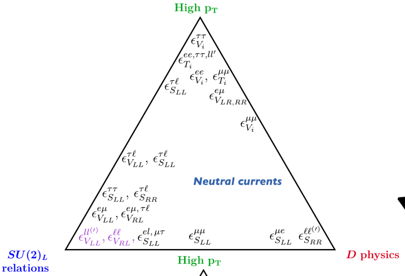
Channel	Statistics [fb^{-1}]	Experiment
$\tau\tau$	36	ATLAS
$\tau\tau, e\mu, e\tau, \mu\tau$	2.2	CMS
$ee, \mu\mu$	139	ATLAS
	140	CMS
	36	CMS
	36	ATLAS

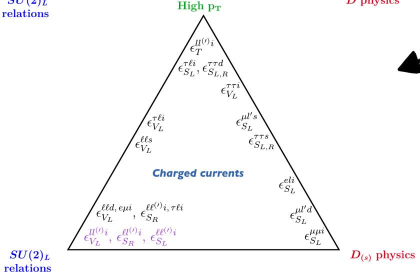


LHC stronger than D-neutral decays!

Fuentes-Martin *et al.*, JHEP11(2020)080

High p_T provides inputs to flavor physics





We systematically went through all options

$$\mathcal{O}_{LQ}^{(1)} = (\bar{L}\gamma_\mu L)(Q\gamma^\mu Q)\,, \qquad \mathcal{O}_{LQ}^{(3)} = (\bar{L}\gamma_\mu \tau^I L)(Q\gamma^\mu \tau^I Q)\,,$$

$$\mathcal{O}_{eu} = (\bar{e}\gamma_\mu e)(\bar{u}\gamma^\mu u)\,, \qquad \mathcal{O}_{Lu} = (\bar{L}\gamma_\mu L)(\bar{u}\gamma^\mu u)\,,$$

$$\mathcal{O}_{Qe} = (\bar{Q}\gamma^\mu Q)(\bar{e}\gamma_\mu e)\,, \qquad \mathcal{O}_{LedQ} = (\bar{L}\gamma_\mu e)(\bar{d}\gamma^\mu Q)\,,$$

$$\mathcal{O}_{LeQu}^{(1)} = (\bar{L}^p e)\epsilon_{pr}(\bar{Q}^r u)\,, \qquad \mathcal{O}_{LeQu}^{(3)} = (\bar{L}^p \sigma_{\mu\nu} e)\epsilon_{pr}(\bar{Q}^r \sigma^{\mu\nu} u)\,,$$

High-p_T already competitive (or better) than low-E

Dark flavored sectors

Flavored dark sectors: (1) The axion

1. The **familon** or **axiflavon**

Wilczek PRL49(1982)1549, Calibbi *et al.* PRD95(2017)095009

Axions and Family Symmetry Breaking

Frank Wilczek
Institute for Theoretical Physics, University of California at Santa Barbara, Santa Barbara, California 93106
(Received 20 September 1982)

Possible advantages of replacing the Peccei-Quinn U(1) quasisymmetry by a group of genuine flavor symmetries are pointed out. Characteristic neutral Nambu-Goldstone bosons will arise, which might be observed in rare K or μ decays. The formulation of Lagrangians embodying these ideas is discussed schematically.

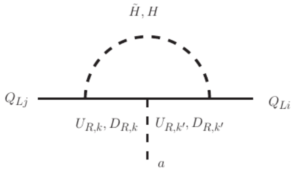
- Horizontal (flavor) symmetries can solve flavor puzzle and provide QCD axion!

2. **QCD axion (DFSZ models) with non universal PQ charges**

$$\mathcal{L}_a = -\frac{\partial_\mu a}{2 f_a}\frac{1}{N}\left[\bar{f}_L\left(U_L^{f\dagger}\boldsymbol{X}_{f_L}U_L^f\right)f_L + \bar{f}_R\left(U_R^{f\dagger}\boldsymbol{X}_{f_R}U_R^f\right)f_R\right]$$

Di Luzio *et al.* Phys.Rept. 870 (2020) 1-117

3. **Radiative SM corrections generate flavor violation**



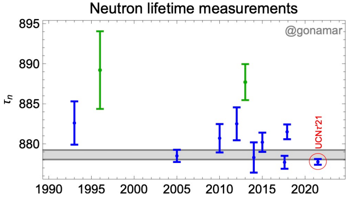
$$16\pi^2\frac{d\mathbf{c}_q}{d\ln\mu} = \frac{1}{2}\left(\mathbf{y}_u\mathbf{y}_u^\dagger + \mathbf{y}_d\mathbf{y}_d^\dagger\right)\mathbf{c}_q - \mathbf{y}_u\mathbf{c}_u\mathbf{y}_u^\dagger + \frac{1}{2}\mathbf{c}_q\left(\mathbf{y}_u\mathbf{y}_u^\dagger + \mathbf{y}_d\mathbf{y}_d^\dagger\right) - \mathbf{y}_d\mathbf{c}_d\mathbf{y}_d^\dagger - c_H\left(\mathbf{y}_u\mathbf{y}_u^\dagger - \mathbf{y}_d\mathbf{y}_d^\dagger\right),$$

JMC, Pospelov, Vuong, Ziegler, Zupan PRD 102 (2020) 1, 015023

Flavored dark sectors: (2) Dark Baryons

- **Dark particles with baryon number $\Rightarrow$ Baryon-number violating signatures**
  - $m_\chi > m_p$ **to avoid proton decay!**

1. **The "neutron lifetime anomaly"**



Martin Gonzalez-Alonso's twitter

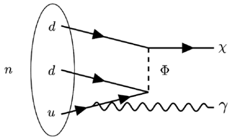
- Another $\sim 4\sigma$ discrepancy!

$$\tau_n^{\text{bottle}} = 878.49(49)\ s$$
$$\tau_n^{\text{beam}} = 888(2)\ s$$

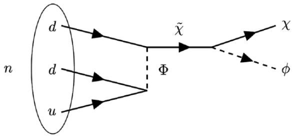
- **Exotic Solution: Loosing neutrons in the bottle decaying onto dark baryons!**

Fornal&Grinstein, PRL120,191801(2018)

- Expt signature with one SM particle



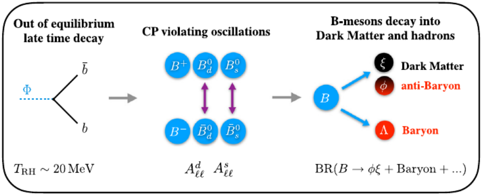
- Expt signature purely invisible



Flavored dark sectors: (2) Dark Baryons

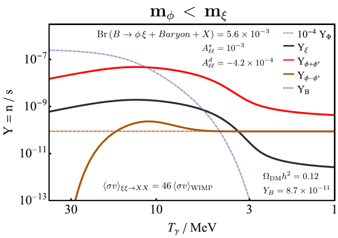
- **Dark particles with baryon number $\Rightarrow$ Baryon-number violating signatures**
  - $m_\chi > m_p$ **to avoid proton decay!**

2. **The "mesogenesis" mechanism for baryogenesis**

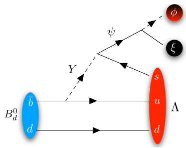


Elor,Escudero, Nelson, PRD99(2019)3,035031, Alonso-Alvarez, Elor, Escudero, arXiv: 2101.02706

- Produces successful baryogenesis and "antibaryonic" DM with SM *CP*-violation!



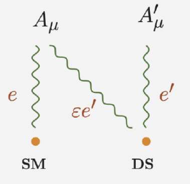
- **Testable in laboratories!**



See LHCb prospects in Brea Rodríguez *et al.* arXiv: 2106.12870

Flavored dark sectors: (3) The dark photon

- **The massless dark-photon**
  - No renormalizable coupling to SM fermions
    Holdon, PLB166(1986)196, del Águila *et al.* NPB456(1995) 531



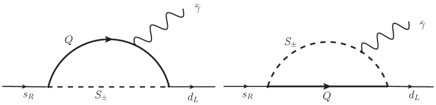
Fabbrichesi *et al.*, arXiv: 2005.01515

  - Couples via higher dimension operators!

$$\frac{1}{M^2} P_{\mu\nu}(\overline{q}_L \sigma^{\mu\nu} C_u \widetilde{H} u_R + \overline{q}_L \sigma^{\mu\nu} C_d H d_R + \bar{l}_L \sigma^{\mu\nu} C_e H e_R + \text{H.c.}).$$

Dobrescu, PRL94(2005)151802

  - **Flavor naturally in simplified models**



Fabbrichesi *et al.* PRL119((2017)031801

- **Doesn't mix with the photon:** Difficult to test experimentally
  - **Look for flavor violating processes!**
- **Topic of increasing interest:** 50^+ th's and exp's for a Snowmass document

3rd meeting on Searches for Hidden Sectors at Kaon and Hyperon Factories
lunes 12 jul. 2021 15:00 → 18:30 Europe/Zurich

An Example: The flavor phenomenology of the QCD axion

PHYSICAL REVIEW D **102,** 015023 (2020)

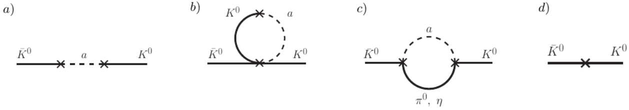
Quark flavor phenomenology of the QCD axion

Jorge Martin Camalich,[1,2] Maxim Pospelov,[3,4] Pham Ngoc Hoa Vuong,[5] Robert Ziegler,[6,7] and Jure Zupan[8]

- **Full phenomenological survey of quark flavor phenomenology**

  See also Feng *et al.* PRD57(1998)5875-5892

  1. Recast bounds of many searches in 2-body decays
     - ★ E.g. $B \to \pi a$ for the coupling of the axion to *bottom-down*
  2. Analyze and provide theoretical predictions for new decays
     - ★ $K \to \pi\pi a$, $\Lambda \to na$, ...
  3. Calculate neutral-meson mixing rigorously using ChPT

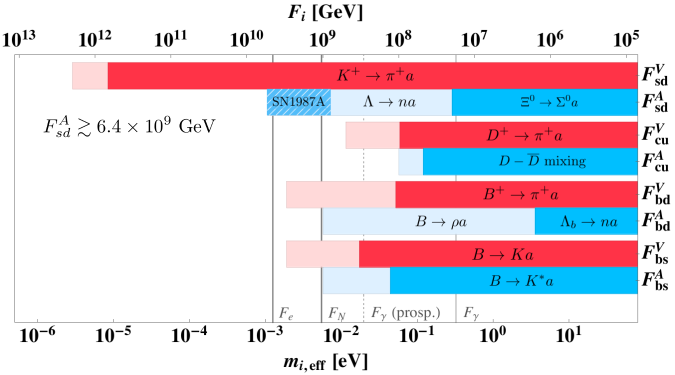


  4. Incorporate RGEs for derivation and comparison of bounds

An Example: The flavor phenomenology of the QCD axion

$$\mathcal{L}_a = \frac{\partial_\mu a}{2 f_a} \bar{\psi}_i \gamma^\mu \left(c_{ij}^V + c_{ij}^A \gamma_5 \right) \psi_j$$

- Define $F_{sd}^{V,A} = 2 f_a / c_{sd}^{V,A}$



JMC, Pospelov, Vuong, Ziegler, Zupan PRD 102 (2020) 1, 015023

Strongest absolute limit on f_a from $K^+ \to \pi^+ a$ (NA62)!

NA62, JHEP 03 (2021) 058

The SN 1987A bound on flavor: Muons

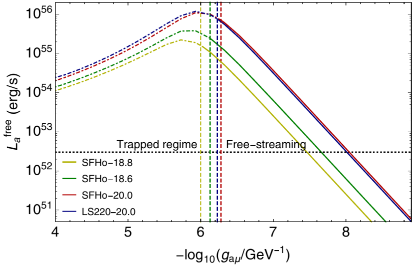
- **Proto-NS are very dense (supranuclear) and hot ($T \sim 30$ MeV) environments**

> Heavier flavors (muons and strange)
> can exist in equilibrium in the plasma

- **SN cooling Limits on couplings of dark bosons to muons** (Raffelt's criterion)
  - The QCD axion Bollig *et al.*PRL125(2020)5,051104

★ Astro and EoS uncertainties

Model name	Equation of state	Progenitor mass ($M_\odot$)	NS bary. mass ($M_\odot$)
SFHo-18.8	SFHo [48]	18.8 [49]	1.351
SFHo-18.6	SFHo [48]	18.6 [50]	1.553
SFHo-20.0	SFHo [48]	20.0 [51]	1.947
LS220-20.0	LS220 [52]	20.0 [51]	1.926



Best limit on $g_{a\mu}$

$g_{a\mu} < 10^{-7.4}$ GeV

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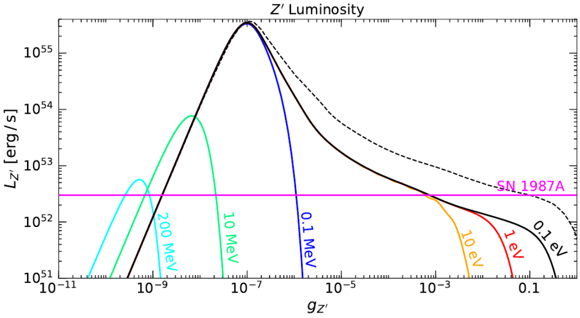
  - Light Z' bosons



Croon *et al.* JHEP 01 (2021) 107

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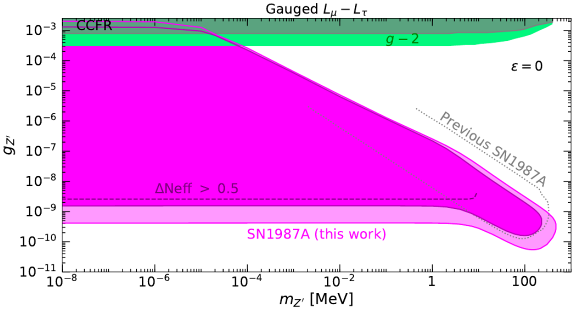
  - Gauge-flavored $L_\tau - L_\mu$ Z'



Croon *et al.* JHEP 01 (2021) 107

The SN 1987A bound on flavor: Strangeness

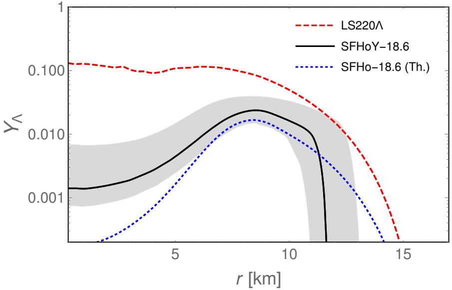
- **There are hyperons (Λ's) in proto-neutron stars!**
  - Abundancies sustained by weak processes

$$pe^- \leftrightarrow \Lambda\nu_e, \qquad \Lambda \to pe^-\bar{\nu}, \ldots$$

  - High temperatures and supranuclear densities

Thermal effects: $n_\Lambda \simeq n_n \exp\left(-\frac{m_\Lambda - m_n}{T}\right) \simeq 0.01 \times n_n$

- **Same SN simulations for SN 1987A + Λ EoS**



JMC *et al.* PRD103(2021)12,L121301

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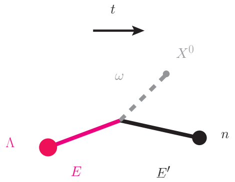
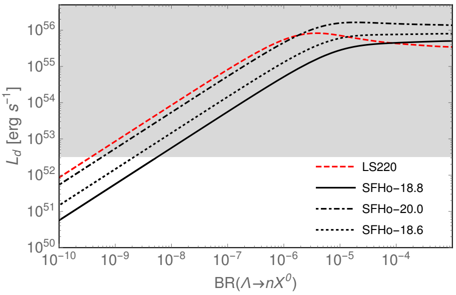
- **Very strong bound from** $\Lambda \to nX^0$



"Model-independent" SN bound

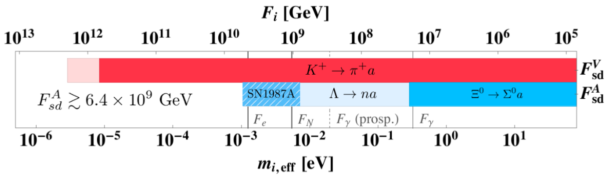
$\mathrm{BR}(\Lambda \to nX^0) \lesssim 8.0 \times 10^{-9}$



JMC *et al.* PRD103(2021)12,L121301

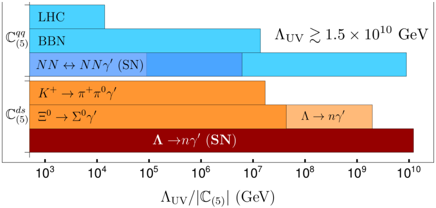
Application of the SN bound to dark flavored sectors

- **Axions**



  - Best on axions with **tuned axial couplings**
  - **BESIII projections** are **1 order of magnitude below** the SN bound

- **Massless dark photon**

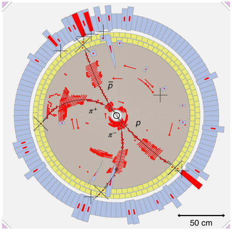


Strongest limit on the couplings of massless dark-photon to quarks

The ongoing hyperon experimental revolution

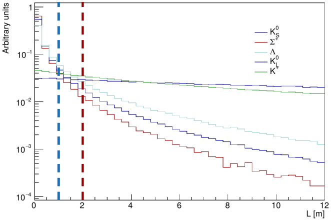
- **Recent experimental "revolution" on hyperon physics after 40^+ yrs ...**

- **Polarized-hyperon factories (BESIII&SCTF)**



Nature Physics 15, 631-634(2019)

- **LHCb:** 10^{2-3} more hyps than B's



Alves Junior *et al.* JHEP 05 (2019) 048

- **Cleaning up the old data base**
  - The α_π parameter in $\Lambda \to p\pi^-$ in BESIII

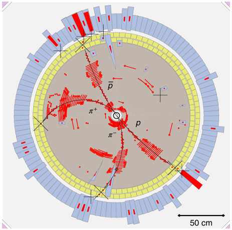
$$\frac{d\Gamma}{d\cos\theta} = \frac{\Gamma}{2}(1 + P\alpha_\pi \cos\theta)$$

- ★ **BESIII measurement** $(17 \pm 3)\%$ **larger than "old" PDG!** ($>5\sigma$)
- ★ **NEW:** Vigorous program on *CP* violation with hyperons

The ongoing hyperon experimental revolution

- **Recent experimental “revolution” on hyperon physics after 40^{+} yrs ...**

▸ **Polarized-hyperon factories (BESIII&SCTF)**



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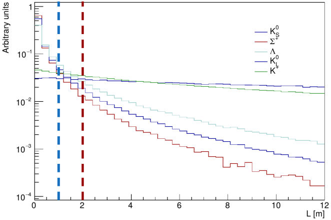
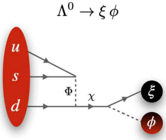
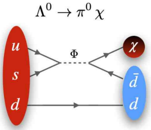
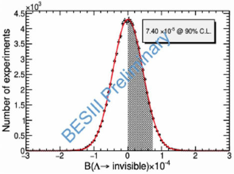


Alves Junior *et al.* JHEP 05 (2019) 048

- **Searching for flavored dark sectors!**
  - ▸ **NEW:** BR($\Lambda \to$ invisible) $< 7.4 \times 10^{-5}$ @ 90% CL Liu Kai’s poster @ PANIC2021







Conclusions

1. **We are witnessing a golden era in flavor physics**

   - **Titanic progress on the experimental side**

   - **CKM metrology:** High level of maturity and precision
   - **Rare and ultra-rare flavor phenomena:** Precision

2. **Flavor anomalies**

   "Extraordinary claims require Extraordinary evidence"
   – *C. Sagan*

   - **Approaching that level at LHCb in "R_K"**
   - Wait to Belle II ... ($\sim$ 2027)

3. **Traditional sensitive-based flavor physics can be done at high p_T**

4. **Exploration and searching for dark-flavor sectors**