BSM probes with charm

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Testing the Standard Model with $|\Delta c| = |\Delta u| = 1$ FCNCs of mesons and baryons:

- $c \to u\gamma$ Br $\sim 10^{-6} - 10^{-4}$
- $c \to u\mu\mu, uee$ Br $\sim 10^{-7} - 10^{-6}$
- $c \to u\nu\bar{\nu}, a, Z', ...$ Br $\lesssim 10^{-5}$

Probe different physics (dipole couplings, 4-fermion operators, light NP, ..)

Complementary to kaon and B-physics – charm is unique probe of flavor in the up-sector.

0112235, 1510.00965, 1805.08516 , 2011.09478, ...

TH Progress: New BSM strategies for $|\Delta c| = |\Delta u| = 1$

SM tests in rare charm decays are null tests based on approximate symmetries of the SM: GIM, CP, cLFC, LFU, LNC, $SU(3)_F$

Advantages charm (vs beauty):

i) GIM-suppression very efficient: $C_\nu^{\rm SM} = C_{10}^{\rm SM} = 0$

$$O_{10} = \bar{u}_L \gamma_\mu c_L \, \bar{\ell} \gamma^\mu \gamma_5 \ell \,, \quad O_\nu = \bar{u}_L \gamma_\mu c_L \, \bar{\nu} \gamma^\mu (1 - \gamma_5) \nu$$

ii) $SU(3)_F$ partner modes - related SM-like and NP-sensitive 4-fermion operators exist.

charm: $ucqq$ (FCNC) vs $uscd$ (SM); not in beauty: second light up-type quark missing.

More pheno-tricks from state-of-the-art b-physics studies come in handy: angular distributions.

BSM-sensitive Charm decays

resonant and multi-bodies, mesons and baryons,.. $P_{1,2,3} = \pi, K$

radiative $c \to u\gamma$: $D \to V\gamma$, $V = \rho, ..$, $D \to P_1 P_2 \gamma$,
$D \to A\gamma$, $A = K_1, ..$, $D \to P_1 P_2 P_3 \gamma$,
$\Lambda_c \to p\gamma$, $\Xi_c^0 \to \Lambda(\to p\pi)\gamma$,....

semileptonic $c \to u\ell\ell^{(\prime)}$: $D \to \pi\mu\mu$, $D \to \mu\mu$, $D \to P_1 P_2 \ell\ell$,
$\Lambda_c \to p\ell\ell$, $\Xi_c^0 \to \Lambda(\to p\pi^-)\ell\ell$,...

dineutrinos/MET/ALPs $c \to u\nu\bar{\nu}$: $D \to \pi\nu\bar{\nu}$, $D \to \nu\bar{\nu}$, $D \to P_1 P_2 \nu\bar{\nu}$,
$\Lambda_c \to p\nu\bar{\nu}$, $\Xi_c^0 \to \Lambda(\to p\pi^-)\nu\bar{\nu}$,...

Very little probed so far

radiative $c \to u\gamma$: $D \to V\gamma$, $V = \rho, ..,$ $D \to P_1 P_2 \gamma$,
$D \to A\gamma$, $A = K_1, ..$ $D \to P_1 P_2 P_3 \gamma$, $\Lambda_c \to p\gamma$, $\Xi_c^0 \to \Lambda(\to p\pi)\gamma$,....
$B(D^0 \to \rho^0 \gamma) = (1.77 \pm 0.31) \cdot 10^{-5}$ Belle'16, Cabibbo-favored modes:
$B(\Lambda_c \to \Sigma\gamma) < 2.6 \cdot 10^{-4}$, $B(\Xi_c^0 \to \Xi^0 \gamma) < 1.8 \cdot 10^{-4}$ Belle 2206.12517
$B(\Lambda_c \to \Sigma\gamma) < 4.4 \cdot 10^{-4}$ BESIII 2212.07214

semileptonic $c \to u\ell\ell^{(\prime)}$: $D \to \pi\mu\mu$, $D \to \mu\mu$, $D \to P_1 P_2 \ell\ell$,
$\Lambda_c \to p\ell\ell$, $\Xi_c^0 \to \Lambda(\to p\pi^-)\ell\ell$,... $B(D \to \pi\pi\mu\mu) \simeq 9.6 \cdot 10^{-7}$ LHCb'18 ,
$B(\Lambda_c \to p\mu\mu) \lesssim 7.7 \cdot 10^{-8}$ LHCb'17, [$D \to \pi\mu\mu$, $D \to \mu\mu$ upper limits]

dineutrinos/MET/ALPs $c \to u\nu\bar{\nu}$: $D \to \pi\nu\bar{\nu}$, $D \to \nu\bar{\nu}$, $D \to P_1 P_2 \nu\bar{\nu}$,
$\Lambda_c \to p\nu\bar{\nu}$, $\Xi_c^0 \to \Lambda(\to p\pi^-)\nu\bar{\nu}$,... $B(D^0 \to nothing) < 9.4 \cdot 10^{-5}$
Belle'16, $B(D^0 \to \pi^0 \nu\bar{\nu}) < 2.1 \cdot 10^{-4}$ BESIII 2112.14236

$$c \to u\gamma$$

Photons

$c \to u\gamma$ probe NP in dipole operators O_7, O_7', incl. CP-violation

Need ways to control SM BGD.

Recent data-driven proposals:

A) use charm as test lab for QCD frameworks

e.g. A_{FB} in $D \to PP\gamma$ modes 2009.14212, 2104.08287

B) use plethora of modes available to charm and extract $\mathcal{A}_{\rm SM}$ from SM-like modes; nulltest $=$ correlation

Observables: barnching ratios, CPA's and those sensitive to the photon polarization λ_γ:
Time-dependent CP asymmetries (TDCPAs), up-down asymmetries

theory and observables: 2203.14982 SU(3)-F techniques

Decay	U-Spin	$SU(3)_F$	$SU(3)_F$ IRA
$\Lambda_c \to \Sigma^+\gamma$	$V_{cs}^* V_{ud} A_\Sigma$	$V_{cs}^* V_{ud} B_\Sigma$	$V_{cs}^* V_{ud} D$
$\Xi_c^0 \to \Xi^0\gamma$	$V_{cs}^* V_{ud} A'_\Sigma$	$V_{cs}^* V_{ud} B'_\Sigma$	$V_{cs}^* V_{ud} D'$
$\Lambda_c \to p\gamma$	$-\Sigma A_\Sigma + \Delta A_\Delta + A_7$	$\Sigma B_\Sigma - \Delta B_\Delta + B_7$	$\Sigma D - \Delta\tilde{b}_4 + D_7$
$\Xi_c^+ \to \Sigma^+\gamma$	$\Sigma A_\Sigma + \Delta A_\Delta + A_7$	$-\Sigma B_\Sigma - \Delta B_\Delta + B_7$	$\Sigma D + \Delta\tilde{b}_4 - D_7$
$\Xi_c^0 \to \Lambda\gamma$	$-\sqrt{\frac{3}{2}}\Sigma A'_\Sigma - \frac{1}{2}(\Delta A'_\Delta + A'_7)$	$\sqrt{\frac{3}{2}}\Sigma B'_\Sigma + \sqrt{\frac{3}{2}}\Delta B_\Delta + \frac{1}{\sqrt{6}} B_7$	$-\sqrt{\frac{3}{2}}\Sigma D' + \sqrt{\frac{3}{2}}\Delta\tilde{b}_4 + \frac{1}{\sqrt{6}} D_7$
$\Xi_c^0 \to \Sigma^0\gamma$	$-\frac{1}{\sqrt{2}}\Sigma A'_\Sigma + \frac{\sqrt{3}}{2}(\Delta A'_\Delta + A'_7)$	$-\frac{1}{\sqrt{2}}\Sigma B'_\Sigma + \frac{3}{\sqrt{2}}\Delta B_\Delta + \sqrt{\frac{1}{2}} B_7$	$\frac{1}{\sqrt{2}}\Sigma D' + \frac{3}{\sqrt{2}}\Delta\tilde{b}_4 + \frac{1}{\sqrt{2}} D_7$
$\Xi_c^+ \to p\gamma$	$V_{cd}^* V_{us} A_\Sigma$	$V_{cd}^* V_{us} B_\Sigma$	$V_{cd}^* V_{us} D$
$\Xi_c^0 \to n\gamma$	$-V_{cd}^* V_{us} A'_\Sigma$	$V_{cd}^* V_{us} B'_\Sigma$	$-V_{cd}^* V_{us} D'$

Table 1: Flavor symmetry relations of charmed anti-triplet baryons. $A_\Sigma^{(\prime)}$ and $A_\Delta^{(\prime)}$ refer to the U-spin triplet and singlet SM contributions of the W-exchange diagrams. $A_7^{(\prime)} = A_{\text{NP}}^{(\prime)} + A_{\text{LD}}^{(\prime)}$ denote the $c \to u\gamma$ short distance and long distance contributions with intermediate vector resonances. $\Sigma = \frac{V_{cs}^* V_{us} - V_{cd}^* V_{ud}}{2}$, $\Delta = \frac{V_{cs}^* V_{us} + V_{cd}^* V_{ud}}{2} = -\frac{V_{cb}^* V_{ub}}{2}$. Top: CF, SM-like decays, Middle: SCS, NP-sensitive, Bottom: DCS, SM-like decays Relations for charm sextett-decays ($\Omega_c \to \Lambda, \Sigma^0, \Xi^0$) also in 2203.14982.

Extract B_Σ from SM-decay $\Lambda_c \to \Sigma^+\gamma$ and use to predict SM value of SCS-decay ($\Lambda_c \to p\gamma$, $\Xi_c^+ \to \Sigma^+\gamma$); probe NP in B_7 amplitude

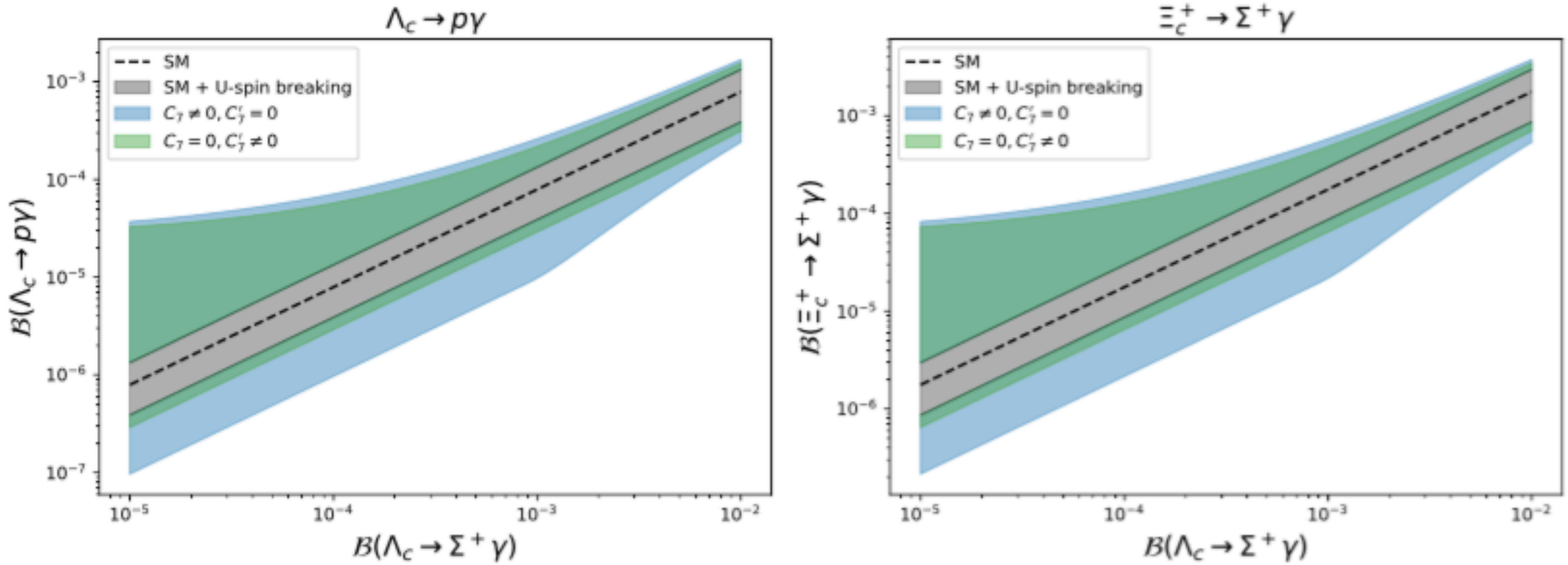
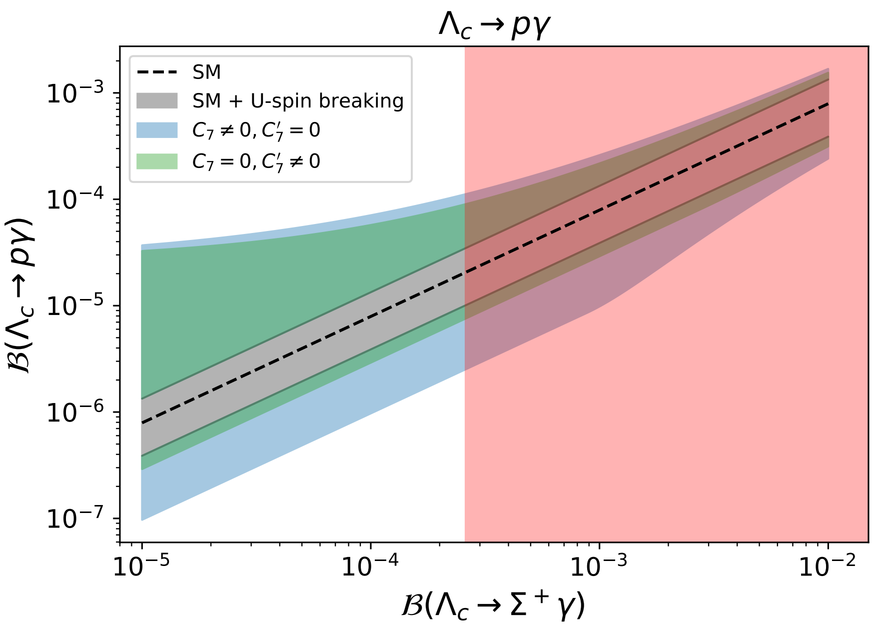
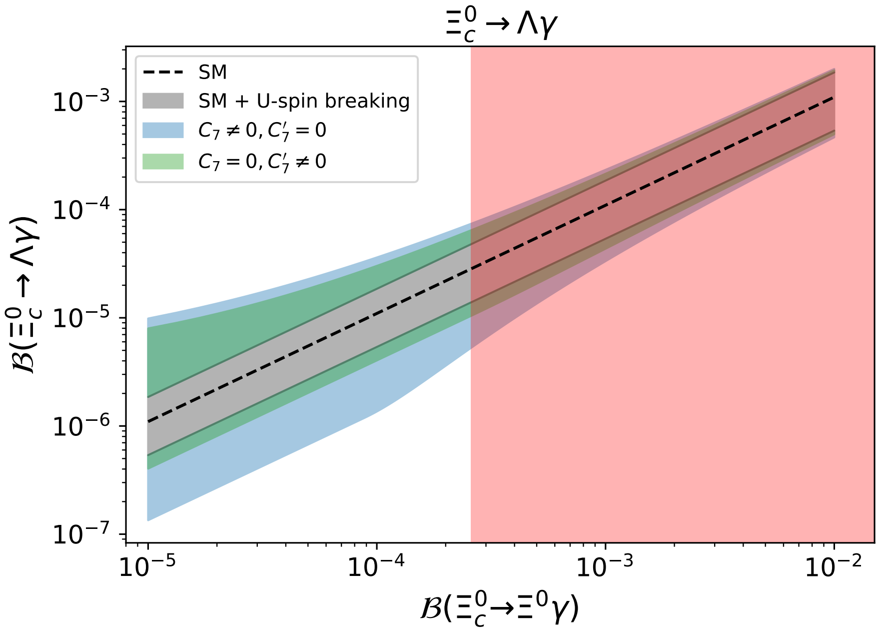


Figure 1: NP effects in the branching ratios of the BSM sensitive decay modes as a function of the branching ratios of the SM-like decay modes, for $\lambda_\gamma^{\text{CF}} = -0.5$. The black dashed line denotes the SM in the U-spin limit. The gray shaded area shows $\pm 30\%$ U-spin breaking in $A_{L/R}^{\text{SM}}$. The blue (green) region illustrates the BSM reach in C_7 (C_7'). We set $C_7' = 0$ ($C_7 = 0$) and varied the other coefficient within $-0.3 \leq C_7^{(\prime)} \leq 0.3$. The BSM regions also include the $\pm 30\%$ U-spin breaking of the SM amplitudes. Cabibbo-favored modes: $B(\Lambda_c \to \Sigma\gamma) < 2.6 \cdot 10^{-4}$, Belle 2206.12517, that is $B(\Lambda_c \to p\gamma) \lesssim 10^{-4}$,

Rare radiative decays of $\Lambda_c, \Xi_c, \Omega_c$





Theory 2203.14982 plus Belle exclusion (red areas) 2206.12517:

$B(\Lambda_c \to \Sigma\gamma) < 2.6 \cdot 10^{-4}$ predicts $B(\Lambda_c \to p\gamma) \lesssim 10^{-4}$

$B(\Xi_c^0 \to \Xi^0\gamma) < 1.8 \cdot 10^{-4}$ predicts $B(\Xi_c^0 \to \Lambda\gamma) \lesssim 7 \cdot 10^{-5}$

Beyond branching ratios: Rare rad. $\Lambda_c, \Xi_c, \Omega_c$ decays

Probing photon polarization 2203.14982

P_{B_c}: polariation of charm baryon, α_B: weak decay parameter of secondary decays ($\alpha_B = 0$ for strong decays)

The full angular distribution $B_c \to B_1(\to B_2\pi)\gamma$:

$$\frac{\mathrm{d}^2\mathcal{B}}{\mathrm{d}\cos(\vartheta_\gamma)\mathrm{d}\cos(\vartheta_B)} \propto [1 + P_{B_c}\alpha_B \cos(\vartheta_\gamma)\cos(\vartheta_B) + \alpha_B \lambda_\gamma \cos(\vartheta_B) + P_{B_c}\lambda_\gamma \cos(\vartheta_\gamma)] \,. \quad (1)$$

The polarization asymmetries:

$$A^\gamma_{\mathsf{FB}} = \frac{1}{\mathcal{B}}\left(\int_0^1 \mathrm{d}\cos(\vartheta_\gamma)\frac{\mathrm{d}\mathcal{B}}{\mathrm{d}\cos(\vartheta_\gamma)} - \int_{-1}^0 \mathrm{d}\cos(\vartheta_\gamma)\frac{\mathrm{d}\mathcal{B}}{\mathrm{d}\cos(\vartheta_\gamma)}\right) = \frac{P_{B_c}\lambda_\gamma}{2} \,. \quad (2)$$

$$A^B_{\mathsf{FB}} = \frac{1}{\mathcal{B}}\left(\int_0^1 \mathrm{d}\cos(\vartheta_B)\frac{\mathrm{d}\mathcal{B}}{\mathrm{d}\cos(\vartheta_B)} - \int_{-1}^0 \mathrm{d}\cos(\vartheta_B)\frac{\mathrm{d}\mathcal{B}}{\mathrm{d}\cos(\vartheta_B)}\right) = \frac{\alpha_B\lambda_\gamma}{2} \,. \quad (3)$$

extract λ_γ^{SM} from Cabibbo-favored partner mode

Beyond branching ratios: Rare rad. $\Lambda_c, \Xi_c, \Omega_c$ decays

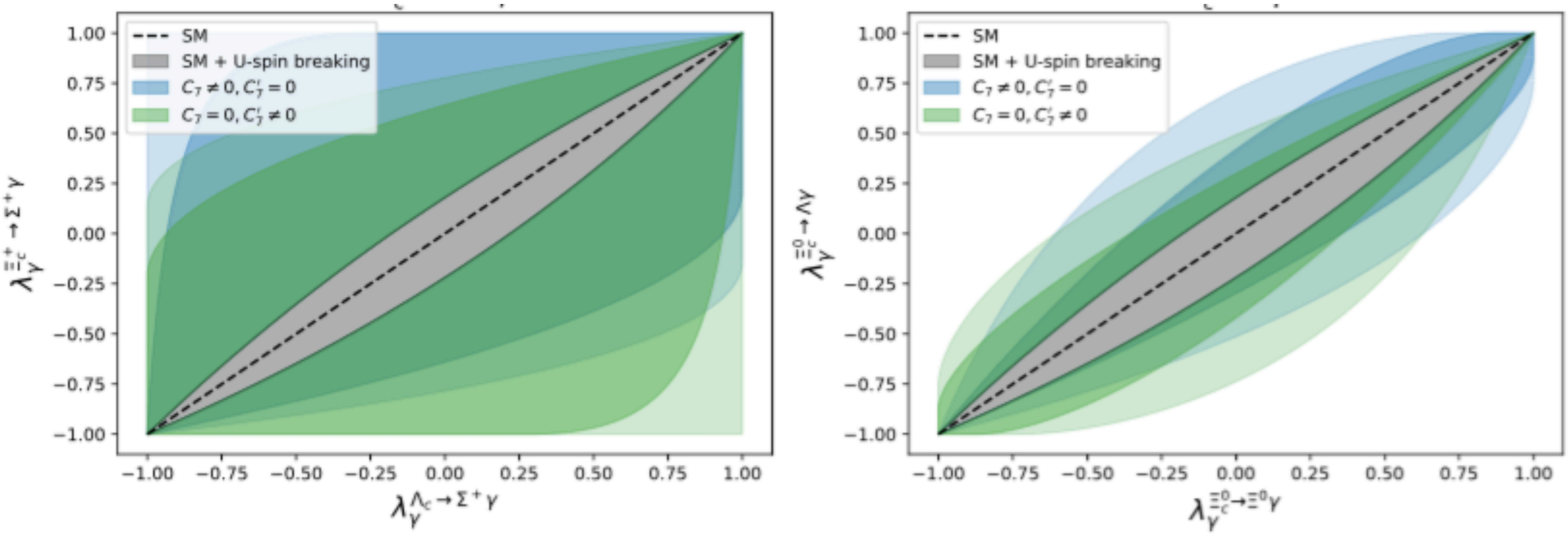


Figure 2: BSM reach of λ_γ of BSM modes $\Xi_c^+ \to \Sigma^+\gamma$ (left) and $\Xi_c^0 \to \Lambda\gamma$ (right) versus photon polarization of SM-like modes, $\Lambda_c \to \Sigma^+\gamma$ and $\Xi_c^0 \to \Xi^0\gamma$, respectively, for $B^{\text{CF}} = 5 \cdot 10^{-4}$. The black dashed line denotes the SM in the U-spin limit. The gray shaded area shows $\pm 20\%$ U-spin breaking between $r_{\text{SM}}^{\text{CF}}$ and $r_{\text{SM}}^{\text{SCS}}$. The blue (green) region illustrates the BSM reach in C_7 (C_7'). We set $C_7' = 0$ ($C_7 = 0$) and varied the other coefficient within $-0.3 \leq C_7^{(\prime)} \leq 0.3$. For the darker shaded area we used the SM amplitudes in the exakt U-spin limit. For the lighter shaded area we additionally considered $\pm 30\%$ U-spin breaking in $F_{L/R}^{\text{SM}}$, while keeping the U-spin breaking of the ratio $r_{\text{SM}}^{\text{SCS}}$ limited to $\pm 20\%$.

Photon polarization in $c \to u\gamma$ from untagged TDA

Time-dependent analysis (TDA) $D^0, \bar{D}^0 \to V\gamma$, $V = \rho^0, \Phi, \bar{K}^{*0}$ (decays to CP eigenstate with CP eigenvalue ξ) 1210.6546 ,1802.02769

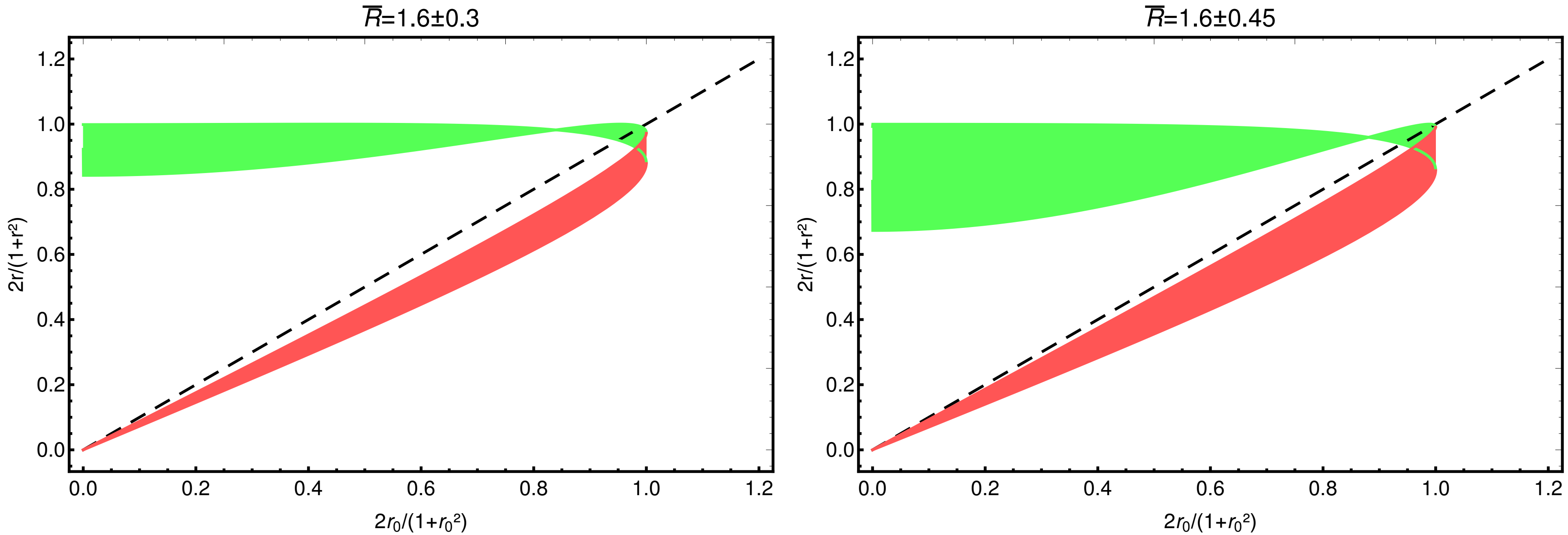
$$\Gamma(t) = \mathcal{N} e^{-\Gamma t} \left(\cosh[\Delta\Gamma t/2] + A^{\Delta} \sinh[\Delta\Gamma t/2] + \zeta C \cos[\Delta m t] - \zeta S \sin[\Delta m t]\right)$$

$A^{\Delta}(D^0 \to \bar{K}^{*0}\gamma) \simeq \frac{4\,\xi_{\bar{K}^{*0}} \left|\frac{q}{p}\right| \cos\varphi}{\left(1+\left|\frac{q}{p}\right|^2\right)} \frac{r_0}{1+r_0^2}$ Here, r_0 is ratio of wrong-chirality (RH) to LH-photons in SM-like process $D^0 \to \bar{K}^{*0}\gamma$.

Up to $SU(3)$-breaking: $r(D^0 \to \Phi\gamma) = r_0$, $\quad r(D^0 \to \rho\gamma) = r_0$; perturbative $r = C_7'/C_7$, in SUSY, r unconstrained.

Br's	$D^0 \to \rho^0\gamma$	$D^0 \to \omega\gamma$	$D^0 \to \Phi\gamma$	$D^0 \to \bar{K}^{*0}\gamma$ (SM-domin.)
Belle 2016	$(1.77 \pm 0.31) \times 10^{-5}$	–	$(2.76 \pm 0.21) \times 10^{-5}$	$(4.66 \pm 0.30) \times 10^{-4}$
BaBar 2008	–	–	$(2.81 \pm 0.41) \times 10^{-5}$	$(3.31 \pm 0.34) \times 10^{-4}$
CLEO 1998	–	$< 2.4 \times 10^{-4}$	–	–
LHCb			wip	

Photon polarization in $c \to u\gamma$ from untagged TDA



$2r/(1+r^2)$ as a function of $2r_0/(1+r_0^2)$, in the cases a) (SM case) $C_7, C_7' \simeq 0$ (black, dashed curve), c) $C_7 \simeq 0$ (green, upper band) and d) $C_7' \simeq 0$ (red, lower band). The upper (lower) plots correspond to $\bar{R}_{ave} = 1.6 \pm 0.3$ ($\bar{R} = 1.6 \pm 0.45$ from 50% inflated uncertainty).

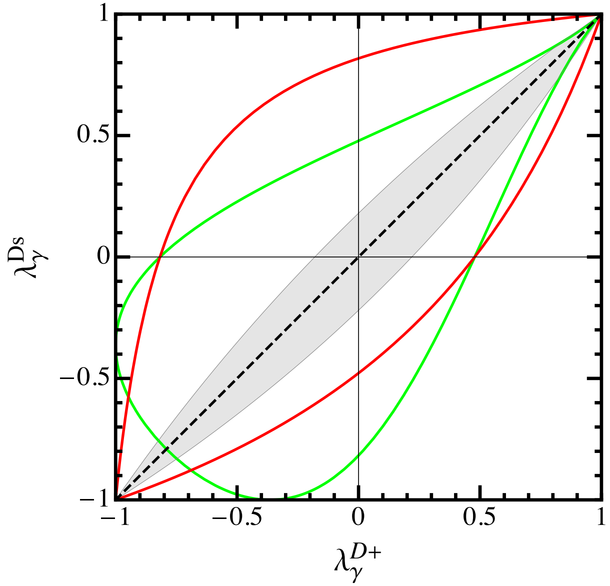
$\bar{R} = 1/f^2 \frac{|V_{cs}|^2}{|V_{cd}|^2} \frac{\mathcal{B}(D^0 \to \rho\gamma)}{\mathcal{B}(D^0 \to \bar{K}^{*0}\gamma)}$ with leading U-spin breaking removed $f = m_\rho f_\rho / (m_{K^{*0}} f_{K^{*0}})$

Photon polarization from up-down asymmetry

Method 2: probe the photon polarization with an up-down asymmetry in $D^+ \to K_1^+(\to K\pi\pi)\gamma$ (a la $B \to K_1\gamma$ 1812.04679 , and (Gronau, Pirjol, Grossman, Kou) $\frac{d\Gamma}{ds_{13}\, ds_{23}\, d\cos\vartheta} \propto |\boldsymbol{J}|^2(1+\cos^2\vartheta) + \lambda_\gamma 2\,\mathrm{Im}[\boldsymbol{n}\cdot(\boldsymbol{J}\times\boldsymbol{J}^*)]\cos\vartheta\,,\ \lambda_\gamma = -\frac{1-r_0^2(\bar{K}_1)}{1+r_0^2(\bar{K}_1)}$

The corresponding BSM-sensitive mode is $D_s \to K_1^+(\to K\pi\pi)\gamma$.

Method 2 requires D-tagging but unlike TDA, does not depend on strong phases between the left- and right-handed amplitude.



grey: SM, red, green: BSM scenarios

$$c \to u\nu\bar{\nu}$$

$c \to u\nu\bar{\nu}$ transitions: all of them are excellent nulltest of SM due to GIM

$D^+, D_s \to M\nu\bar{\nu}$ has BGD from $D^+, D_s \to \tau(\to M\nu)\bar{\nu}$; reducible via cuts

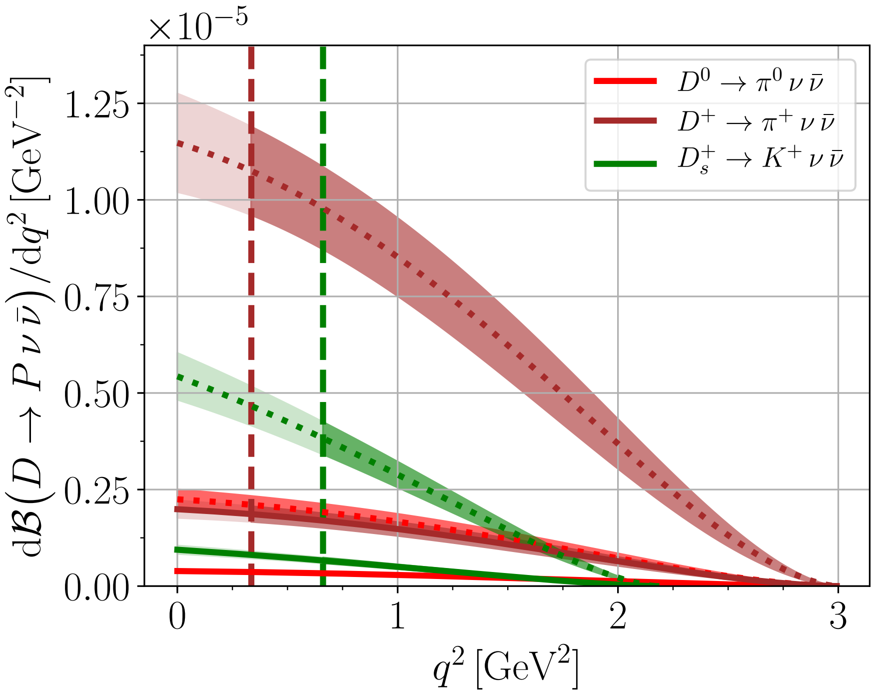


Figure 3: Differential branching ratios for $D^0 \to \pi^0\nu\bar{\nu}$, $D^+ \to \pi^+\nu\bar{\nu}$ and $D_s^+ \to K^+\nu\bar{\nu}$ in red, brown and green, respectively for the LU (cLFC) limit in solid (dotted) lines. this plot shows BSM distributions The uncertainty bands are due to the form factors, the vertical dashed lines illustrate the cuts needed to avoid the τ background. from 2010.02225

Upper limits $\mathcal{B}^{\text{max}}(h_c \to F\nu\bar{\nu})$ depend on lepton flavor structure (LFV,cLFC,LFU) 2010.02225

$h_c \to F$	$\mathcal{B}^{\text{max}}_{\text{LU}}$ $[10^{-7}]$	$\mathcal{B}^{\text{max}}_{\text{cLFC}}$ $[10^{-6}]$	$\mathcal{B}^{\text{max}}$ $[10^{-6}]$	$N^{\text{max}}_{\text{LU}}/\eta_{\text{eff}}$	$N^{\text{max}}_{\text{cLFC}}/\eta_{\text{eff}}$	$N^{\text{max}}/\eta_{\text{eff}}$
$D^0 \to \pi^0$	6.1	3.5	13	47 k (395 k)	270 k (2.3 M)	980 k (8.3 M)
$D^+ \to \pi^+$	25	14	52	77 k (650 k)	440 k (3.7 M)	1.6 M (14 M)
$D_s^+ \to K^+$	4.6	2.6	9.6	6 k (50 k)	34 k (290 k)	120 k (1.1 M)
$D^0 \to \pi^0\pi^0$	1.5	0.8	3.1	11 k (95 k)	64 k (540 k)	230 k (2.0 M)
$D^0 \to \pi^+\pi^-$	2.8	1.6	5.9	22 k (180 k)	120 k (1.0 M)	450 k (3.8 M)
$D^0 \to K^+K^-$	0.03	0.02	0.06	0.2 k (1.9 k)	1.3 k (11 k)	4.8 k (40 k)
$\Lambda_c^+ \to p^+$	18	11	39	14 k (120 k)	82 k (700 k)	300 k (2.6 M)
$\Xi_c^+ \to \Sigma^+$	36	21	76	28 k (240 k)	160 k (1.4 M)	590 k (5.0 M)

to date only a single limit exists: $B(D^0 \to \pi^0\nu\bar{\nu}) < 2.1 \cdot 10^{-4}$ BESIII 2112.14236

Cross checking: $D \to$ nothing

$\mathcal{B}(D^0 \to \text{inv.}) < 9.4 \cdot 10^{-5}$, at 90 % CL. (Belle '16). Consistency check; constrains operators with light right-handed neutrinos

$$Q^{ij}_{LR} = (\bar{u}_L \gamma_\mu c_L)(\bar{\nu}_{jR} \gamma^\mu \nu_{iR}), \quad Q^{ij}_{RR} = (\bar{u}_R \gamma_\mu c_R)(\bar{\nu}_{jR} \gamma^\mu \nu_{iR}),$$

$$Q^{ij}_{S(P)} = (\bar{u}_L c_R)(\bar{\nu}_j (\gamma_5) \nu_i), \quad Q^{ij}_{T(T5)} = \frac{1}{2}(\bar{u}\, \sigma_{\mu\nu}\, c)(\bar{\nu}_j\, \sigma^{\mu\nu} (\gamma_5) \nu_i),$$

$Q^{ij}_{S(P)}$ would have effect less than $\sim 10\%$ of LU upper limits iff improved limit exists 2010.02225

$$\mathcal{B}(D^0 \to \text{inv.})^{hypothetical} \lesssim 2 \cdot 10^{-6}. \tag{4}$$

would reinforce EFT framework "NP is heavy".

$D \to$ nothing constrains LNV $\Delta L = 2$ interactions $\mathcal{O}^{(7)}_{4a} = L^\alpha_i L^\beta_j \bar{Q}^b_\alpha \bar{U}^c_a H^\rho \epsilon_{\beta\rho}$, de Gouvea

Existing Belle limit on $D \to$nothing probes LNV effects $\Lambda^{ij}_{\text{LNV}} \gtrsim 1.5$ TeV . 2010.02225

$$c \to ull$$

Rare electroweak decays of $\Lambda_c, \Xi_c, \Omega_c$

theory and observables: 2107.13010, 2202.02331 highlights for BSM searches: GIM ($C_{10}^{\rm SM} = 0$), angular distributions, CP, cLFV, LFU

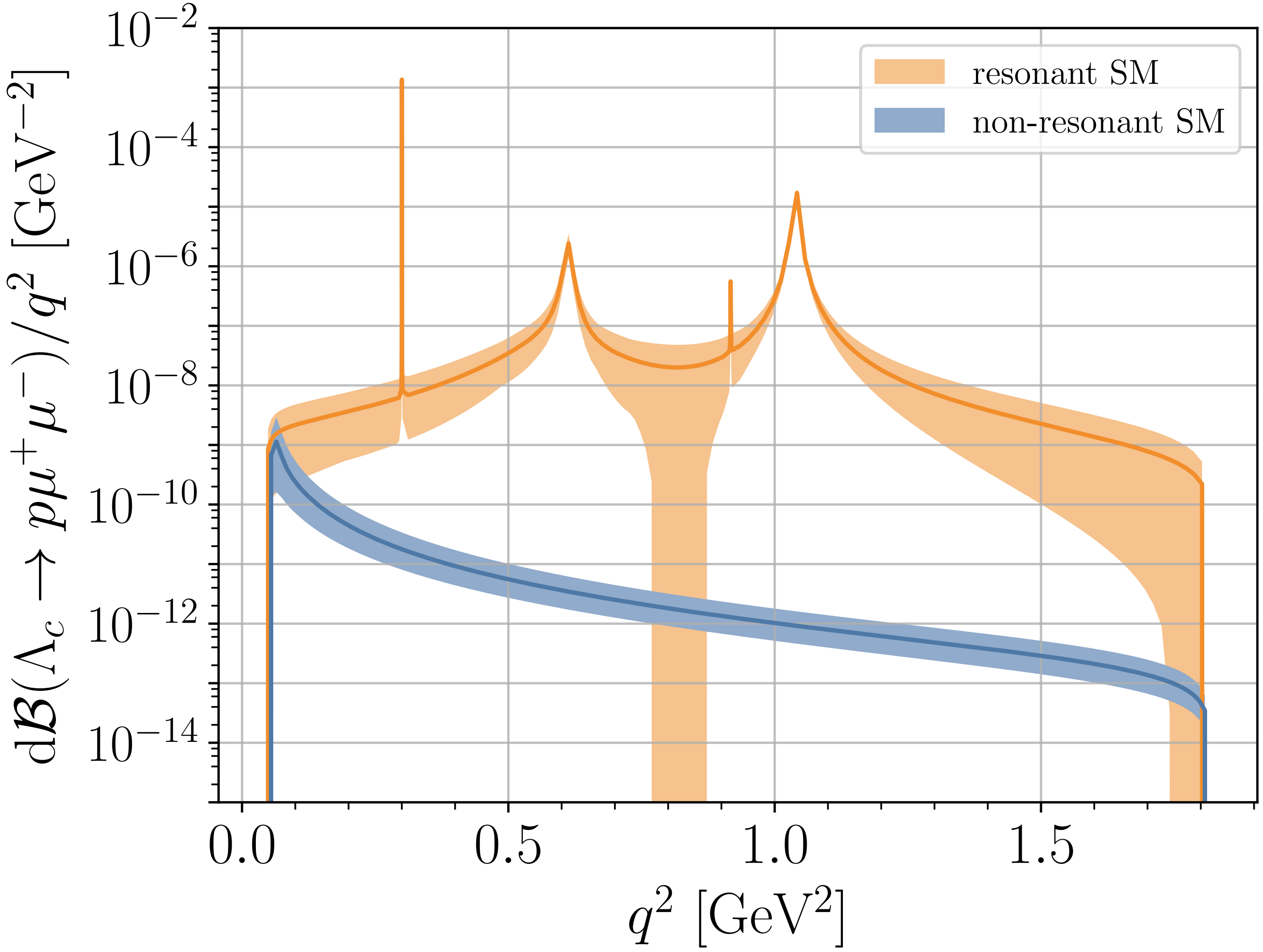
The differential angular distribution for unpolarized Λ_c, (polarized Λ_c worked out in 2202.02331) reads:

$$\frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2 \mathrm{d}\cos\vartheta_\ell} = \frac{3}{2}\left(K_{1ss}\sin^2\vartheta_\ell + K_{1cc}\cos^2\vartheta_\ell + K_{1c}\cos\vartheta_\ell\right)$$

$\rightarrow$ 3 observables: branching ratio $(-)$, longitudinal pol. fraction F_L $(+)$, Forward-Backward asymmetry $A_{\rm FB}^{\ell} \propto K_{1c} \propto C_{10}$. $(++)$

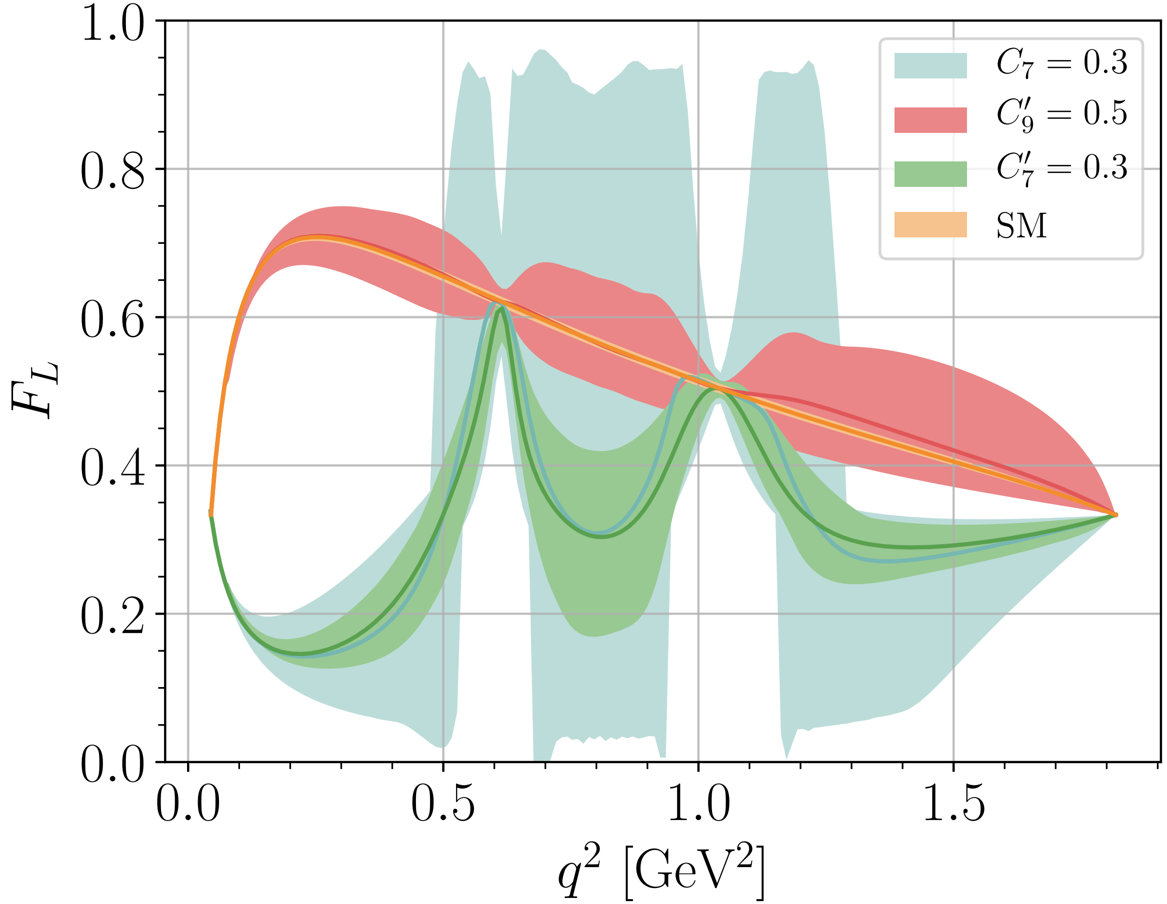
$\Lambda_c \rightarrow p$ form factors from lattice 1712.05783 – $SU(3)_F$-relations to others 2203.14982

$-\sqrt{6}h_\perp^{\Xi_c^0\rightarrow\Lambda} = \sqrt{2}h_\perp^{\Xi_c^0\rightarrow\Sigma^0} = h_\perp^{\Xi_c^+\rightarrow\Sigma^+} = h_\perp^{\Lambda_c\rightarrow p}$; Endpoint relations (at q^2 =max): 2107.12993


resonant SM
non-resonant SM
$\mathrm{d}\mathcal{B}(\Lambda_c \to p\mu^+\mu^-)/q^2$ [GeV^{-2}]
q^2 [GeV^2]
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
0.0
0.5
1.0
1.5

2107.13010

Longitudinal polarization: $(+)$



2107.13010

Sensitivity to dipole coefficients!

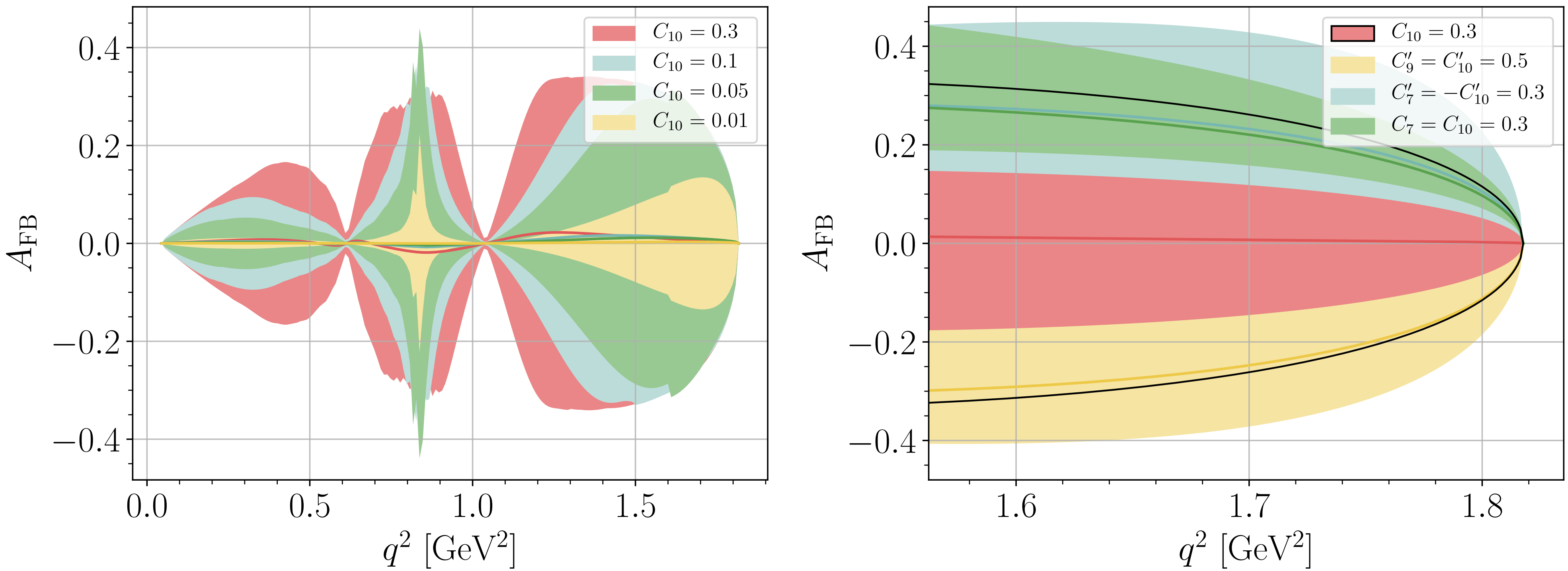


Figure 4: The forward-backward asymmetry $A_{\rm FB}$ of $\Lambda_c \to p\mu^+\mu^-$ decays for different values of C_{10} in the full q^2-region (left panel) and for various BSM contributions in the high q^2 region (right panel)

$A_{\rm FB} \propto C_{10}$ clean null test of SM (GIM); Three more GIM-based null tests in 4-body decays

$\Xi_c^+ \to \Sigma^+ (\to p\pi^0)\ell^+\ell^-$, $\Xi_c^0 \to \Lambda^0 (\to p\pi^-)\ell^+\ell^-$, $\Omega_c^0 \to \Xi^0 (\to \Lambda^0\pi^0)\ell^+\ell^-$, 2202.02331

A Puzzle in hadronic charm CPX

Can ΔA_{CP} come mainly from $A_{CP}(D \to \pi^+\pi^-)$?

CP and U-Spin puzzle 2207.08539, 2210.16330 - two approx symmetries

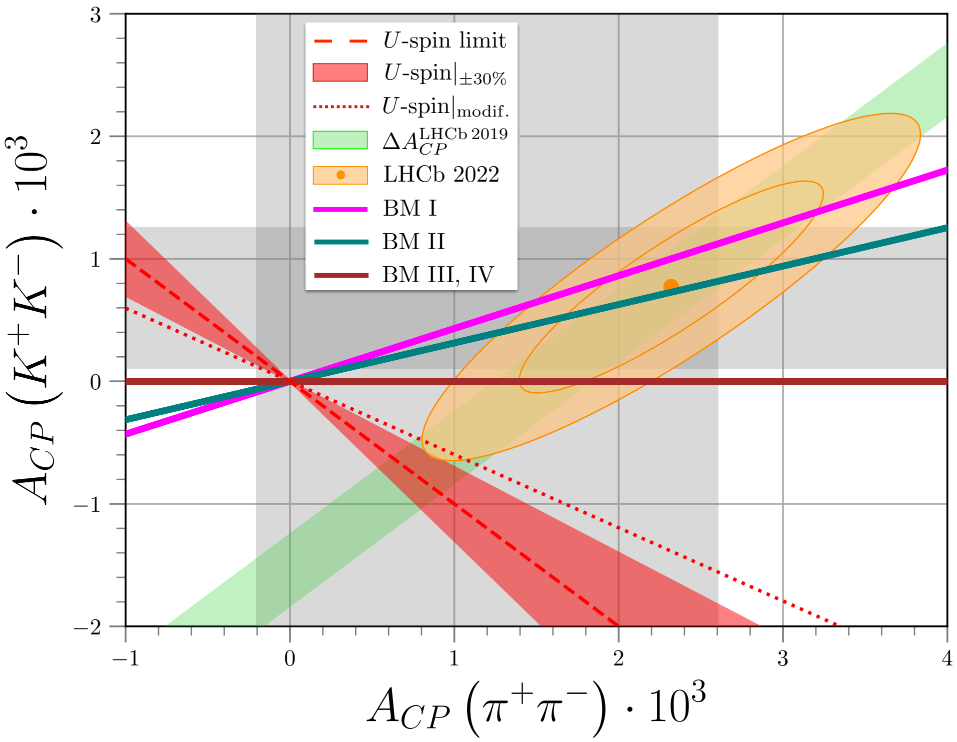


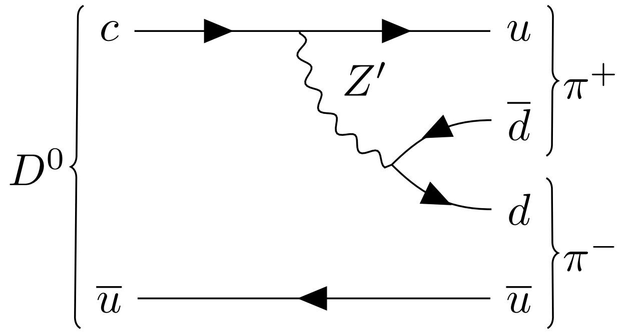
Fig from 2210.16330, LHCb result from 2209.03179; Talk by Federico Betti

$$\frac{(\text{coupling})^2}{(\text{mass})^2} \sim \frac{1}{(25\,GeV)^2}$$

Is this even explainable?

Single solution known 2210.16330

BSM effects in semileptonic 4-fermion operators $\sim \bar{u}_R \gamma_\mu c_R \bar{d}_R \gamma^\mu d_R$.
Very light Z', sub 20 GeV (CMS ISR constraints), leptophob (LHCb $A \to \mu\mu$ search)



$$\frac{(\text{coupling})^2}{(\text{mass})^2} \sim \frac{1}{(25\,GeV)^2}$$

Signatures in low mass dijets, $J/\Psi/\Psi'$ decays,
$A_{CP}(D \to \pi^0\pi^0), A_{CP}(D \to \pi^+\pi^0) \sim A_{CP}(D \to \pi^+\pi^-)$.

Summary

- Very little experimentally explored in rare charm decays – lots of blanks in PDG and opportunities
- Theory control by null tests
- Charm is advantageous because $SU(3)$-related partners exist: measure the SM-like CF-decay and use symmetry to obtain the SM prediction of the SCS, BSM-sensitive mode. Then measure the SCS decay and test the SM. Many tests in radiative charm baryons and mesons.
- NP sensitivity from null tests in branching ratios $c \to u\nu\bar{\nu}$ (GIM).
  Upper limits on $B(\Lambda_c \to p\nu\bar{\nu})$ depends lepton flavor.
- Angular distributions $C_{10}^{SM} = 0$ kills couplings to axial-vector lepton currents $\bar{\ell}\gamma_\mu\gamma_5\ell$, hence $I_{5,6,7}^{SM} = 0$, as well as $A_{FB}^{\ell\, SM}(\Lambda_c \to p\mu\mu) = 0$. More observables in full distribution.
- BSM effects in $|\Delta c| = |\Delta u| = 1$ can be huge.
- Complementary search to K,B-decays.