Charm Decay Opportunities for BSM and Puzzles

1. Null tests for e^+e^- and pp-colliders
2. U-spin/CP puzzle and pion form factor

Gudrun Hiller, TU Dortmund

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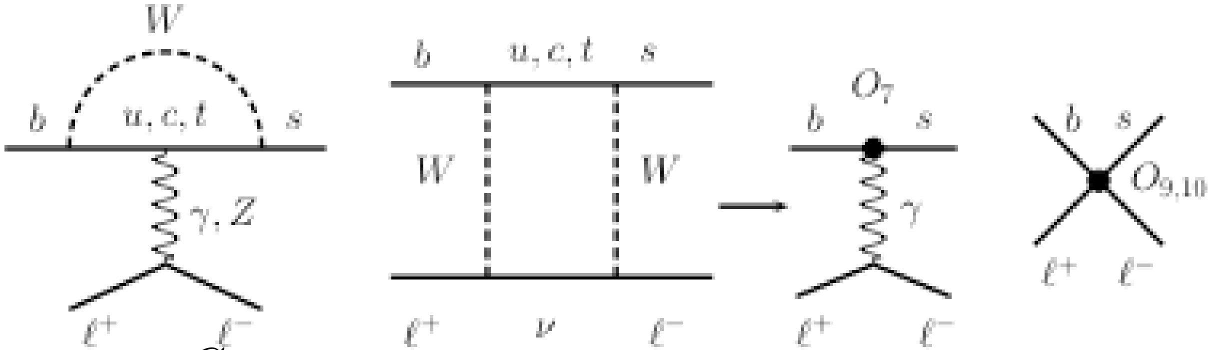
We look for New Physics in Flavor Changing Neutral Currents (FCNCs), because they are suppressed in SM by 1. loop-factor 2. CKM-mixing 3. GIM (mass degeneracies of quarks in loop; very strong in Charm,Top FCNCs, where d, s, b are in loop)



$$\mathcal{H}_{\rm eff} = -4\frac{G_F}{\sqrt{2}}V_{tb}V_{ts}^*\sum_i C_i(\mu)O_i(\mu), \qquad G_F/\sqrt{2} = g^2/(8m_W^2)$$

$$\mathcal{O}_9 = \bar{s}_L\gamma_\mu b_L\,\bar{\ell}\gamma^\mu\ell \text{ (vector)} \quad \mathcal{O}_{10} = \bar{s}_L\gamma_\mu b_L\,\bar{\ell}\gamma^\mu\gamma_5\ell \text{ (axial-vector)}$$

Ongoing precision programs in B-physics. ($b \to s\ell\ell, \gamma$ global fit, $b \to d\ell\ell, \gamma$ 2209.04457)

Testing the Standard Model with $c \to u$ 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, ... Adolph, de Boer, Bause, Bharucha, Brod, Bigi, Burdman, d'Ambrosio, Cata, Fajfer, Feldmann, Gisbert, Golowich, Golz, Hewett, Kosnic, Magorsch, Meinel, Pakvasa, Petrov, Seidel, Singer, Silva, Solomonidi, Zwicky, ...

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, $B(\Xi_c^0 \to \Xi^0\mu^+\mu^-) < 6.5 \cdot 10^{-5}$,
$B(\Xi_c^0 \to \Xi^0 e^+ e^-) < 9.9 \cdot 10^{-5}$ Belle 2312.02580

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

BES III arXiv:2404.05973, $B(D_s^+ \to K^+ \pi^0 e^+ e^-) < 7.1 \cdot 10^{-5}$

New submissions for Wed, 10 Apr 24

[1] **arXiv:2404.05973** [**pdf**, **ps**, **other**]

Search for the Rare Decays $D_s^+ \to h^+(h^0)e^+e^-$

BESIII Collaboration: M. Ablikim, M. N. Achasov, P. Adlarson, O. Afedulidis, X. C. Ai, R. Aliberti, A. Amoroso, Q. An, Y. Bai, O. Bakina, I. Balossino, Y. Ban, H.-R. Bao, V. Batozskaya, K. Begzsuren, N. Berger, M. Berlowski, M. Bertani, D. Bettoni, F. Bianchi, E. Bianco, A. Bortone, I. Boyko, R. A. Briere, A Brueggemann, H. Cai, X. Cai, A. Calcaterra, G. F. Cao, N. Cao, S. A. Cetin, J. F. Chang, W. L. Chang, G. R. Che, G. Chelkov, C. Chen, C. H. Chen, Chao Chen, G. Chen, H. S. Chen, M. L. Chen, S. J. Chen, S. L. Chen, S. M. Chen, T. Chen, X. R. Chen, X. T. Chen, Y. B. Chen, Y. Q. Chen, Z. J. Chen, Z. Y. Chen, S. K. Choi, X. Chu, G. Cibinetto, F. Cossio, J. J. Cui, H. L. Dai, J. P. Dai, A. Dbeyssi, R. E. de Boer, D. Dedovich, C. Q. Deng, Z. Y. Deng, A. Denig, Denysenko, M. Destefanis, et al. (576 additional authors not shown)

Comments: 10 pages, 2 figures, 1 table

Subjects: **High Energy Physics - Experiment (hep-ex)**

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, $SU(3)_F$

GIM-suppression very efficient: In SM, everything follows from tree-level W-exchange plus RGE, μ_b-matching 1707.00988 :

$$O_7 = \bar{u}_L \sigma_{\mu\nu} c_R F^{\mu\nu}, \quad O_9 = \bar{u}_L \gamma_\mu c_L \, \bar{\ell}\gamma^\mu \ell,$$

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

$C_7^{\text{eff SM}} \lesssim 0.01$, $C_9^{\text{eff SM}} \lesssim 0.05$ 1510.00311 $\quad C_\nu^{\text{SM}} = 0, \quad C_{10}^{\text{SM}} = 0$

SM-Phenomenology completely dominated by 4-quark operators; Classify as CF $\sim V_{cs}^* V_{ud}$, SCS $\sim V_{cq}^* V_{uq}, V_{cq}^* V_{uq}, q = d, s$, DCS $\sim V_{cd}^* V_{us}$

$c \to u\nu\bar{\nu}$ transitions: all of them are excellent nulltests of the 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

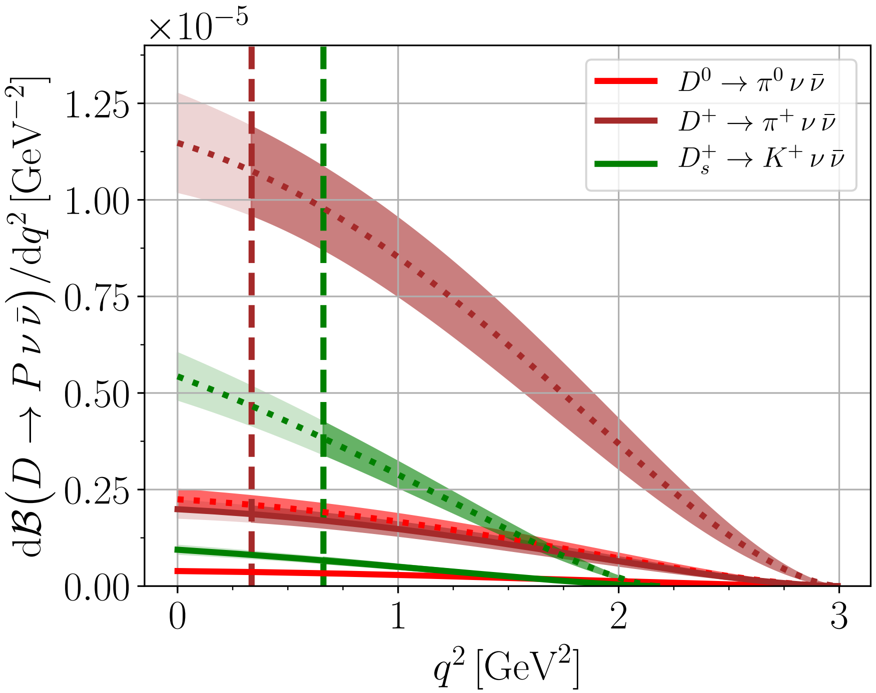


Figure 1: Differential branching ratios for $D^0 \to \pi^0\nu\bar{\nu}$, $D^+ \to \pi^+\nu\bar{\nu}$ and $D_s^+ \to K^+\nu\bar{\nu}$ in red, brown and green, respectively for the LU (cLFC) limit in solid (dotted) lines. this plot shows BSM distributions The uncertainty bands are due to the form factors, τ background removable by q^2-cut (vertical dashed lines) from 2010.02225

Leading semileptonic 4-fermion operators at scale above v (SMEFT) contributing to dineutrino modes $q \to q'\nu\bar{\nu}$

$$\mathcal{L}_{\text{eff}} \supset \frac{C^{(1)}_{\ell q}}{v^2}\bar{Q}\gamma_\mu Q\,\bar{L}\gamma^\mu L + \frac{C^{(3)}_{\ell q}}{v^2}\bar{Q}\gamma_\mu \tau^a Q\,\bar{L}\gamma^\mu \tau^a L + \frac{C_{\ell u}}{v^2}\bar{U}\gamma_\mu U\,\bar{L}\gamma^\mu L + \frac{C_{\ell d}}{v^2}\bar{D}\gamma_\mu D\,\bar{L}\gamma^\mu L\,. \quad (1)$$

$SU(2)_L \times U(1)_Y$ gauge invariance links up and down quarks, $Q = (u, d)$ and left-handed neutrinos and charged leptons $L = (\nu, \ell)$.

$$C_L{}^U = K_L{}^D = C^{(1)}_{\ell q} + C^{(3)}_{\ell q}\,, \quad C^U_R = K^U_R = C_{\ell u}\,, \quad C^D_L = K^U_L = C^{(1)}_{\ell q} - C^{(3)}_{\ell q}\,, \quad C^D_R = K^D_R = C_{\ell d}\,.$$

LH contribution to $c \to u\nu\bar{\nu}$ (C^U_L) identical to $s \to d\ell\bar{\ell}$ (K^D_L) etc

RH contribution to $c \to u\nu\bar{\nu}$ (C^U_R) identical to $c \to u\ell\bar{\ell}$ (K^U_R)

L,R denotes left or right handed quark currents; only SM-like light neutrinos.

Dineutrino vs lepton specific limits

left-handed $c \to u\nu\bar{\nu}$ (C_L^U)

Process	WC	ee	$\mu\mu$	$\tau\tau$	$e\mu$	$e\tau$	$\mu\tau$
$pp \to \ell^+\ell^-$	$\mathcal{K}_{L,R}^{sd\ell\ell'}$	3.8	2.3	5.37	2.0	6.1	6.6
$K \to \ell^+\ell^- + \pi$	$\mathcal{K}_{L,R}^{sd\ell\ell'} \cdot 10^2$	5	1.6	-	0.066	-	-
$K \to \nu\bar{\nu} + \pi$	$\mathcal{K}_{R}^{sd\ell\ell'} \cdot 10^2$	[-1.9,0.7]	[-1.9,0.7]	[-1.9,0.7]	1.1	1.1	1.1
$pp \to \nu\bar{\nu} + X$	$\mathcal{K}_{L}^{sd\ell\ell'}$	4.1 (3.3)	4.1 (3.3)	4.1 (3.3)	2.9 (2.2)	2.9 (2.2)	2.9 (2.2)
$pp \to \nu\bar{\nu} + X$	$\mathcal{K}_{R}^{sd\ell\ell'}$	5.7 (4.6)	5.7 (4.6)	5.7 (4.6)	4.1 (3.3)	4.1 (3.3)	4.1 (3.3)

Table 1: Limits on $sd\ell\ell'$ WCs. The first row is based on 2304.12837, while the second and third row are taken from 2007.05001 and the NEW ones from $pp \to \nu\bar{\nu} + X$ are from 2403.17063 with projections for $3000\, fb^{-1}$ in parentheses, using $SU(2)$.

- synergy between high p_T flavor and rare decays
- rare kaon decays are most powerful when existing (no decays into taus)
- $pp \to MET + j$ is comparable to conventional Drell-Yan and better for taus in final state: best bounds!

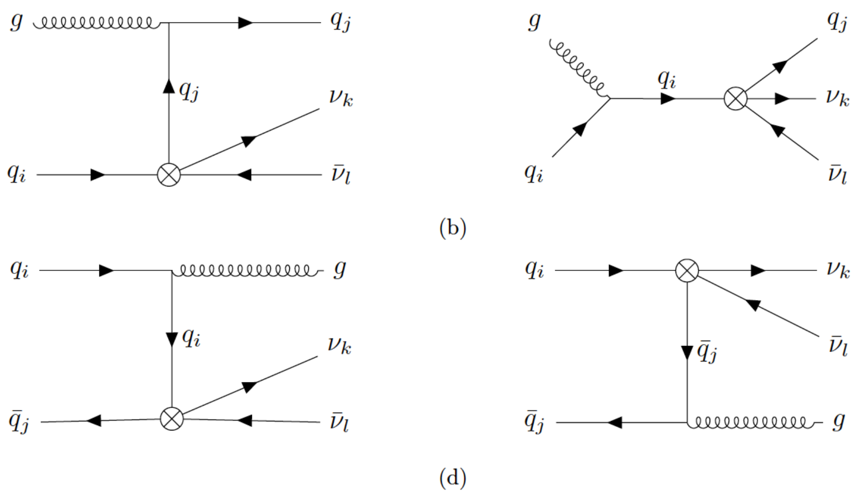
Dineutrino vs lepton specific limits

right-handed $c \to u\nu\bar{\nu}$ (C_R^U)

Process	WC	ee	$\mu\mu$	$\tau\tau$	$e\mu$	$e\tau$	$\mu\tau$
$pp \to \ell^+\ell^-$	$\mathcal{K}_{L,R}^{cu\ell\ell'}$	2.9	1.6	5.6	1.6	4.7	5.1
$D \to \ell^+\ell^- + \pi$	$\mathcal{K}_{L,R}^{cu\ell\ell'}$	4.0	0.9	-	2.2	-	-
$K \to \nu\bar{\nu} + \pi$	$\mathcal{K}_{L}^{cu\ell\ell'} \cdot 10^2$	$[-1.9, 0.7]$	$[-1.9, 0.7]$	$[-1.9, 0.7]$	1.1	1.1	1.1
$pp \to \nu\bar{\nu} + X$	$\mathcal{K}_{L}^{cu\ell\ell'}$	5.7 (4.6)	5.7 (4.6)	5.7 (4.6)	4.1 (3.3)	4.1 (3.3)	4.1 (3.3)
$pp \to \nu\bar{\nu} + X$	$\mathcal{K}_{R}^{cu\ell\ell'}$	4.1 (3.3)	4.1 (3.3)	4.1 (3.3)	2.9 (2.2)	2.9 (2.2)	2.9 (2.2)

Table 2: Limits on $cu\ell\ell'$ WCs. The first three rows are from 2007.05001, while the ones from $pp \to \nu\bar{\nu} + X$ are from 2403.17063

Dineutrino vs lepton specific limits



energy enhanced by $\hat{s}/\Lambda_{NP}^2$ relative to SM p_T-distribution (analytically shown in 2403.17063)

Dineutrinos

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

ULs for Belle II w $50\,\text{ab}^{-1}$ (FCC-ee@Z w $N(c\bar{c}) = 550 \cdot 10^9$) via SMEFT and dilepton data 2010.02225 theory and observables: 2107.13010, 2202.02331 highlights for BSM searches: GIM ($C_{10}^{\text{SM}} = 0$), angular distributions, CP, cLFV, LFU

Differential angular distribution for unpolarized $\Lambda_c \to p\mu\mu$, (polarized Λ_c in 2202.02331) reads:

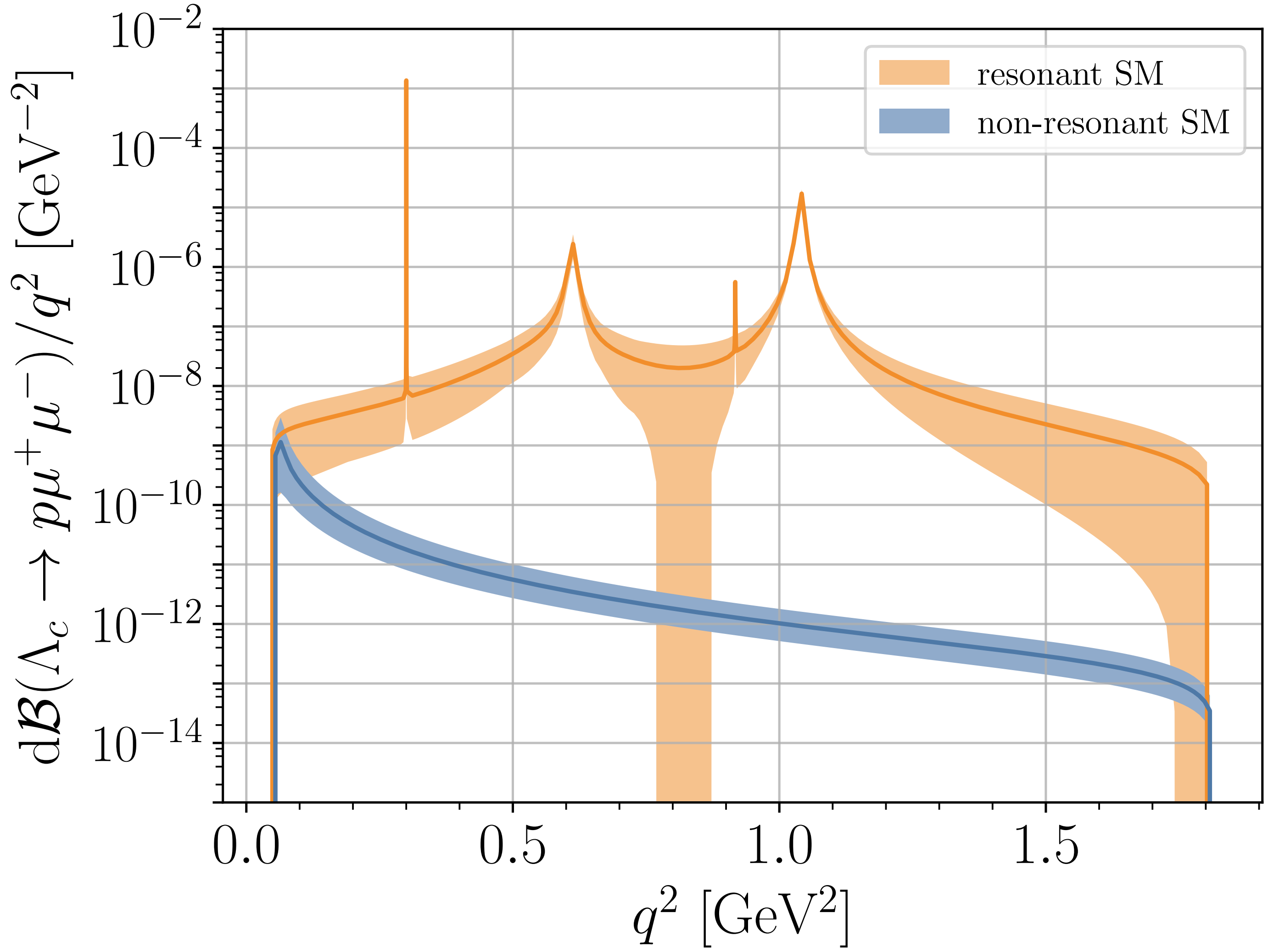
$$\frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2 \mathrm{d}\cos\vartheta_\ell} = \frac{3}{2}\left(K_{1ss}\sin^2\vartheta_\ell + K_{1cc}\cos^2\vartheta_\ell + K_{1c}\cos\vartheta_\ell\right)$$

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

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

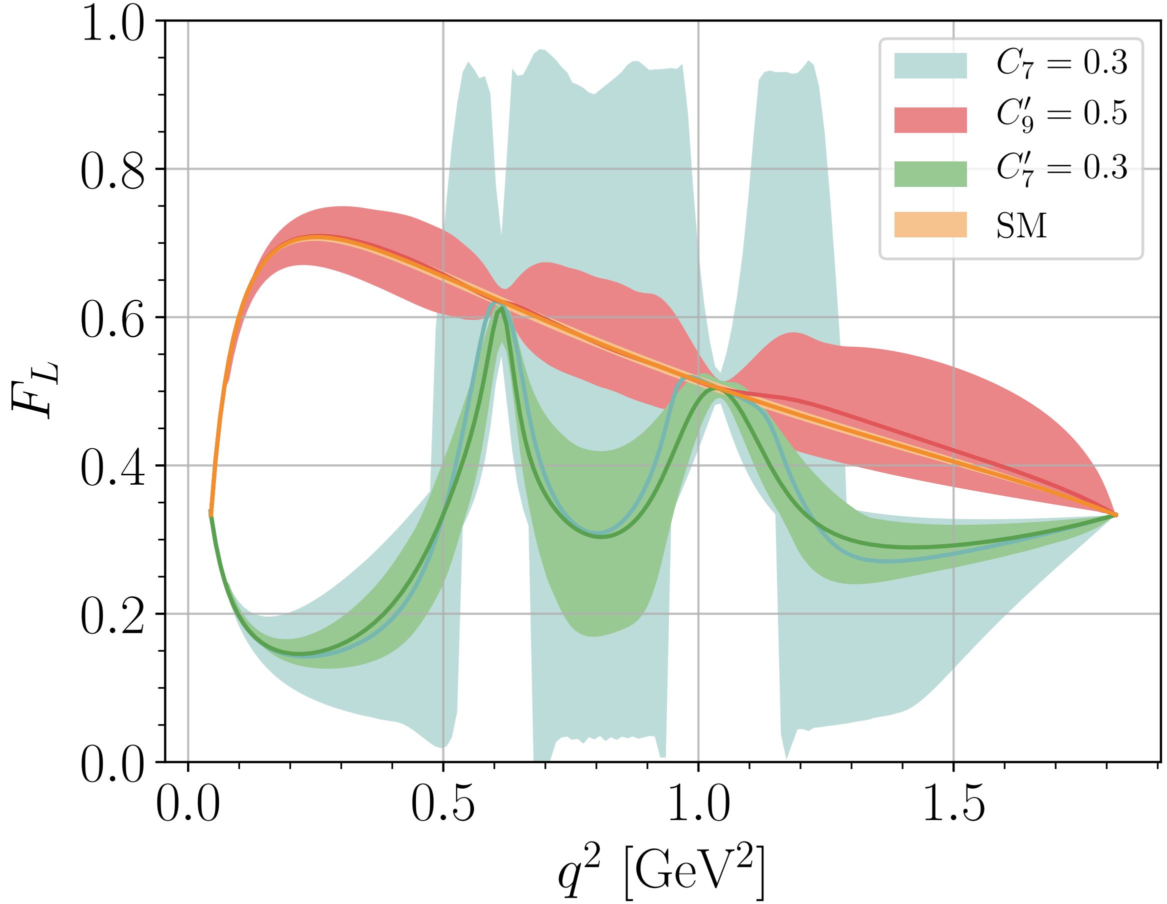
$-\sqrt{6}h_{\perp}^{\Xi_c^0\to\Lambda} = \sqrt{2}h_{\perp}^{\Xi_c^0\to\Sigma^0} = h_{\perp}^{\Xi_c^+\to\Sigma^+} = h_{\perp}^{\Lambda_c\to p}$; Endpoint relations (at q^2 =max): 2107.12993

Branching ratio: $(-)$



2107.13010

Longitudinal polarization: $(+)$



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Sensitivity to dipole coefficients!

GIM null tests: AFB $(++)$

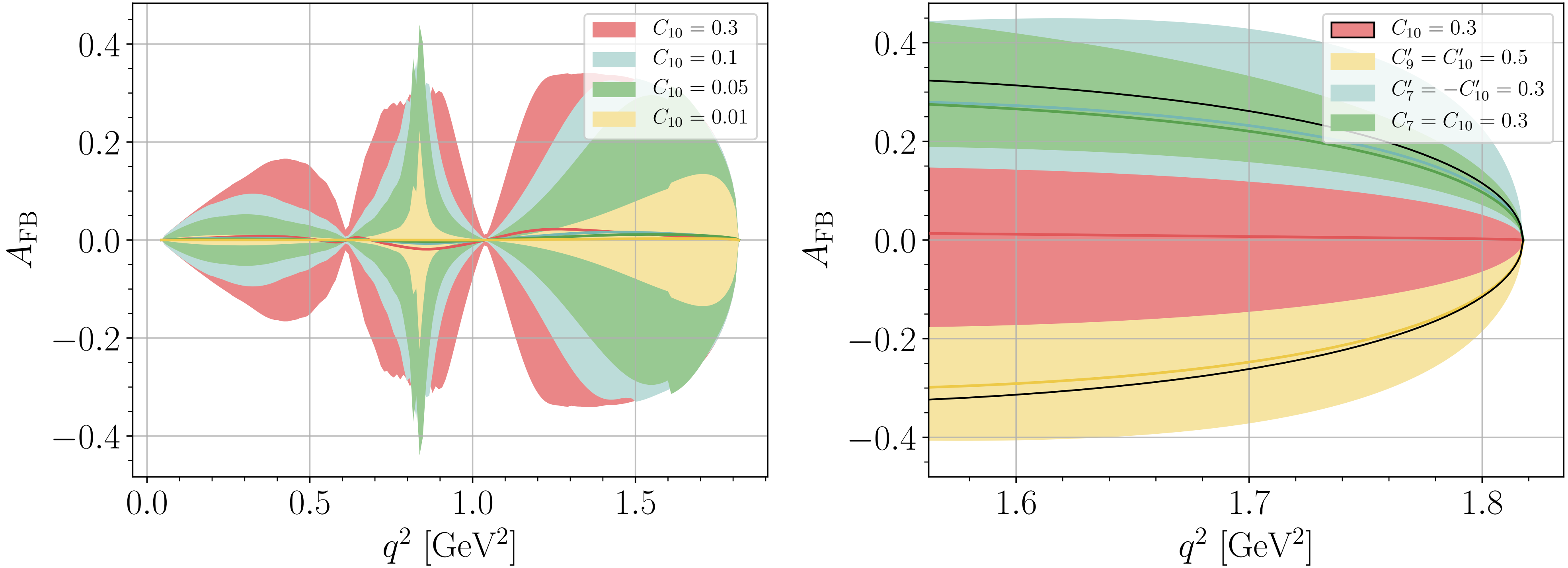


Figure 2: The forward-backward asymmetry A_{FB} of $\Lambda_c \to p\mu^+\mu^-$ decays for different values of C_{10} in the full q^2-region (left panel) and for various BSM contributions in the high q^2 region (right panel)

$A_{\mathrm{FB}} \propto C_{10}$ 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/UX

$\Delta A_{CP} = A_{CP}(D \to K^+K^-) - A_{CP}(D \to \pi^+\pi^-)$ from $A_{CP}(\pi^+\pi^-)$?

CP & U-Spin puzzle 2207.08539, 2210.16330 two approx symmetries challenged

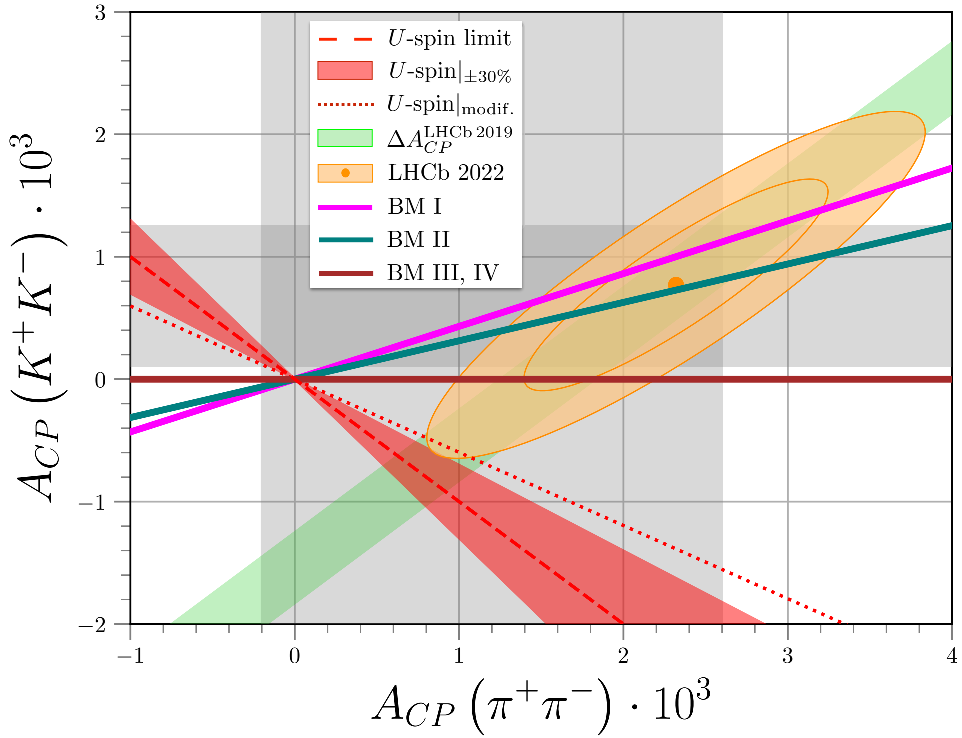


Fig from 2210.16330, LHCb result (orange ellipse) from 2209.03179 SM theory recently 2305.11951, 2312.13245

CP violation suppressed in charm
t predominantly tree, h: higher order: loops, FSI, rescattering

$$A = A(D^0 \to \pi^+\pi^-)^{\text{SM}} = \Sigma\, t + V_{cb}^* V_{ub} h e^{i\delta} \,,$$
$$\bar{A} = A(\bar{D}^0 \to \pi^+\pi^-)^{\text{SM}} = \Sigma^* t + V_{cb} V_{ub}^* h e^{i\delta} \,,$$

where $\Sigma = (V_{cd}^* V_{ud} - V_{cs}^* V_{us})/2$ and $V_{cs}^* V_{us} \simeq -V_{cd}^* V_{ud} \gg V_{cb}^* V_{ub}$.

$$A_{\text{CP SM}}^{\pi^-\pi^+} = \frac{|A|^2 - |\bar{A}|^2}{|A|^2 + |\bar{A}|^2} \simeq 2 \cdot \text{Im}\left(\frac{V_{cb}^* V_{ub}}{V_{cd}^* V_{ud}}\right) \frac{h}{t} \sin\delta \simeq 1.2 \cdot 10^{-3} \frac{h}{t} \sin\delta$$

Data $A_{\text{CP}}^{\pi^-\pi^+} = (23.2 \pm 6.1) \cdot 10^{-4}$ implies $h/t \sin\delta \sim 2$

SM: FSI-interactions (Pich, Solomonidi, Silva) 2305.11951: $h/t \sin\delta \lesssim 0.2$, however 2203.04056 (Bediaga et al) , 1706.07780

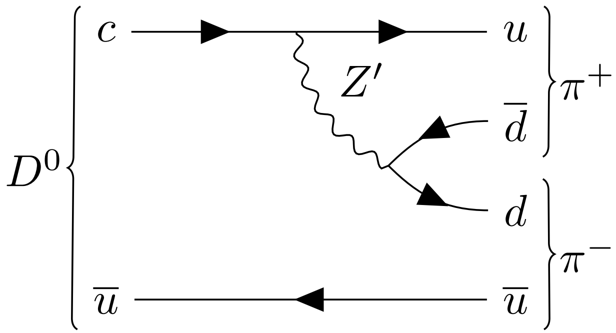
(Khodjamirian, Petrov) $h/t \sin\delta \lesssim 0.1$. LCSR (Lenz, Piscopo et al) 2312.13245 $h/t \sin\delta \lesssim 0.1$.

We need the U-spin breaking on top.

Is large $A_{\rm CP}^{\pi^-\pi^+} = (23.2 \pm 6.1) \cdot 10^{-4}$ and $A_{\rm CP}^{K^-K^+}$ SM-like even explainable?

Single solution known 2210.16330 break U-spin explicitly, couple to charm, only $SU(2)_L$-singlets to avoid Kaons, anomaly-free
$SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)'$

Model	F_{Q_i}			F_{u_i}			F_{d_i}			F_{L_i}			F_{e_i}			F_{ν_i}		
BM I	0	0	0	9	-16	7	20	-11	-9	15	-6	-9	-16	0	16	6	12	-18
BM II	0	0	0	-19	9	10	20	-8	-12	4	1	-5	15	2	-17	8	2	-10
BM III	0	0	0	G	-F	0	F	-G	0	0	0	0	0	-G	F	0	G	-F
BM IV	0	0	0	-F_u	F_u	0	F_d	0	-F_d	0	0	0	F_e	0	-F_e	F_ν	-F_ν	0



A light Z' in hadronic charm CPX/UX

To avoid the constraints from $D-\bar{D}$-mixing, the $\bar{u}_R\gamma_\mu c_R$ coupling has to be small. To still get the effect in 4-quark operators $\sim \bar{u}_R\gamma_\mu c_R\bar{d}_R\gamma^\mu d_R$ the Z' has be light.

Sub 20 GeV Z' (CMS ISR constraints), leptophob (LHCb $A\to\mu\mu$ search), BM I,II dead, BM III $F \gg G$, BM IV $F_e \ll F_d$

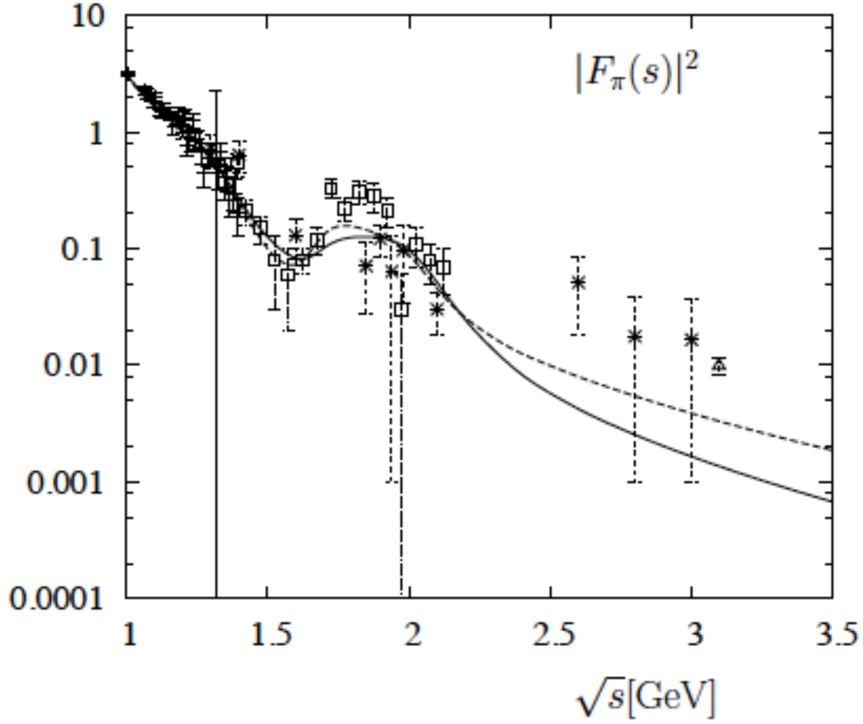
Model	F_{Q_i}			F_{u_i}			F_{d_i}			F_{L_i}			F_{e_i}			F_{ν_i}		
BM III	0	0	0	G	-F	0	F	-G	0	0	0	0	0	-G	F	0	G	-F
BM IV	0	0	0	-F_u	F_u	0	F_d	0	-F_d	0	0	0	F_e	0	-F_e	F_ν	-F_ν	0

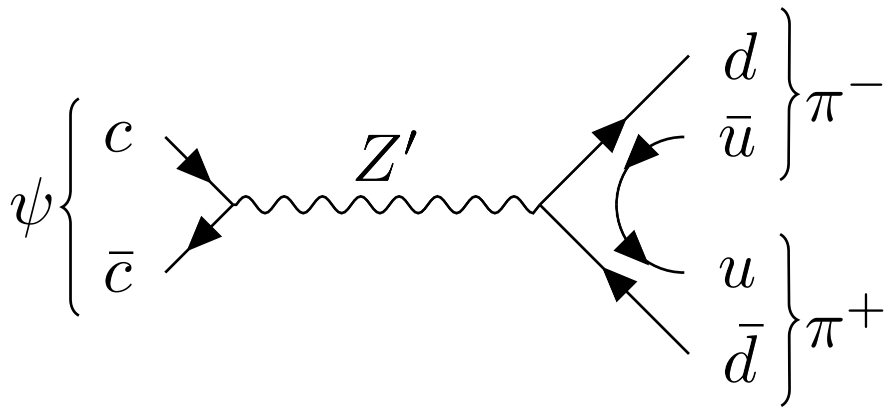
Signatures in low mass dijets, $J/\Psi/\Psi'$, Υ decays, $A_{CP}(D\to\pi^0\pi^0), A_{CP}(D\to\pi^+\pi^0)\sim A_{CP}(D\to\pi^+\pi^-)$.

Model	light quarks	b	c	e	μ	τ	ν_R
BM III$\|_{M_{Z'}=2.5\,\mathrm{GeV}}$	75	0	0	0	0	0	25
BM III$\|_{M_{Z'}=15\,\mathrm{GeV}}$	38	0	37	0	0	12	13
BM III-s$\|_{M_{Z'}=2.5\,\mathrm{GeV}}$	86	0	0	0	0	0	14
BM III-s$\|_{M_{Z'}=15\,\mathrm{GeV}}$	75	0	0	0	0	12	13
BM IV$\|_{M_{Z'}=5\,\mathrm{GeV}}$	79	0	21	0	0	0	0
BM IV$\|_{M_{Z'}=15\,\mathrm{GeV}}$	54	28	18	0	0	0	0

Table 3: Tree-level branching fractions in % for the different Z' decay modes to fermion-antifermion pairs. Results for BM III and BM III-s are given in the limit $G \ll F$. In BM IV, branching ratios depend on the different charge assignments $F_{u,d,e,\nu}$, see main text for details. The branching ratios shown in this table are obtained from $F_u = 985$, $F_d = 1393$, $F_e = 1$ in BMVpart and $F_\nu = 0$. Branching ratios in all BMs differ perceptibly between the low and high $M_{Z'}$ windows, as the decays $Z' \to b\bar{b}$, $c\bar{c}$, $\tau^+\tau^-$ are kinematically forbidden or suppressed in the few GeV range. Corrections to branching ratios from kinetic mixing are generically $\lesssim 10^{-7}$.

What else can the hadrophilic light Z' do for you?





plot from hep-ph/0409080, discrepancy of pion form factor (from $e\pi$-scattering plus theory) with $Br(J/\psi \to \pi^+\pi^-)$ (triangle).

Simultaneous explanation with charm CP data in BM III for $M_{Z'} \sim 3$ GeV, BM IV for $M_{Z'} \sim (5-6)$ GeV 2210.16330

Summary

- Rare charm decays can test the SM and signal new physics using null tests of the SM
- Very little experimentally explored in rare charm decays – lots of blanks in PDG, but plenty of recent progress.
- BSM effects in $|\Delta c| = |\Delta u| = 1$ can be large.
- U-spin/CP puzzle hints at combined breaking of SM symmetries. Possible connection with other low energy puzzles.
- Complementary search to K,B-decays.
- Plenty of Terra Incognita in flavor phenomenology — explore synergies

”charm is the new beauty”

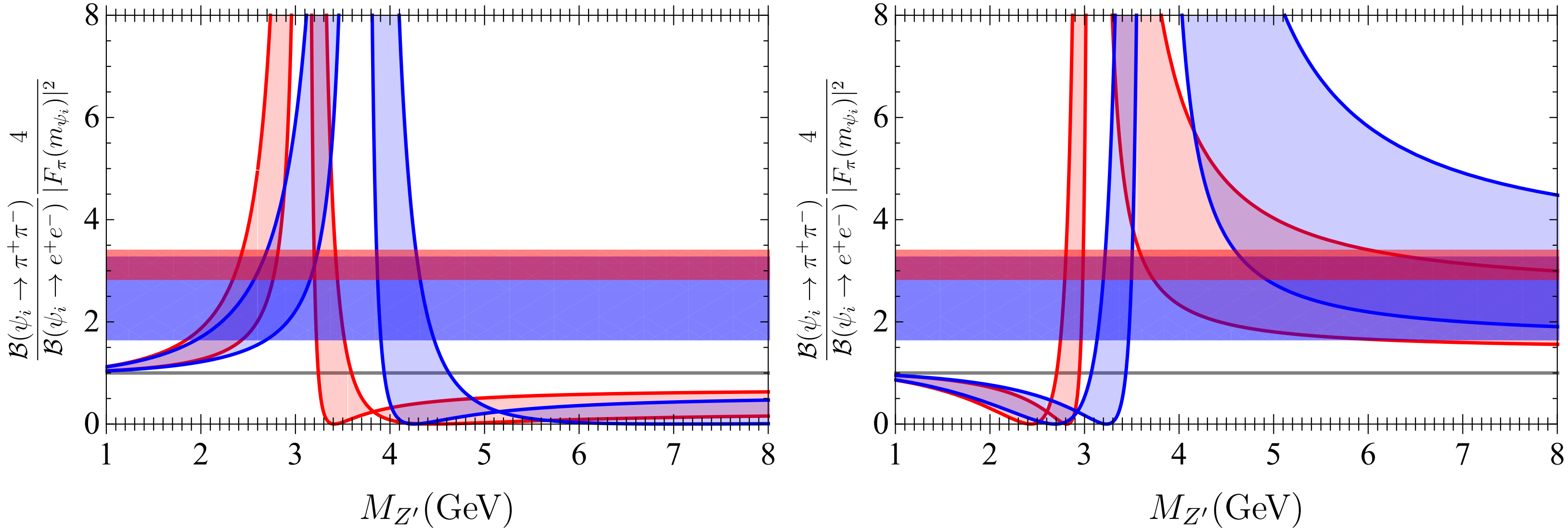


Figure 3: Constraints from charmonium decays. Horizontal red (blue) bands denote the left-hand side of (**??**) from 1 sigma ranges of J/ψ-data with $|F_\pi(m_{J/\psi})| = 0.056$ (ψ' decays with $|F_\pi(m_{\psi'})| = 0.04$.). Curves correspond to the predictions of BM III with $F \gg G$ (left) and BM IV (right). The SM prediction via photon-exchange is shown by the grey line.