HFCPV2021，暨南大学，2021/11/13

全国第十八届重味物理和 CP 破坏研讨会

SUMMARY

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華中師範大學

MANY INTERESTING TALKS:

Overview talks:

张黎明	Recent Experimental Progress in Heavy Flavor Physics
于福升	Recent Theoretical Progress in Heavy Flavor Physics

Highlights from LHCb, BESIII, Belle, ATLAS & CMS:

钱文斌	Highlights from LHCb
刘北江	Highlights from BESIII
贾森	Highlights from Belle
李冰	Latest results from ATLAS
蒋楚翘	$b \to s \ell \bar{\ell}$ angular analyses on CMS

a series of detailed talks:

- Spectroscopy： excited states & exotic states;

李培荣	Recent XYZ results at BESIII
傅金林	Hadron spectroscopy and exotics at LHCb

- Rare b- and c-hadron decays & CPV:

何吉波	味物理中的反常
张艳席	Recent CPV results at LHCb
李蕾	Strong phase measurement of D decays at BESIII
俞洁晟	LHCb 上 b 强子非粲重子衰变模式的研究
耿聪	Hadronic decays of charmed mesons and baryons at BESIII
柯百谦	Leptonic decays of charmed mesons at BESIII
孙亮	charm physics at LHCb
李郁博	Results on charmed baryons at Belle

+26 very nice theory talks!

MANY INTERESTING TALKS:

- **26 theory talks:**
  - **spectroscopy, production, decay & decays of b- and c-hadrons;**
  - **CPV in two-body & multibody decays of hadrons & tau-lepton;**
  - **New physics explanations of flavor anomalies, including $(g-2)_{mu}$;**
  - **Correlations with neutrino physics, cosmology & astrophysics;**
  - **Many new observables, new methods & new physics models proposed;**
- **Exp. + LQCD + theory: we are entering into a precision flavor physics era!**

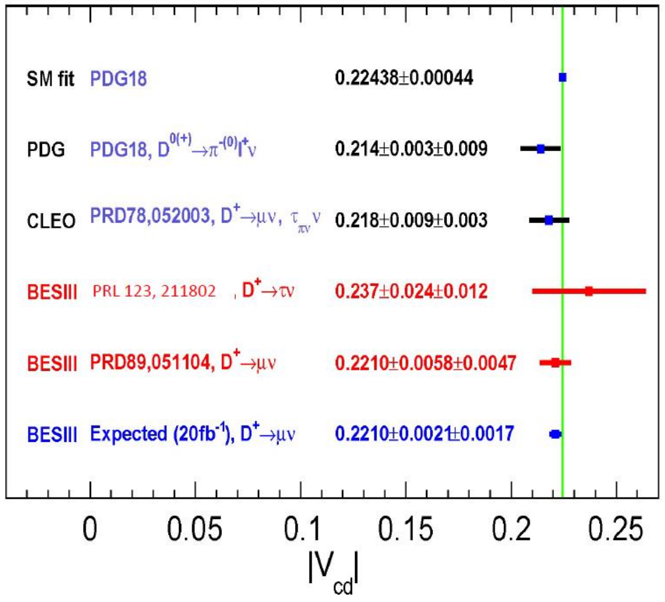
$D_s^+ \to \tau^+\nu_\tau$ AND SEMILEPTONIC D DECAYS:

- **Pure leptonic decay:** $D_s^+ \to \tau^+\nu_\tau$ via $\tau^+ \to e^+\nu_e\bar{\nu}_\tau$

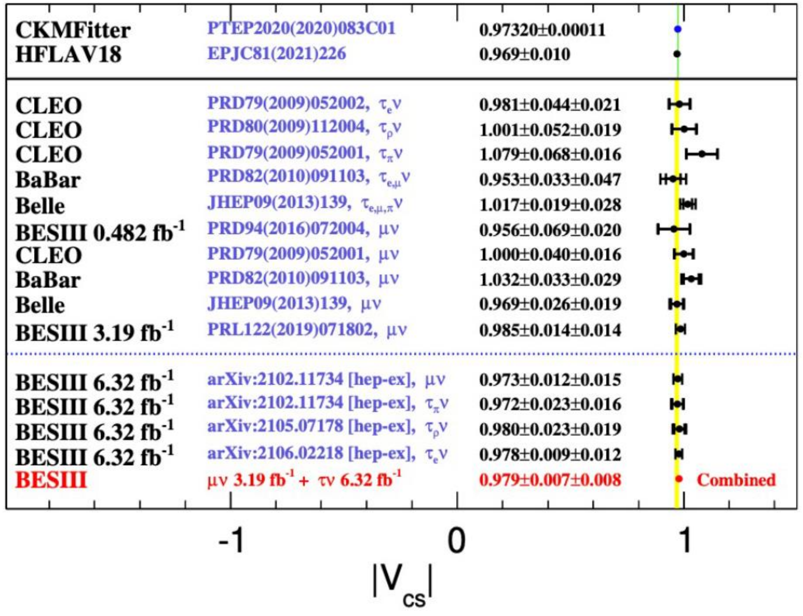
Extraction of $|V_{cd(s)}|$

Take f_D^{LQCD} as input:

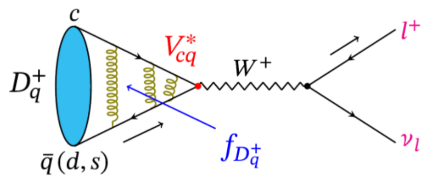
$|V_{cd}|=(0.2210\pm0.0058\pm0.0047)$ ($\mu^+\nu$ mode)



- Input $f_{D_s^+} = 249.9 \pm 0.5$ MeV from LQCD calculations



Most precise measurement



$$\Gamma(D_{(s)}^+ \to l^+\nu) = \frac{G_F^2 f_{D_{(s)}^+}^2}{8\pi}|V_{cd(s)}|^2 m_l^2 m_{D_{(s)}^+}\left(1-\frac{m_l^2}{m_{D_{(s)}^+}^2}\right)^2$$

$$B(D_s^+ \to \mu^+\nu_\mu) = (5.35 \pm 0.13_{\text{stat.}} \pm 0.16_{\text{syst.}}) \times 10^{-3}$$

$$B(D_s^+ \to \tau^+\nu_\tau) = (5.21 \pm 0.25_{\text{stat.}} \pm 0.17_{\text{syst.}}) \times 10^{-2}$$

- No evidence for LFUV in leptonic charm decays with BESIII data until now!

V_{UB}/V_{CB} PUZZLE:

◻ Exclusive decays:

Semileptonic form factors for $B \to D^*\ell\nu$ at nonzero recoil from 2 + 1-flavor lattice QCD

2105.14019

A. Bazavov,[1] C.E. DeTar,[2] Daping Du,[3] A.X. El-Khadra,[4,5] E. Gámiz,[6] Z. Gelzer,[4] Steven Gottlieb,[7] U.M. Heller,[8] A.S. Kronfeld,[9] J. Laiho,[3] P.B. Mackenzie,[9] J.N. Simone,[9] R. Sugar,[10] D. Toussaint,[11] R.S. Van de Water,[9] and A. Vaquero[2,*]
(Fermilab Lattice and MILC Collaborations)

- in tension with Belle 2018 data & preliminary results from JLQCD!

◻ Inclusive decays:

Measurements of q^2 Moments of Inclusive $B \to X_c\ell^+\nu_\ell$ Decays with Hadronic Tagging
Belle Collaboration • R. van Tonder et al. (Sep 3, 2021)
e-Print: 2109.01685 [hep-ex]
pdf cite

Measurement of Differential Branching Fractions of Inclusive $B \to X_u\ell^+\nu_\ell$ Decays
Belle Collaboration • L. Cao et al. (Jul 29, 2021)
e-Print: 2107.13855 [hep-ex]
pdf cite

Third order corrections to the semileptonic b→c and the muon decays
Matteo Fael (KIT, Karlsruhe, TTP), Kay Schönwald (KIT, Karlsruhe, TTP), Matthias Steinhauser (
Published in: Phys.Rev.D 104 (2021) 1, 016003 • e-Print: 2011.13654 [hep-ph]
pdf DOI cite

Three loop calculations and inclusive Vcb
Marzia Bordone (INFN, Turin and Turin U.), Bernat Capdevila (INFN, Turin and
Published in: Phys.Lett.B 822 (2021) 136679 • e-Print: 2107.00604 [hep-ph]
pdf DOI cite

UTfit update

V_{cb} and V_{ub}

from FLAG 2019 arXiv:1902.08191
$|V_{cb}|$ *(excl)* = (39.09 ± 0.68) 10^{-3}

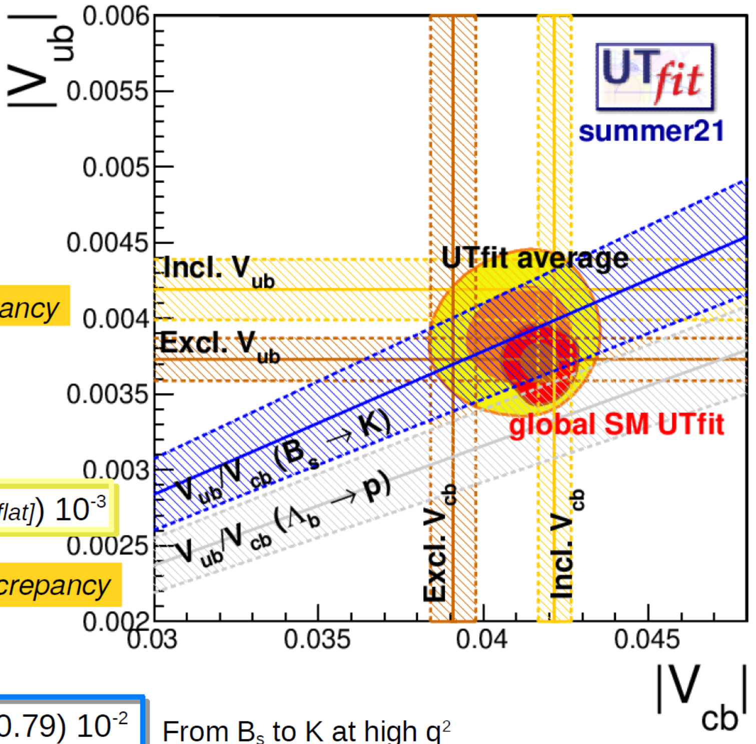
$|V_{cb}|$ *(incl)* = (42.16 ± 0.50) 10^{-3}
from Bordone et al. arXiv:2107.00604

~2.8σ discrepancy

from FLAG 2019 arXiv:1902.08191
$|V_{ub}|$ *(excl)* = (3.73 ± 0.14) 10^{-3}

$|V_{ub}|$ *(incl)* = (4.19 ± 0.17 ± 0.18 *[flat]*) 10^{-3}
from GGOU HFLAV 2021 adding a flat uncertainty covering the spread of central values

~1.5σ discrepancy



$|V_{ub}/V_{cb}|$ *(LHCb)* = (9.46 ± 0.79) 10^{-2} From B_s to K at high q^2

$|V_{ub}/V_{cb}|$ *(LHCb)* = (7.9 ± 0.6) 10^{-2} From Λ_b, excluded following FLAG guidelines

Marcella Bona 5

$$\mathrm{Br}(\bar{B} \to X_c\ell\bar{\nu}) \propto \frac{|V_{cb}|^2}{\tau_B}\left[\Gamma_{\mu_3}\mu_3 + \Gamma_{\mu_G}\frac{\mu_G^2}{m_b^2} + \Gamma_{\tilde{\rho}_D}\frac{\tilde{\rho}_D^3}{m_b^3} + \Gamma_{r_E}\frac{r_E^4}{m_b^4} + \Gamma_{r_G}\frac{r_G^4}{m_b^4} + \Gamma_{s_B}\frac{s_B^4}{m_b^4} + \Gamma_{s_E}\frac{s_E^4}{m_b^4} + \Gamma_{s_{qB}}\frac{s_{qB}^4}{m_b^4}\right]$$

$$\downarrow$$

$$V_{cb} = ?$$

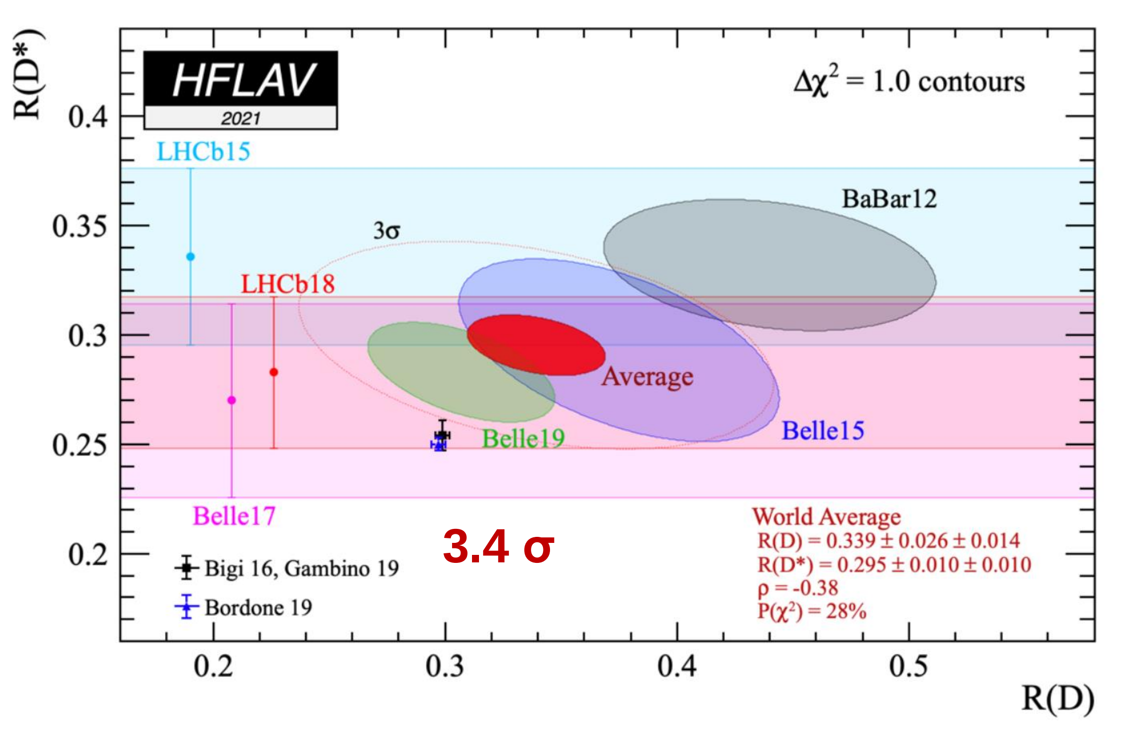
In progress:
- V_{cb} from q^2 moments

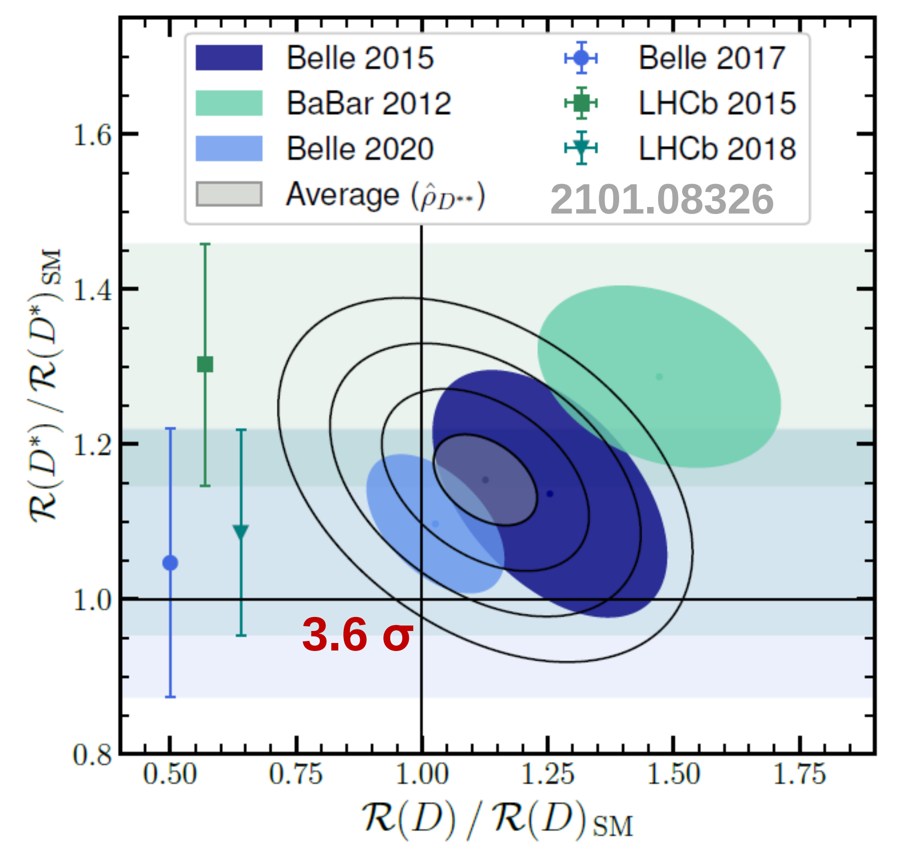
[Fael, Mannel, Vos, 2019]

R(D) & R(D*) :

different assumptions for unknown correlation $\rho_{D^{**}}$!

☐ Semileptonic decays: R(D) & R(D*)





$$F_i = \left(a_i + b_i \frac{\alpha_s}{\pi}\right)\xi + \frac{\Lambda_{\rm QCD}}{2m_b}\sum_j c_{ij}\xi^j_{\rm SL} + \frac{\Lambda_{\rm QCD}}{2m_c}\sum_j d_{ij}\xi^j_{\rm SL} + \left(\frac{\Lambda_{\rm QCD}}{2m_c}\right)^2\sum_j g_{ij}\xi^j_{\rm SSL}$$

$$R(D) = 0.2981 \pm 0.0029$$
$$R(D^*) = 0.2504 \pm 0.0026$$

~4σ   Bordone et al., 1912.09335

No final conclusion yet, new experimental and Lattice QCD data are needed!

R(D) & R(D*) :

- **Difficult to explain the $R(D^{(*)})$ anomalies in SM; ⟹ possible NP?**

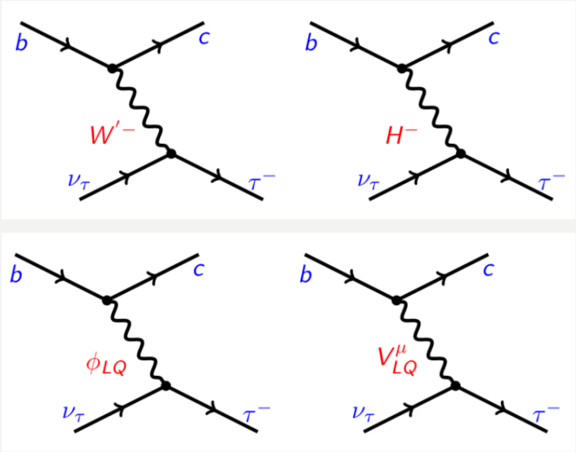
$R(D)$: 1.4σ

$R(D^*)$: 2.5σ

combined: $\sim 3.4\sigma$

⟹ NP $\sim 10-15\%$ of a SM tree decay $\Rightarrow$ huge effect

- If NP interfere with SM we need it to be 10%
- If NP doesn't interfere with SM, we need it to be a 40% effect



Evidence for an excess of $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$ decays #1
BaBar Collaboration • J.P. Lees (Annecy, LAPP) et al. (May, 2012)
Published in: *Phys.Rev.Lett.* 109 (2012) 101802 • e-Print: 1205.5442 [hep-ex]
pdf links DOI cite 960 citations

Measurement of the branching ratio of $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$ relative to $\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell$ decays with hadronic tagging at Belle #4
Belle Collaboration • M. Huschle (Karlsruhe U., EKP) et al. (Jul 12, 2015)
Published in: *Phys.Rev.D* 92 (2015) 7, 072014 • e-Print: 1507.03233 [hep-ex]
pdf links DOI cite 743 citations

Measurement of the ratio of branching fractions $\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)/\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu)$ #5
LHCb Collaboration • Roel Aaij (CERN) et al. (Jun 29, 2015)
Published in: *Phys.Rev.Lett.* 115 (2015) 11, 111803, *Phys.Rev.Lett.* 115 (2015) 15, 159901 (erratum) • e-Print: 1506.08614 [hep-ex]
pdf links DOI cite 934 citations

- **Many explanations!**

R(D) & R(D*) :

Hu/LI/Yang, 1810.04939

Most general $SU(3)_C \otimes U(1)_Q$-invariant $\mathcal{L}_{eff}$ @ $\mu_b = m_b$ scale:

$$\mathcal{L}_{\text{SM}}^{(6)} = -\frac{4G_F}{\sqrt{2}} V_{cb}\, \mathcal{O}_{V_L} + \text{H.c.},$$

$$\mathcal{L}_{\text{NP}}^{(6)} = -\frac{4G_F}{\sqrt{2}} V_{cb} \left(C_{V_L}\mathcal{O}_{V_L} + C_{V_R}\mathcal{O}_{V_R} + C_{S_L}\mathcal{O}_{S_L} + C_{S_R}\mathcal{O}_{S_R} + C_T\mathcal{O}_T\right) + \text{H.c.}$$

$$\mathcal{O}_{V_{L(R)}} = (\bar{c}\gamma^\mu P_{L(R)} b)(\bar{\tau}\gamma_\mu P_L \nu_\tau),$$

$$\mathcal{O}_{S_{L(R)}} = (\bar{c} P_{L(R)} b)(\bar{\tau} P_L \nu_\tau),$$

$$\mathcal{O}_T = (\bar{c}\sigma^{\mu\nu} P_L b)(\bar{\tau}\sigma_{\mu\nu} P_L \nu_\tau).$$

Observables considered:

- Ratios $R(D)$ and $R(D^*)$;
- Differential distributions $d\Gamma\left(B \to D^{(*)}\tau\nu\right)/dq^2$;
- Leptonic decay rate $Br(B_c \to \tau\, \nu_\tau\,) \leq 10(30)\%$;
- Longitudinal polarization fraction $P_L^{D^*}$;
- Polarization fraction of the τ lepton $P_\tau^{D^*}$;

$$P_{\text{L}}^{D^*}(q^2) = \frac{\mathrm{d}\Gamma^{\lambda_{D^*}=0}(B \to D^*\tau\nu)/\mathrm{d}q^2}{\mathrm{d}\Gamma(B \to D^*\tau\nu)/\mathrm{d}q^2}$$

$P_{\mathbf{L}}^{D^*} = 0.60 \pm 0.08 \pm 0.04$ vs Belle, 1901.06380

$P_{\mathbf{L}}^{D^*} = 0.455 \pm 0.003$ ~1.5σ

$$P_\tau^{D^{(*)}}(q^2) = \frac{\mathrm{d}\Gamma^{\lambda_\tau=1/2}(B \to D^{(*)}\tau\nu)/\mathrm{d}q^2 - \mathrm{d}\Gamma^{\lambda_\tau=-1/2}(B \to D^{(*)}\tau\nu)/\mathrm{d}q^2}{\mathrm{d}\Gamma(B \to D^{(*)}\tau\nu)/\mathrm{d}q^2}$$

$$P_\tau(D^*)^{\text{exp}} = -0.38^{+0.51+0.21}_{-0.51-0.16}$$ Belle, 1612.00529

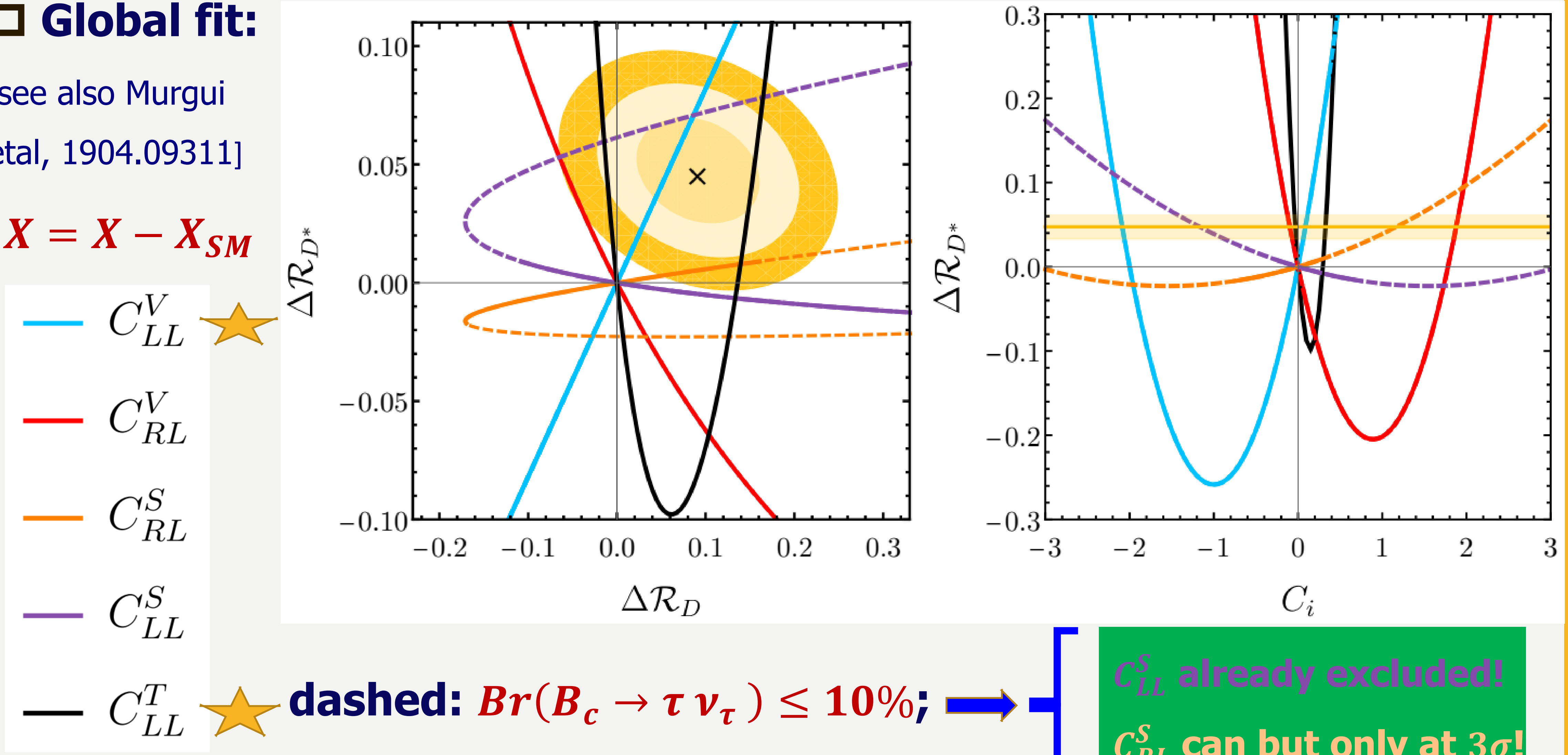
R(D) & R(D*) :

Hu/LI/Yang, 1810.04939

Global fit:

[see also Murgui etal, 1904.09311]

$\Delta X = X - X_{SM}$



dashed: $Br(B_c \to \tau\,\nu_\tau) \leq 10\%$;

C_{LL}^{S} **already excluded!**

C_{RL}^{S} **can but only at** 3σ**!**

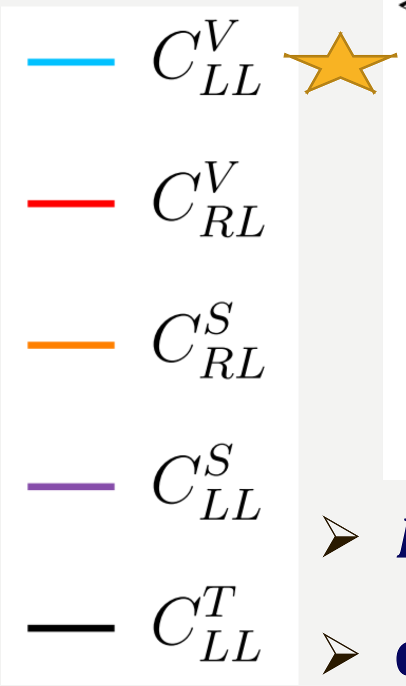
R(D) & R(D*) :

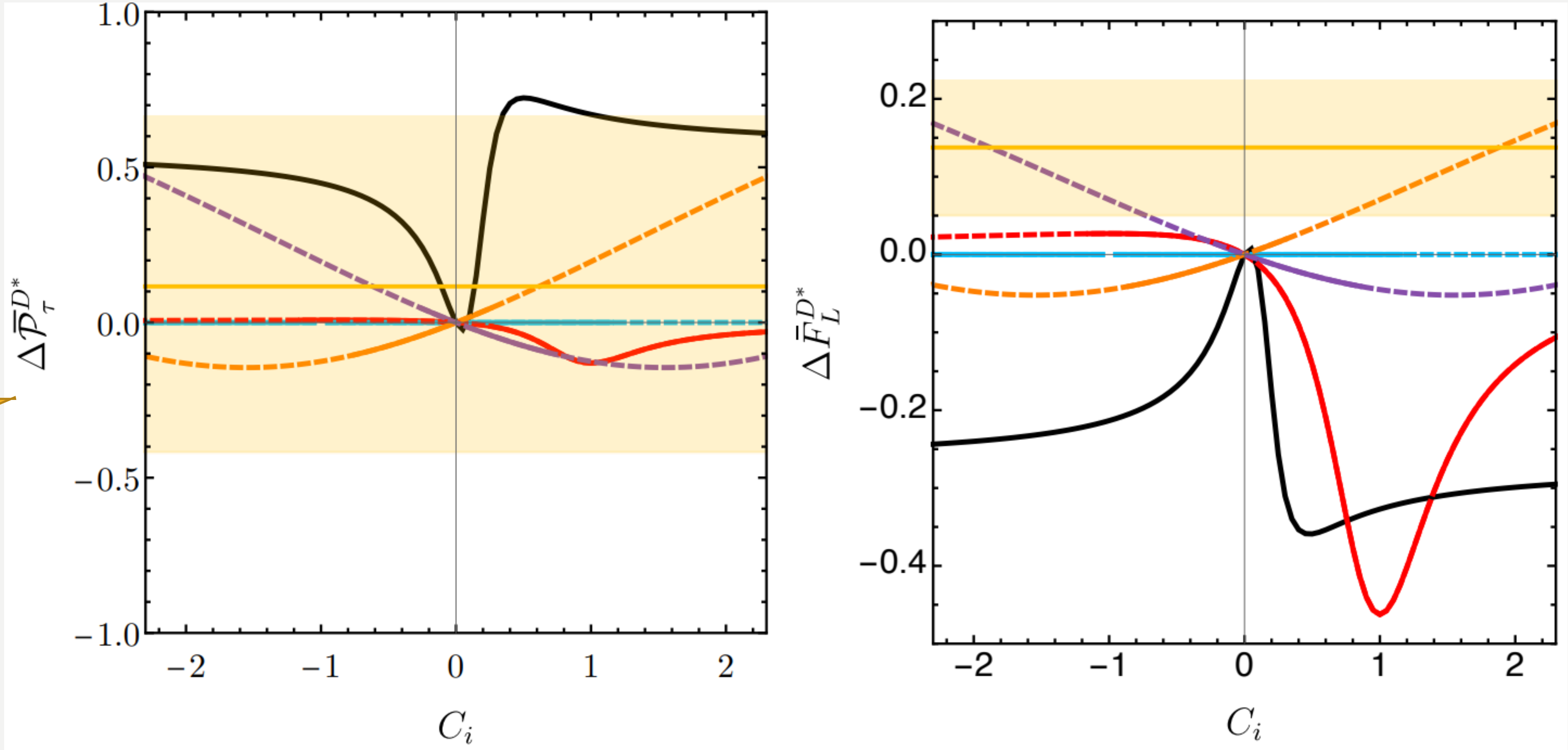
Hu/LI/Yang, 1810.04939

☐ Global fit:

[see also Murgui etal, 1904.09311]

$\Delta X = X - X_{SM}$

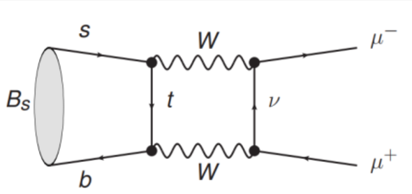




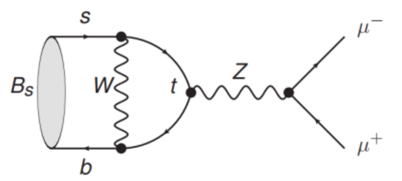
- ➢ **$P_{L}^{D^*}$ & $P_{\tau}^{D^*}$ very potential to distinguish different contributions;**
- ➢ **difficult to accommodate 1σ $P_{L}^{D^*}$ for any C_i; even excluded C_{LL}^{T}!**

$B_{s,d} \to \ell^+\ell^-$:

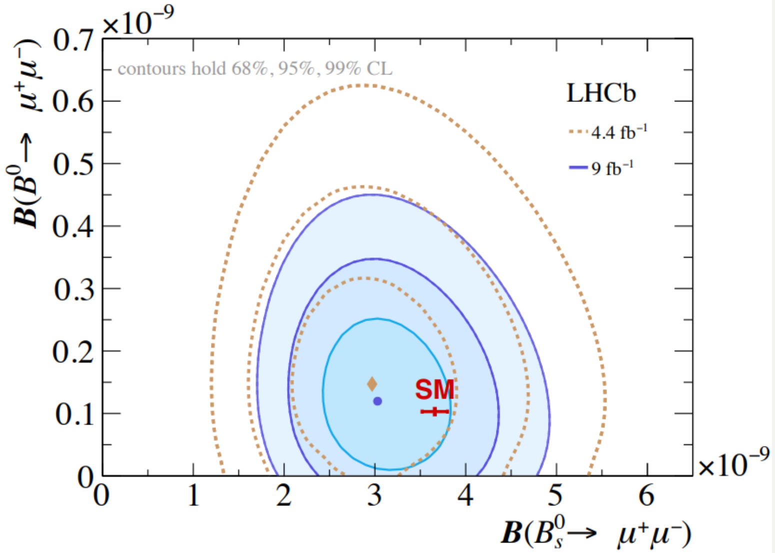
□ FCNC rare decays: beauty of the rarest!



"Instantaneous", "non-radiative" branching fraction

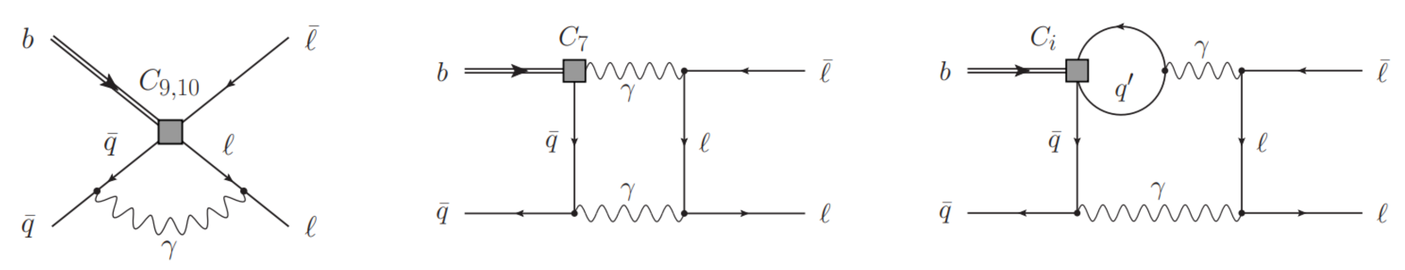


$$\mathrm{Br}(B_s \to \mu^+\mu^-) = \frac{G_F^2\alpha^2}{64\pi^3} f_{B_s}^2 \tau_{B_s} m_{B_s}^3 |V_{tb}V_{ts}^*|^2 \sqrt{1-\frac{4m_\mu^2}{m_{B_s}^2}} \times \left\{ \left| \frac{2m_\mu}{m_{B_s}}(C_{10}-C'_{10}) + (C_P - C'_P) \right|^2 + \left(1-\frac{4m_\mu^2}{m_{B_s}^2}\right) |C_S - C'_S|^2 \right\}$$



- SM only $C_{10}[\bar{s}\gamma_\mu P_L b][\bar{\ell}\gamma^\mu\gamma_5\ell]$ ⇒ helicity suppression. Sensitive to scalar couplings.
- SM C_{10} calculations includes NNLO QCD, NLO EW matching corrections at EW scale, NNLL renormalization-group evolution to the b-quark mass scale including QED logarithms
- LHCb [1703.05747] $(3.0^{+0.7}_{-0.6}) \times 10^{-9}$ vs. Theory [Bobeth et al., 1311.0903] $(3.65 \pm 0.23) \times 10^{-9}$

□ Power-enhanced QED effects: [Beneke, Bobeth, R. Szafron, 1708.09152, 1908.07011]



- ➢ more long-distance QCD than f_B;
- ➢ same order as the non-parametric uncertainty, larger than previously estimated QED uncertainty.

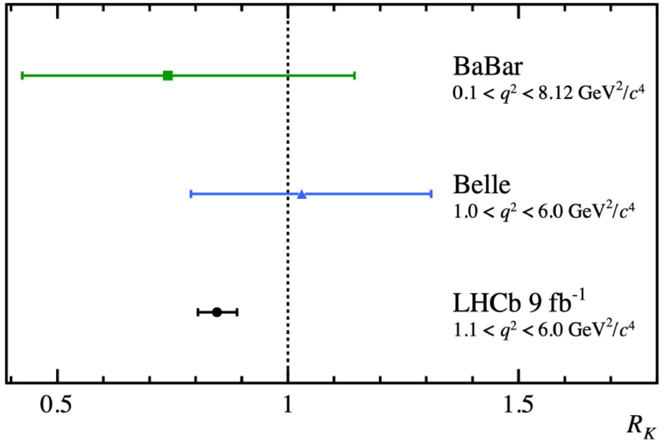
$b \to s\ell^+\ell^-$ transitions:

- **FCNC rare decays:** $b \to s\ell^+\ell^-$

Exciting new experimental value of R_K

LHCb [2103.11769]

$$R_H \equiv \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{d\mathcal{B}(B \to H\mu^+\mu^-)}{dq^2} dq^2}{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{d\mathcal{B}(B \to He^+e^-)}{dq^2} dq^2}$$

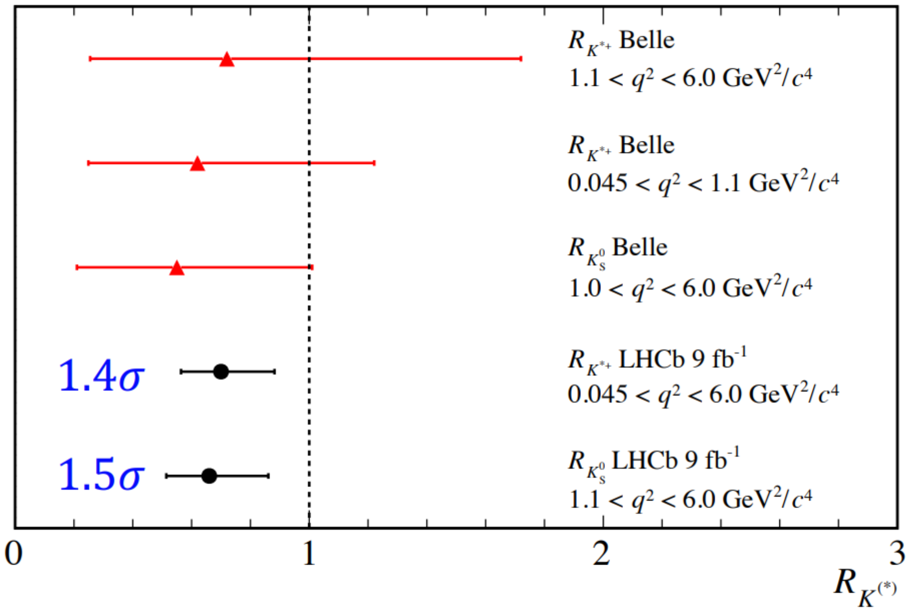


$$R_K^{\rm LHCb} = 0.846^{+0.042+0.013}_{-0.039-0.012}$$

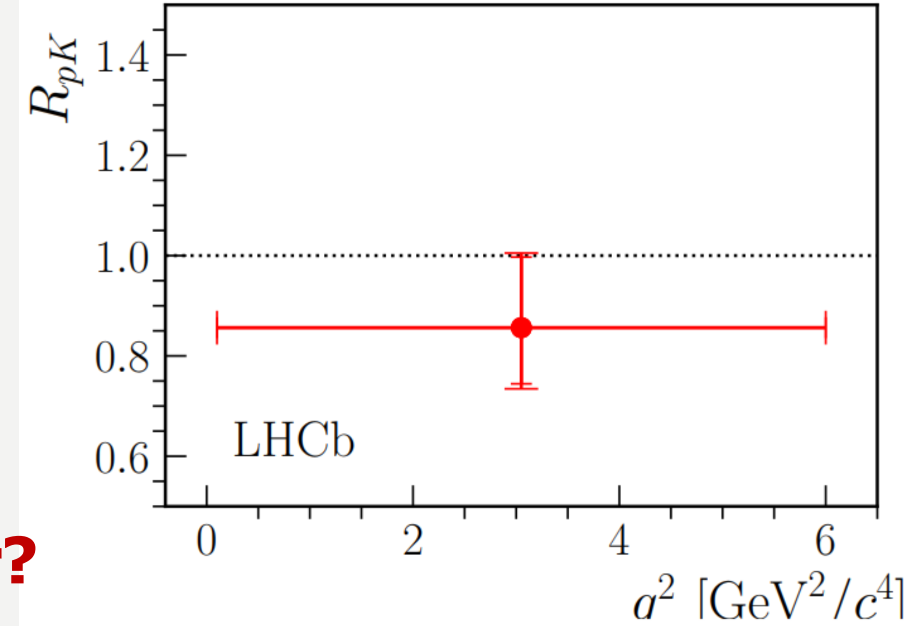
+ Likelihood

$\Rightarrow$ 3.1σ ! !

> 3σ of tension between SM and Exp for the first time in a single **LFUV** observable!



LHCb combined significance w.r.t. SM: 2σ

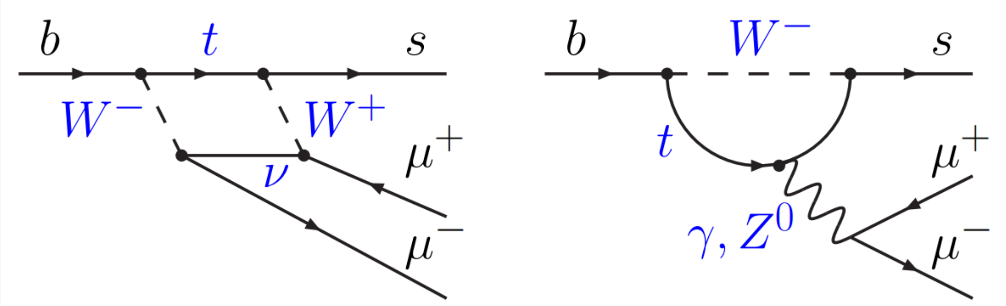


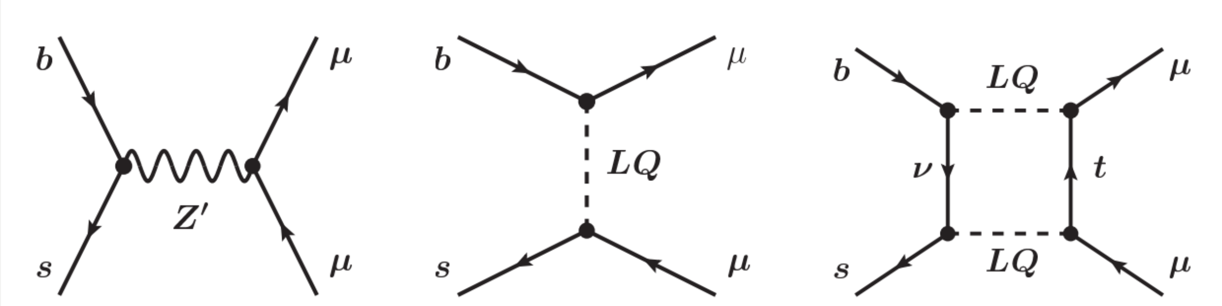
+ R(D) & R(D*) + angular observables

$\Rightarrow$ **Hints of LFUV NP in b sector?**

$b \to s\ell^+\ell^-$ transitions:

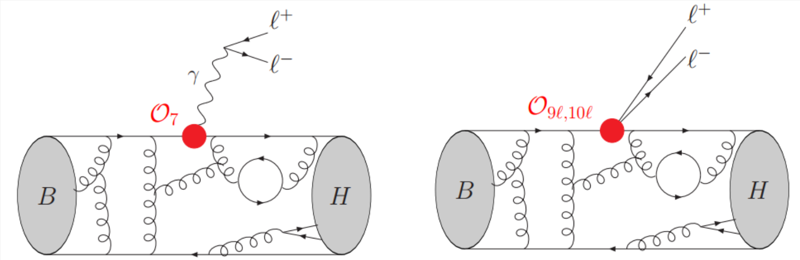
- $b \to s\ell^+\ell^-$ **decays:** **loop-induced FCNC processes;** ⟹ **sensitive to NP;**

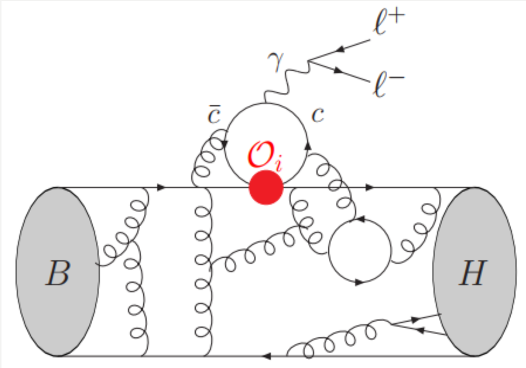




- **Caution: NP could be easily mimiced by non-local hadronic effects;**

$$\mathcal{A}(B \to K^{(*)}\ell\ell) = \mathcal{N}\left[\left(C_9 L_V^\mu + C_{10} L_A^\mu\right)\boldsymbol{\mathcal{F}}_\mu - \frac{L_V^\mu}{q^2}\left(C_7\,\boldsymbol{\mathcal{F}}_{T,\mu} + \boldsymbol{\mathcal{H}}_\mu\right)\right]$$



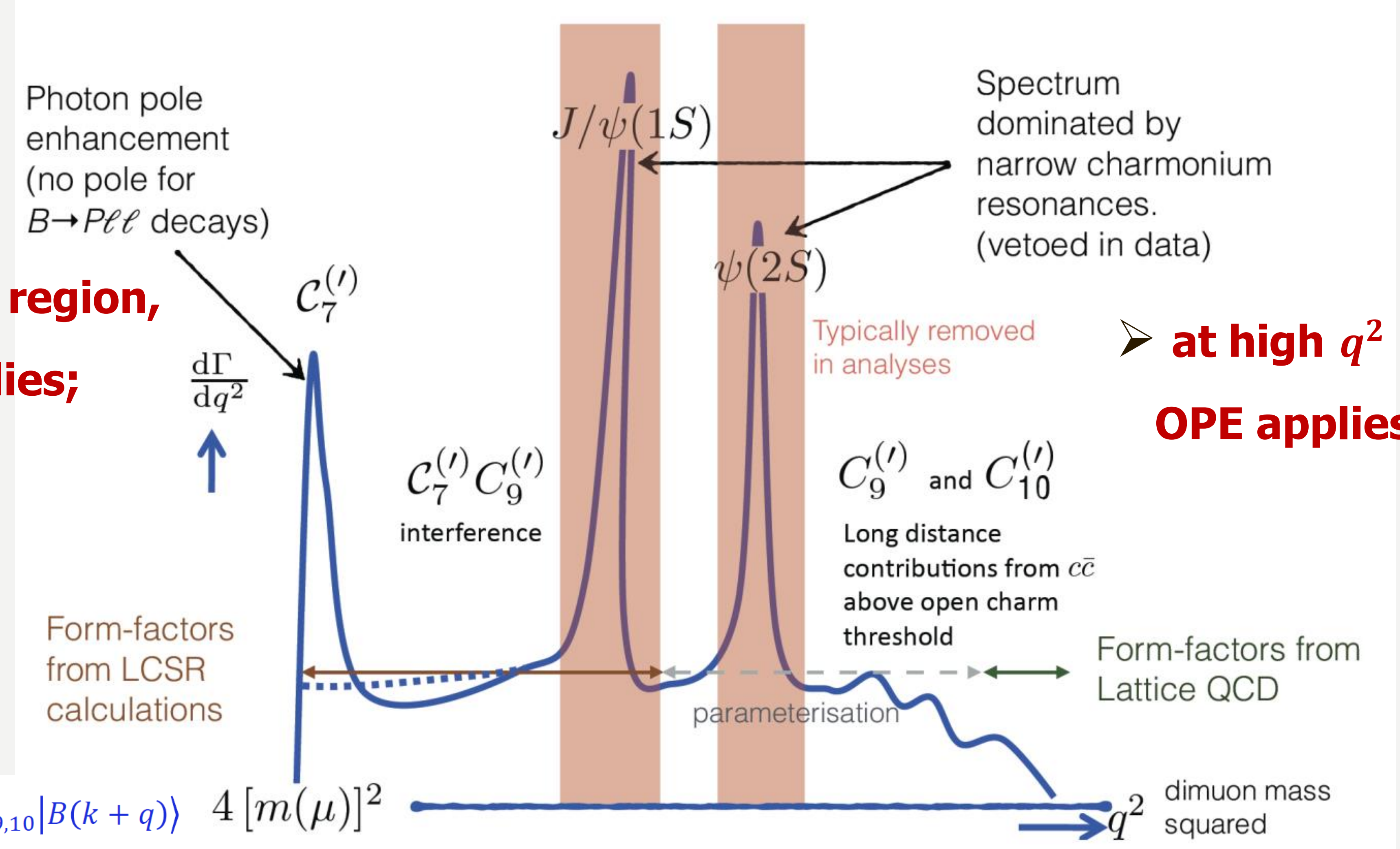


$$\mathcal{F}_\mu = \langle K^{(*)}(k)|O_{7,9,10}|B(k+q)\rangle$$

$$\mathcal{H}_\mu = i\int d^4x\, e^{iq\cdot x}\langle K^{(*)}(k)|T\{j_\mu^{\text{em}}(x), (C_1 O_1^c + C_2 O_2^c)(0)\}|B(k+q)\rangle$$

$b \to s\ell^+\ell^-$ transitions:

- **q^2 spectrum of $B \to K^{(*)}\ell^+\ell^-$ decays:**



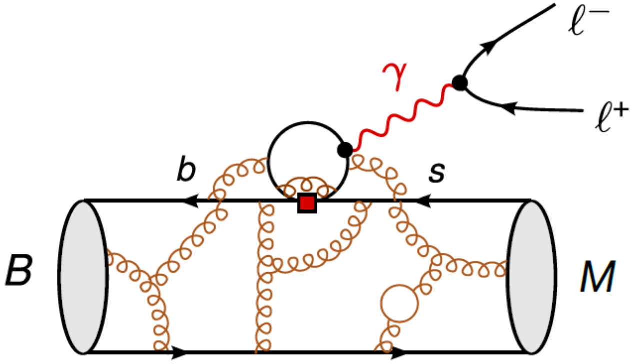
- **at low q^2 region, QCDF applies;**
- **at high q^2 region, OPE applies;**

$\mathcal{F}_\mu = \langle K^{(*)}(k)|O_{7,9,10}|B(k+q)\rangle$

$b \to s\ell^+\ell^-$ transitions:

$$\mathcal{H}_\mu(k,q) = \sum_\lambda \mathcal{S}_\mu^\lambda(k,q)\mathcal{H}_\lambda(q^2)$$

□ Non-local hadronic matrix elements:



$$\mathcal{H}^\mu = \frac{-16i\pi^2}{q^2} \sum_{i=1..6,8} C_i \int dx^4 e^{iq\cdot x} \langle M | T\{j^\mu_{\rm em}(x), O_i(0)\} | B \rangle$$

$$j^\mu_{\rm em} = \sum_q Q_q\, \bar{q}\gamma^\mu q$$

- Contributions at low q^2 from QCD factorization (QCDF) — Beneke, Feldmann, Seidel, arXiv:hep-ph/0106067
- **Beyond-QCDF** contributions **the main source of uncertainty**
- Non-local contributions can mimic New Physics in C_9
- Several approaches to estimate beyond-QCDF contributions at low q^2
  - fit of sum of resonances to data — Blake, Egede, Owen, Pomery, Petridis, arXiv:1709.03921
  - direct fit to angular data — Ciuchini, Fedele, Franco, Mishima, Paul, Silvestrini, Valli, arXiv:1512.07157
  - Light-Cone Sum Rules estimates — Khodjamirian, Mannel, Pivovarov, Wang, arXiv:1006.4945; Gubernari, van Dyk, Virto, arXiv:2011.09813
  - analyticity + experimental data on $b \to s c\bar{c}$ — Bobeth, Chrzaszcz, van Dyk, Virto, arXiv:1707.07305; Gubernari, van Dyk, Virto, arXiv:2011.09813

$b \to s\ell^+\ell^-$ transitions:

- **Global fit results:**

B Flavour Anomalies: 2021 Theoretical Status Report
David London (U. Montreal (main)), Joaquim Matias (Barcelona, Autonoma U. and BIST, Barcelona) (Oct 25, 2021)
e-Print: 2110.13270 [hep-ph]

- ACDMN (M. Algueró, B. Capdevila, S. Descotes-Genon, J. Matias, M. Novoa-Brunet)
  Statistical framework: χ^2-fit, based on private code — arXiv:2104.08921
- AS (W. Altmannshofer, P. Stangl)
  Statistical framework: χ^2-fit, based on public code `flavio` — arXiv:2103.13370
- CFFPSV (M. Ciuchini, M. Fedele, E. Franco, A. Paul, L. Silvestrini, M. Valli)
  Statistical framework: Bayesian MCMC fit, based on public code `HEPfit` — arXiv:2011.01212
- HMMN (T. Hurth, F. Mahmoudi, D. Martínez-Santos, S. Neshatpour)
  Statistical framework: χ^2-fit, based on public code `SuperIso` — arXiv:2104.10058

See also similar fits by other groups:
Geng et al., arXiv:2103.12738, Alok et al., arXiv:1903.09617, Datta et al., arXiv:1903.10086, Kowalska et al., arXiv:1903.10932, D'Amico et al., arXiv:1704.05438, Hiller et al., arXiv:1704.05444, . . .

$b \to s\ell^+\ell^-$ transitions:

Global fit results:

B Flavour Anomalies: 2021 Theoretical Status Report

David London (U. Montreal (main)), Joaquim Matias (Barcelona, Autonoma U. and BIST, Barcelona) (Oct 25, 2021)

e-Print: 2110.13270 [hep-ph]

ACDMN	Complete fit: 246 observables			LFUV + radiative + $B_s \to \mu^+\mu^-$		
1D Hyp.	Best fit	Pull_{SM} (σ)	p-value	Best fit	Pull_{SM} (σ)	p-value
$\mathcal{C}_{9\mu}^{\text{NP}}$	$-1.06^{+0.15}_{-0.14}$	7.0	39.5 %	$-0.82^{+0.22}_{-0.24}$	4.0	36.0 %
$\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{10\mu}^{\text{NP}}$	$-0.44^{+0.07}_{-0.08}$	6.2	22.8 %	$-0.37^{+0.08}_{-0.09}$	4.6	68.0 %

AS	Complete fit: 130 observables		LFUV + $B_s \to \mu^+\mu^-$	
1D Hyp.	Best fit	Pull_{SM} (σ)	Best fit	Pull_{SM} (σ)
$\mathcal{C}_{9\mu}^{\text{NP}}$	-0.80 ± 0.14	5.7	$-0.74^{+0.20}_{-0.21}$	4.1
$\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{10\mu}^{\text{NP}}$	-0.41 ± 0.07	5.9	-0.35 ± 0.08	4.6

HMMN	Complete fit: 173 observables		only $R_{K^{(*)}}$ + $B_{d,s} \to \mu^+\mu^-$	
1D Hyp.	Best fit	Pull_{SM} (σ)	Best fit	Pull_{SM} (σ)
$\mathcal{C}_{9\mu}^{\text{NP}}$	-0.95 ± 0.12	7.6	-0.77 ± 0.21	4.0
$\mathcal{C}_{9\mu}^{\text{NP}} = -\mathcal{C}_{10\mu}^{\text{NP}}$	-0.49 ± 0.08	6.7	-0.38 ± 0.09	4.6

Best fit solution:

$C_{9,\mu}^{NP} = -C_{10,\mu}^{NP}$

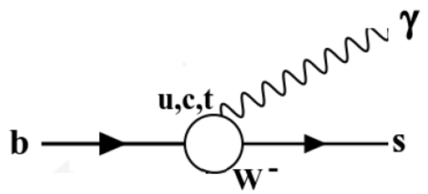
Model buildings!

$b \to s\gamma$ transitions:

☐ Radiative decays:

$B^0 \to K^{*0}e^+e^-$ @ $0.0008 \le q^2 \le 0.257\,\text{GeV}^2$

The $b \to s\gamma$ process is forbidden at tree level in the Standard Model (SM).
Indirect searches grant access to larger energy scales than direct ones.
At LO in SM only O_7 and O_7' contribute



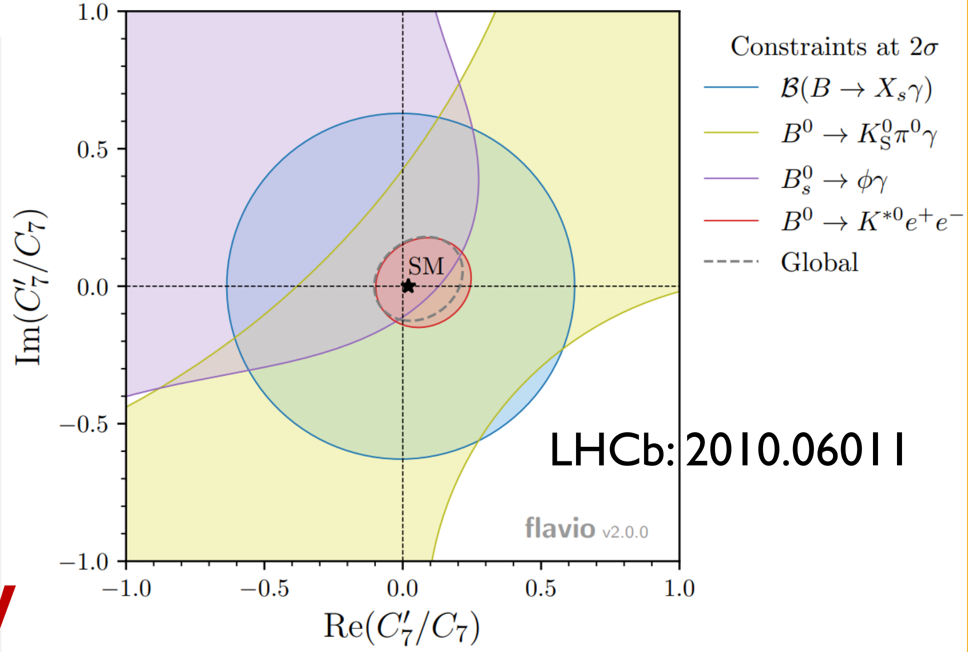
$$\mathcal{H}_{eff} = -4\frac{G_F}{\sqrt{2}}V_{ts}^* V_{tb}(\underbrace{C_7 O_7}_{\text{left}} + \underbrace{C_7' O_7'}_{\text{right}})$$

$C_7^{SM} = -0.2915$

$$F_L = 0.044 \pm 0.026 \pm 0.014,$$
$$A_T^{Re} = -0.06 \pm 0.08 \pm 0.02,$$
$$A_T^{(2)} = +0.11 \pm 0.10 \pm 0.02,$$
$$A_T^{Im} = +0.02 \pm 0.10 \pm 0.01,$$

Wilson coefficient can be constrained through measurement of:

- Branching ratio: $\mathcal{B}_{rad} \propto |C_7|^2 + |C_7'|^2$
- Photon polarization: $\alpha_\gamma{}^{LO} = \frac{1-|\frac{C_7'}{C_7}|^2}{1+|\frac{C_7'}{C_7}|^2}$
- CP asymmetry: $A_{CP} \propto Im\frac{C_7 C_7'}{|C_7|^2+|C_7'|^2}$



LHCb: 2010.06011

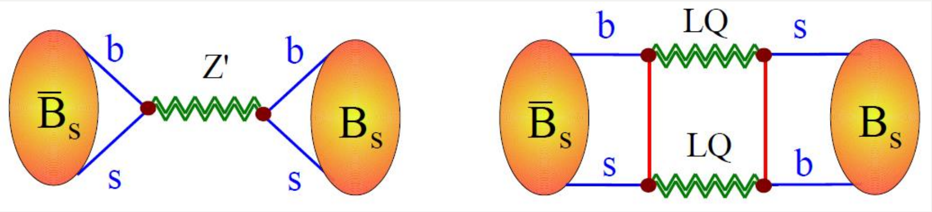
☐ $b \to s\ell^+\ell^-$ @very low q^2: complementary

POINTS SHOULD BE KEPT IN MIND:

- **How to reproduce the needed extra contributions to $\Delta C_{9,\mu} = -\Delta C_{10,\mu}$:**

Z´ boson : heavy neutral gauge boson (Spin 1)

Leptoquarks : Spin 0 or Spin 1 (provide interactions between quarks and leptons)



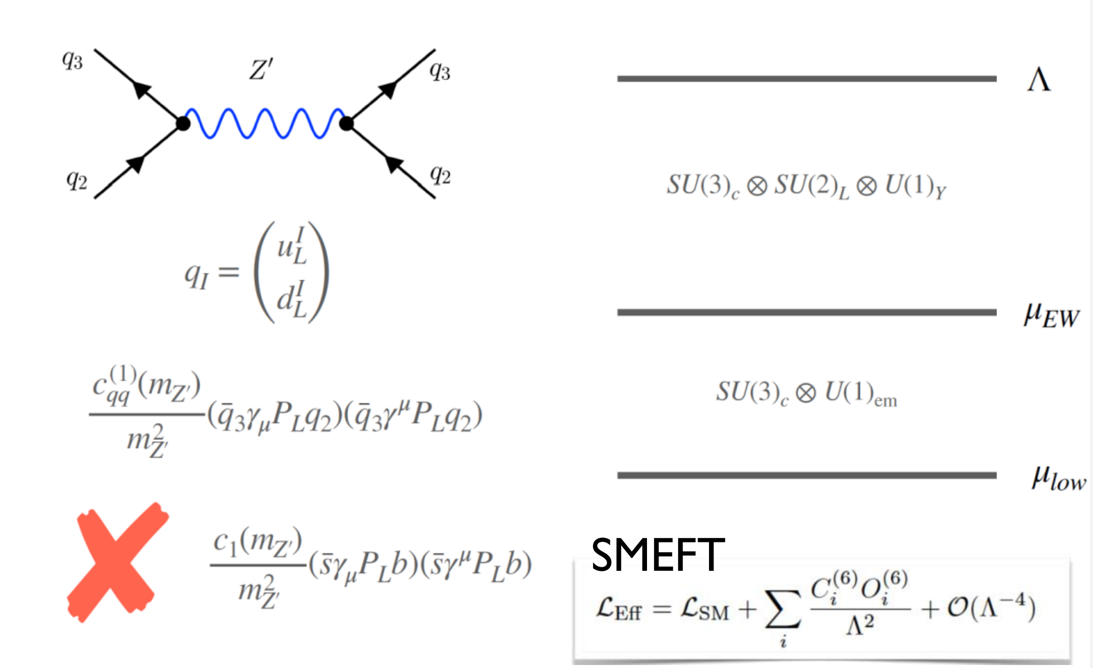
Which LQ explains which anomaly?

	Model	$R_{K^{(*)}}$	$R_{D^{(*)}}$	$R_{K^{(*)}}$ & $R_{D^{(*)}}$
Scalars	$S_1 = (3,1)_{-1/3}$	✗	✓	✗
Scalars	$R_2 = (3,2)_{7/6}$	✗	✓	✗
Scalars	$\widetilde{R}_2 = (3,2)_{1/6}$	✗	✗	✗
Scalars	$S_3 = (3,3)_{-1/3}$	✓	✗	✗
Vectors	$U_1 = (3,1)_{2/3}$	✓	✓	✓
Vectors	$U_3 = (3,3)_{2/3}$	✓	✗	✗

Angelescu, Becirevic, DAF, Sumensari [1808.08179]

$b \to s\tau^+\tau^-$, $b \to s\nu\bar{\nu}$, $b \to s\mu\tau$, charm physic, top physics, ...

Gauge Symmetry at work

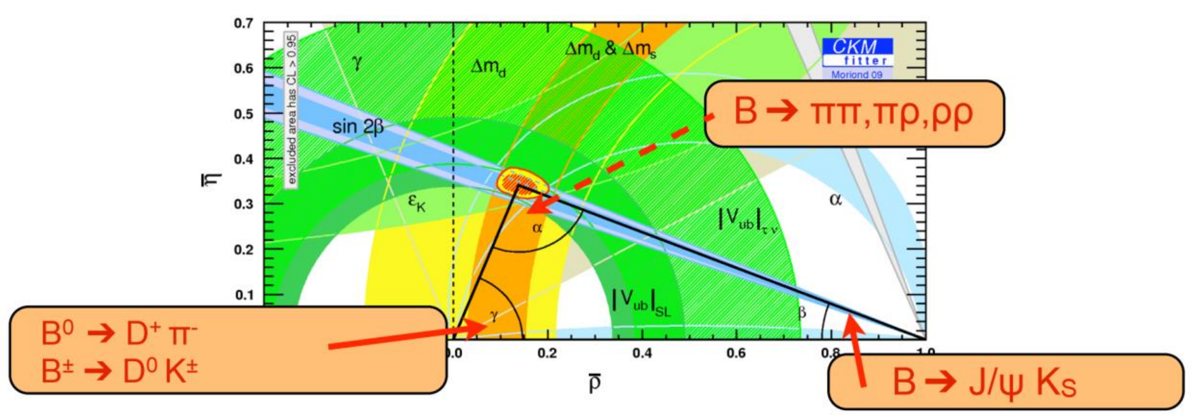


For $\Lambda >> \mu_{\rm EW}$ we should work with Gauge Invariant effective operators.

HADRONIC B DECAYS: TWO-BODY

☐ Hadronic b-hadron decays:

- **direct access to the CKM parameters, especially to the three angles of UT.**

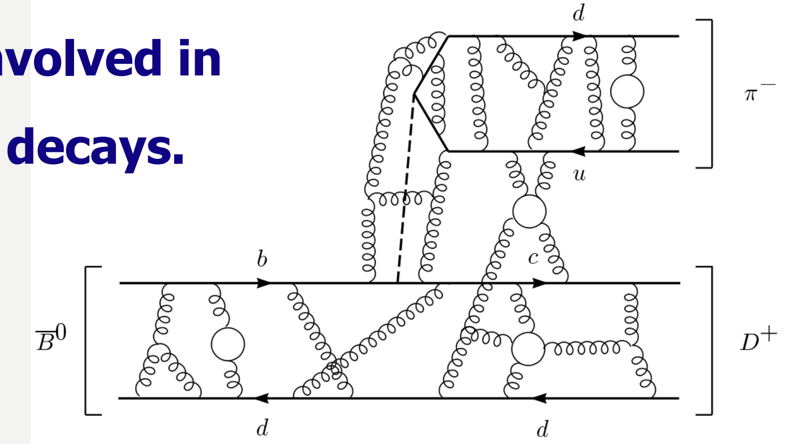


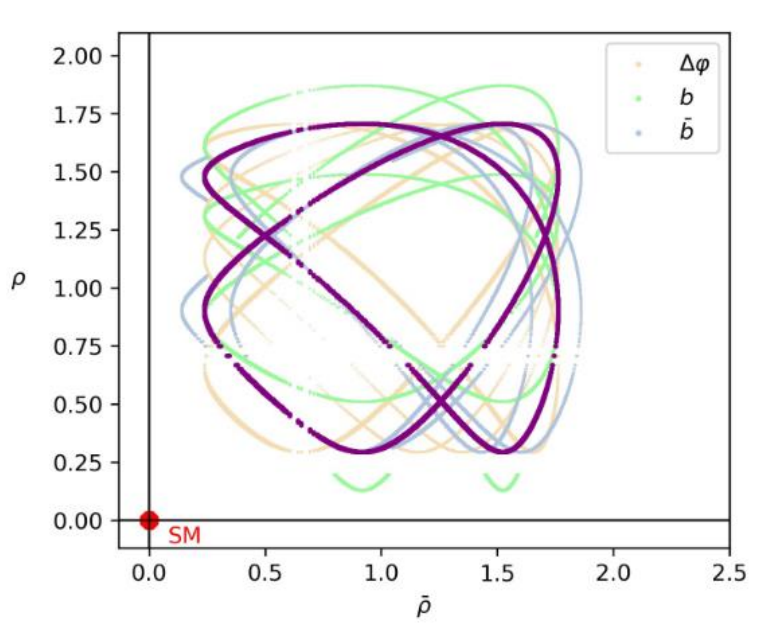
- **indirect probe of new sources of CPV beyond the SM.**

$$A(\bar{B}_s^0 \to D_s^+ K^-) = A(\bar{B}_s^0 \to D_s^+ K^-)_{\rm SM} \left[1 + \bar{\rho}\, e^{i\bar{\delta}} e^{+i\bar{\varphi}}\right]$$

$$A(B_s^0 \to D_s^+ K^-) = A(B_s^0 \to D_s^+ K^-)_{\rm SM} \left[1 + \rho\, e^{i\delta} e^{-i\varphi}\right]$$

- **further insight into strong-interaction effects involved in hadronic decays.**





R. Fleischer and E. Malami, 2110.04240

HADRONIC B DECAYS: TWO-BODY

Hadronic b-hadron decays:

multi-scale problem with highly hierarchical scales!

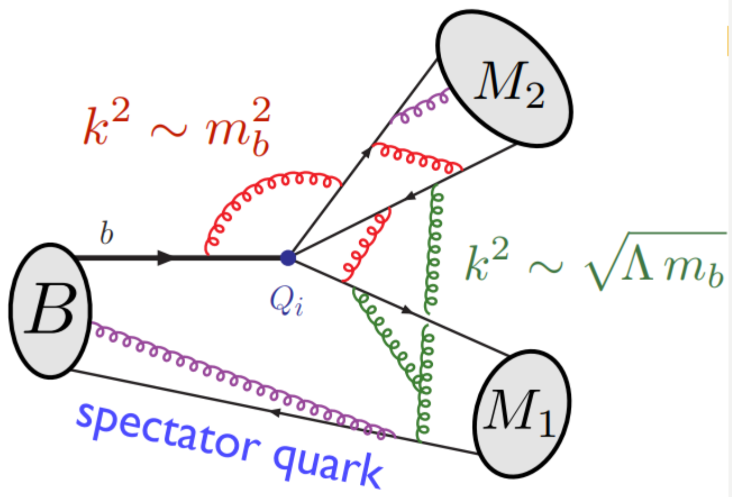
EW interaction scale	$\gg$	ext. mom'a in B rest frame	$\gg$	QCD-bound state effects
$m_W \sim 80$ GeV $m_Z \sim 91$ GeV	$\gg$	$m_b \sim 5$ GeV	$\gg$	$\Lambda_{\rm QCD} \sim 1$ GeV

$$\mathcal{L}_{\rm eff} = -\frac{G_F}{\sqrt{2}} \sum_{p=u,c} V_{pb} V_{pD}^* \left(C_1 \mathcal{O}_1 + C_2 \mathcal{O}_2 + \sum_{i=\rm pen} C_i \mathcal{O}_{i,\rm pen} \right)$$

- **WC C_i**: all physics above m_b; perturbatively calculable, and NNLL program now complete;

[Gorbahn, Haisch '04; Bobeth, Gambino, Gorbahn, Haisch '03; …]

$$\mathcal{A}(\bar{B} \to f) = \sum_i [\lambda_{\rm CKM} \times C \times \langle f|\mathcal{O}|\bar{B}\rangle_{\rm QCD+QED}]_i$$



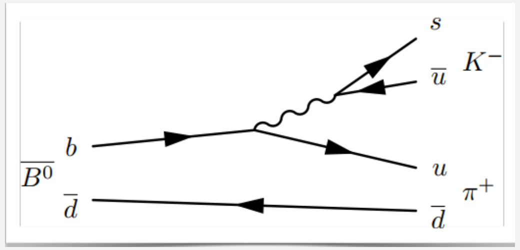
- **General decay amplitude for a given decay:**

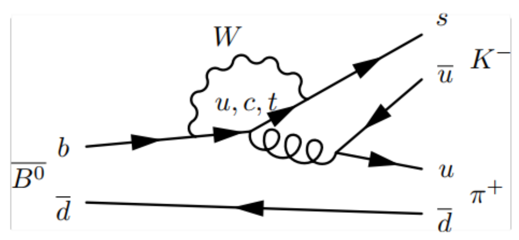
- Dynamical approaches based on factorization theorems: PQCD, QCDF, SCET, $\cdots$
  [Keum, Li, Sanda, Lü, Yang '00; Beneke, Buchalla, Neubert, Sachrajda, '00; Bauer, Flemming, Pirjol, Stewart, '01; Beneke, Chapovsky, Diehl, Feldmann, '02]
- Symmetries of QCD: Isospin, U-Spin, V-Spin, and flavour SU(3) symmetries, $\cdots$
  [Zeppenfeld, '81; London, Gronau, Rosner, He, Chiang, Cheng *et al.*]

HADRONIC B DECAYS: TWO-BODY

- LHCb, 2012.12789

ΔA_{CP} puzzle : $\Delta A_{CP} = A_{CP}(\pi^0 K^-) - A_{CP}(\pi^+ K^-) = (11.5 \pm 1.4)\%$ **differs from 0 by ~8σ!**





$\lambda_u = V_{ub}V_{us}^* \sim \mathcal{O}(\lambda^4)$

$\lambda_c = V_{cb}V_{cs}^* \sim \mathcal{O}(\lambda^2)$

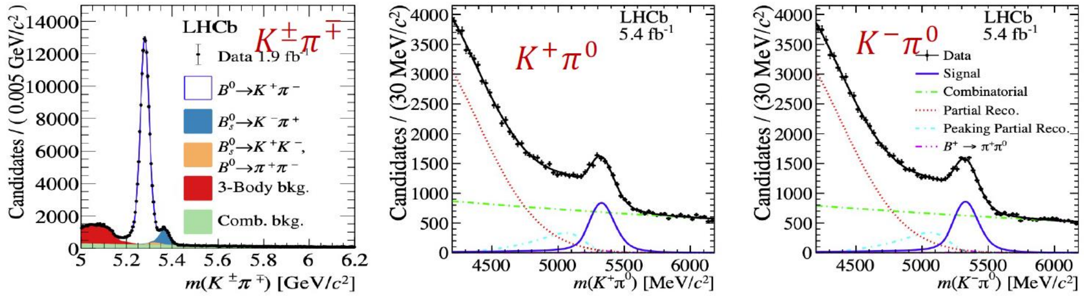
→ Penguin-dominated!

Direct CPV in $B \to K\pi$ system

JHEP 03 (2021) 075
PRL 126 (2021) 091802

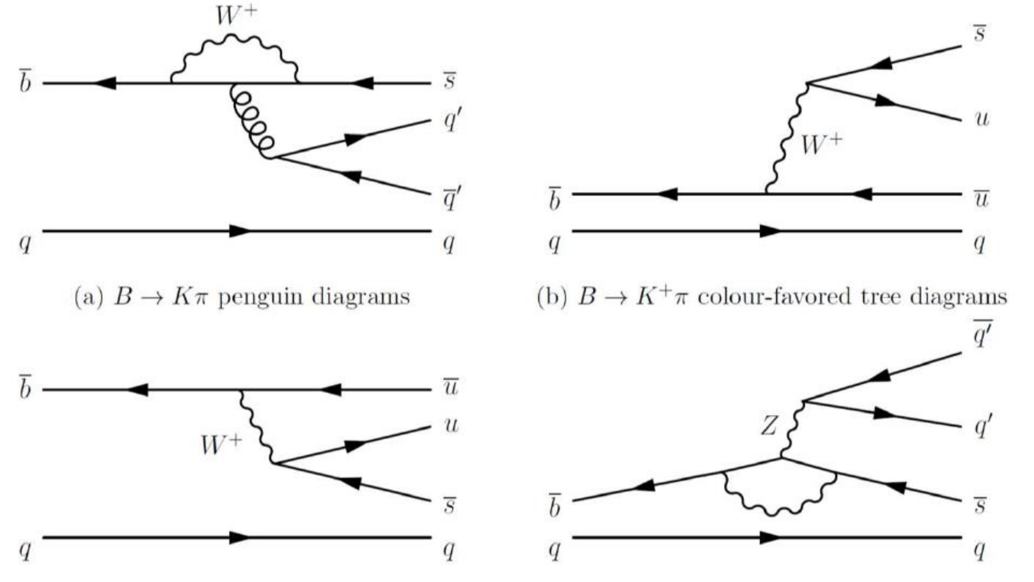
- Isospin symmetry implies $A_{CP}(B^0 \to K^+\pi^-) \approx A_{CP}(B^+ \to K^+\pi^0)$

  Experiment: $\Delta A_{CP}^{K\pi} \neq 0$ at 5.5σ so called "$K\pi$" puzzle
- New measurements



$A_{CP}(B^+ \to K^+\pi^0) = +0.025 \pm 0.015 \pm 0.006 \pm 0.003$
$A_{CP}(B^0 \to K^+\pi^-) = -0.0824 \pm 0.0033 \pm 0.0033$

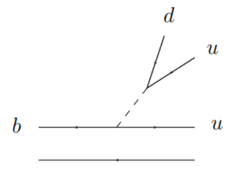
New value of $\Delta A_{CP}^{K\pi} = 0.115 \pm 0.014$, nonzero at > 8$\sigma$



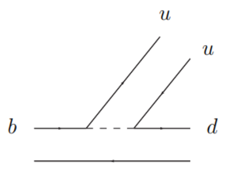
(a) $B \to K\pi$ penguin diagrams
(b) $B \to K^+\pi$ colour-favored tree diagrams
(c) $B \to K\pi^0$ color-suppressed tree diagrams
(d) $B \to K\pi^0$ electroweak penguin diagrams

HADRONIC B DECAYS: TWO-BODY

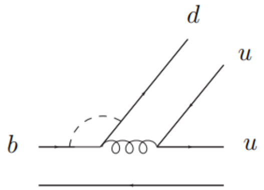
- **Big challenges to theory:**



colour-allowed tree α_1



colour-suppressed tree α_2



QCD penguins α_4

$$\sqrt{2}\,\mathcal{A}_{B^-\to\pi^0K^-} = A_{\pi\bar{K}}[\delta_{pu}\,\alpha_1 + \hat{\alpha}_4^p] + A_{\bar{K}\pi}[\delta_{pu}\alpha_2 + \delta_{pc}\tfrac{3}{2}\alpha^c_{3,\mathrm{EW}}],$$
$$\mathcal{A}_{\bar{B}^0\to\pi^+K^-} = A_{\pi\bar{K}}[\delta_{pu}\,\alpha_1 + \hat{\alpha}_4^p],$$

$$\Delta A_{CP} = A_{CP}(\pi^0K^-) - A_{CP}(\pi^+K^-)$$
$$= -2\sin\gamma[Im(r_C) - Im(r_T r_{EW})] + \cdots$$

$r_C \approx 0.03[\times 2?] - 0.02i, \quad r_T \approx 0.18 - 0.02i \quad r_{\mathrm{EW}} \approx 0.12 - 0.01i,$

f	NLO	NNLO	NNLO + LD	Exp
$\pi^-\bar{K}^0$	$0.71\,^{+0.13}_{-0.14}\,^{+0.21}_{-0.19}$	$0.77\,^{+0.14}_{-0.15}\,^{+0.23}_{-0.22}$	$0.10\,^{+0.02}_{-0.02}\,^{+1.24}_{-0.27}$	-1.7 ± 1.6
π^0K^-	$9.42\,^{+1.77}_{-1.76}\,^{+1.87}_{-1.88}$	$10.18\,^{+1.91}_{-1.90}\,^{+2.03}_{-2.62}$	$-1.17\,^{+0.22}_{-0.22}\,^{+20.00}_{-\ 6.62}$	4.0 ± 2.1
π^+K^-	$7.25\,^{+1.36}_{-1.36}\,^{+2.13}_{-2.58}$	$8.08\,^{+1.52}_{-1.51}\,^{+2.52}_{-2.65}$	$-3.23\,^{+0.61}_{-0.61}\,^{+19.17}_{-\ 3.36}$	-8.2 ± 0.6

Hadronic explanation needs large C and large phase. a problem since 2003.

Beneke, Huber, Li '20

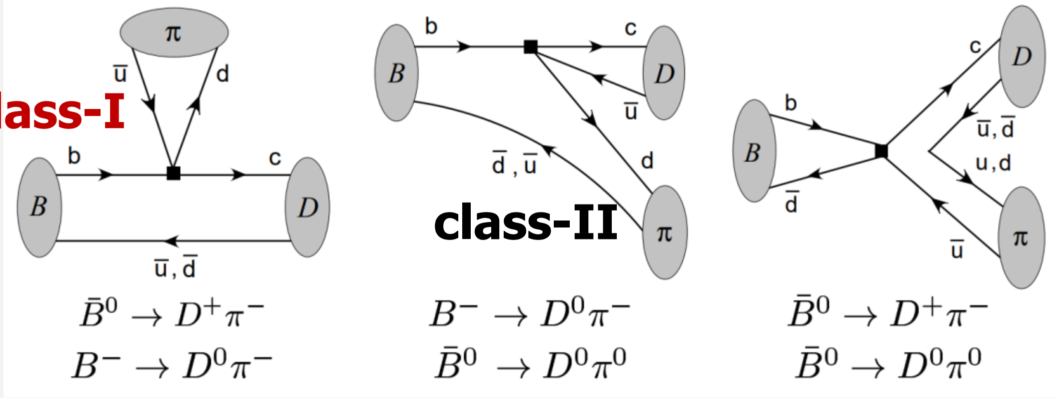
$B \to D^{(*)}L$ DECAYS:

☐ Heavy-light final states:

➢ **At quark-level: mediated by $b \to c\bar{u}d(s)$**

all four quark flavors different from each other,

no penguin operators & no penguin topologies!



➢ **For class-I decays:** QCDF formula much simpler;

[Beneke, Buchalla, Neubert, Sachrajda '99-'03; Bauer, Pirjol, Stewart '01]

$$\mathcal{Q}_2 = \bar{d}\gamma_\mu(1-\gamma_5)u \;\; \bar{c}\gamma^\mu(1-\gamma_5)b$$
$$\mathcal{Q}_1 = \bar{d}\gamma_\mu(1-\gamma_5)T^A u \;\; \bar{c}\gamma^\mu(1-\gamma_5)T^A b$$

$$\langle D_q^{(*)+}L^-|\,\mathcal{Q}_i\,|\bar{B}_q^0\rangle = \sum_j F_j^{\bar{B}_q \to D_q^{(*)}}(M_L^2) \times \int_0^1 du\, T_{ij}(u)\phi_L(u) + \mathcal{O}\left(\frac{\Lambda_{\rm QCD}}{m_b}\right)$$

i) only color-allowed tree topology a_1;

ii) spectator & annihilation power-suppressed;

iii) annihilation absent in $B^0_{d(s)} \to D^-_{d(s)} K(\pi)^+$ etal;

iv) they are theoretically simpler and cleaner!

➢ **Hard kernel T:** both NLO and NNLO results known;

[Beneke, Buchalla, Neubert, Sachrajda '01; Huber, Kränkl, Li '16]

$$T = T^{(0)} + \alpha_s T^{(1)} + \alpha_s^2 T^{(2)} + O(\alpha_s^3)$$

$B \to D^{(*)} L$ DECAYS:

$$\mathcal{A}(\bar{B}^0_{(s)} \to D^+_{(s)} P^-) = i\,\frac{G_F}{\sqrt{2}} V_{cb} V^*_{uq}\, a_1(D^+_{(s)} P^-)\, f_P\, F_0^{B_{(s)}\to D_{(s)}}(m_P^2)\,(m^2_{B_{(s)}} - m^2_{D^+_{(s)}})\,,$$

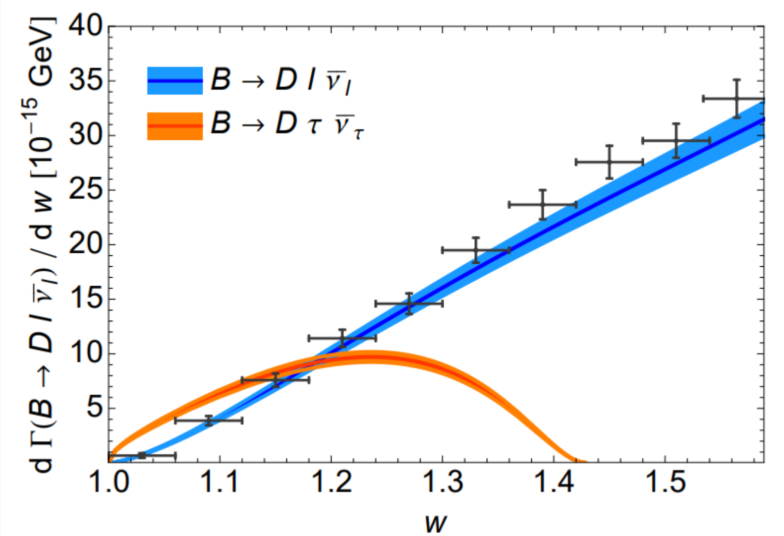
$$\mathcal{A}(\bar{B}^0_{(s)} \to D^{*+}_{(s)} P^-) = -i\,\frac{G_F}{\sqrt{2}} V_{cb} V^*_{uq}\, a_1(D^{*+}_{(s)} P^-)\, f_P\, A_0^{B_{(s)}\to D^*_{(s)}}(m_P^2)\, 2m_{D^{*+}_{(s)}}\,(\epsilon^* \cdot p)\,,$$

$$\mathcal{A}(\bar{B}^0_{(s)} \to D^+_{(s)} V^-) = -i\,\frac{G_F}{\sqrt{2}} V_{cb} V^*_{uq}\, a_1(D^+_{(s)} V^-)\, f_V\, F_+^{B_{(s)}\to D_{(s)}}(m_V^2)\, 2m_V\,(\eta^* \cdot p)\,,$$

- **$B \to D^{(*)}$ transition form factors:**

  Precision results available from LQCD & LCSR calculations,

  together with data on $B_q^0 \to D_q^- l^+ \nu$; [Bernlochner, Ligeti, Papucci, Robinson '17; Bordone, Gubernari, Jung, van Dyk '19]



4-5 σ

Decay mode	LO	NLO	NNLO	NNLO#	Ref. [36]	Ref. [38]	Exp. [7, 8]
$\bar{B}^0 \to D^+\pi^-$	4.20	$4.45^{+0.25}_{-0.40}$	$4.58^{+0.22}_{-0.38}$	$4.74^{+0.61}_{-0.69}$	$3.93^{+0.43}_{-0.42}$		2.65 ± 0.15
$\bar{B}^0 \to D^{*+}\pi^-$	3.77	$4.00^{+0.29}_{-0.40}$	$4.13^{+0.27}_{-0.39}$	$4.26^{+0.75}_{-0.80}$	$3.45^{+0.53}_{-0.50}$		2.58 ± 0.13
$\bar{B}^0 \to D^+\rho^-$	10.98	$11.64^{+0.88}_{-1.18}$	$11.96^{+0.82}_{-1.15}$	$12.28^{+1.40}_{-1.63}$	$10.42^{+1.24}_{-1.20}$		7.6 ± 1.2
$\bar{B}^0 \to D^{*+}\rho^-$	10.32	$10.95^{+1.40}_{-1.55}$	$11.28^{+1.40}_{-1.56}$	$11.61^{+1.88}_{-2.01}$	$9.24^{+0.72}_{-0.71}$		6.0 ± 0.8
$\bar{B}^0 \to D^+K^-$	3.18	$3.37^{+0.17}_{-0.29}$	$3.48^{+0.14}_{-0.28}$		$3.01^{+0.32}_{-0.31}$	3.26 ± 0.15	2.19 ± 0.13
$\bar{B}^0 \to D^{*+}K^-$	2.82	$3.00^{+0.20}_{-0.29}$	$3.10^{+0.19}_{-0.28}$		$2.59^{+0.39}_{-0.37}$	$3.27^{+0.39}_{-0.34}$	2.04 ± 0.47
$\bar{B}^0 \to D^+K^{*-}$	5.48	$5.80^{+0.48}_{-0.62}$	$5.94^{+0.46}_{-0.61}$		$5.25^{+0.65}_{-0.63}$		4.6 ± 0.8
$\bar{B}^0_s \to D_s^+\pi^-$	4.23	$4.49^{+0.27}_{-0.41}$	$4.61^{+0.23}_{-0.39}$		$4.39^{+1.36}_{-1.19}$	4.42 ± 0.21	3.23 ± 0.18
$\bar{B}^0_s \to D_s^{*+}\pi^-$	3.51	$3.73^{+0.88}_{-0.84}$	$3.84^{+0.90}_{-0.85}$		$2.24^{+0.56}_{-0.50}$	$4.30^{+0.90}_{-0.80}$	$2.4^{+0.7}_{-0.6}$

- **Updated predictions vs data:**

  [Huber, Kränkl, Li '16; Cai, Deng, Li, Yang '21]

  $|V_{cb}|$ and $B_{d,s} \to D^{(*)}_{d,s}$ form factors

$B \to D^{(*)} L$ DECAYS:

◻ Non-leptonic/semi-leptonic ratios : [Bjorken '89; Neubert, Stech '97; Beneke, Buchalla, Neubert, Sachrajda '01]

$$R_{(s)L}^{(*)} \equiv \frac{\Gamma(\bar{B}_{(s)}^0 \to D_{(s)}^{(*)+} L^-)}{d\Gamma(\bar{B}_{(s)}^0 \to D_{(s)}^{(*)+} \ell^- \bar{\nu}_\ell)/dq^2|_{q^2=m_L^2}} = 6\pi^2 |V_{uq}|^2 f_L^2 |a_1(D_{(s)}^{(*)+} L^-)|^2 X_L^{(*)}$$

(almost) free from uncertainties from $|V_{cb}|$ & $B_{d,s} \to D_{d,s}^{(*)}$ form factors.

➢ **Updated predictions vs data:** [Cai, Deng, Li, Yang '21]

$\|a_1(D_{(s)}^{(*)+} L^-)\|$	LO	NLO	NNLO	Ref. [36]	Ref. [38]	Exp.
$\|a_1(D^+\pi^-)\|$	1.028	$1.059^{+0.017}_{-0.019}$	$1.073^{+0.005}_{-0.010}$	$1.073^{+0.012}_{-0.014}$	$1.0727^{+0.0125}_{-0.0140}$	0.88 ± 0.04
$\|a_1(D^{*+}\pi^-)\|$	1.028	$1.059^{+0.017}_{-0.019}$	$1.075^{+0.006}_{-0.011}$	$1.071^{+0.013}_{-0.014}$	$1.0713^{+0.0128}_{-0.0137}$	0.92 ± 0.04
$\|a_1(D^+\rho^-)\|$	1.028	$1.059^{+0.017}_{-0.019}$	$1.073^{+0.005}_{-0.010}$	$1.072^{+0.012}_{-0.014}$		0.92 ± 0.08
$\|a_1(D^{*+}\rho^-)\|$	1.028	$1.059^{+0.017}_{-0.019}$	$1.075^{+0.006}_{-0.011}$	$1.071^{+0.013}_{-0.014}$		0.80 ± 0.06
$\|a_1(D^+K^-)\|$	1.028	$1.059^{+0.018}_{-0.019}$	$1.075^{+0.007}_{-0.011}$	$1.070^{+0.010}_{-0.013}$	$1.0702^{+0.0101}_{-0.0128}$	0.92 ± 0.04
$\|a_1(D^{*+}K^-)\|$	1.028	$1.059^{+0.018}_{-0.019}$	$1.078^{+0.009}_{-0.012}$	$1.069^{+0.010}_{-0.013}$	$1.0687^{+0.0103}_{-0.0125}$	0.94 ± 0.11
$\|a_1(D^+K^{*-})\|$	1.028	$1.058^{+0.017}_{-0.019}$	$1.071^{+0.004}_{-0.009}$	$1.070^{+0.010}_{-0.013}$		1.02 ± 0.10
$\|a_1(D_s^+\pi^-)\|$	1.028	$1.059^{+0.017}_{-0.019}$	$1.073^{+0.005}_{-0.010}$	$1.073^{+0.012}_{-0.014}$	$1.0727^{+0.0125}_{-0.0140}$	0.90 ± 0.04
$\|a_1(D_s^{*+}\pi^-)\|$	1.028	$1.059^{+0.017}_{-0.019}$	$1.075^{+0.006}_{-0.011}$	$1.071^{+0.013}_{-0.014}$	$1.0713^{+0.0128}_{-0.0137}$	0.83 ± 0.13
$\|a_1(D_s^+K^-)\|$	1.028	$1.059^{+0.018}_{-0.019}$	$1.075^{+0.007}_{-0.011}$	$1.070^{+0.010}_{-0.013}$	$1.0702^{+0.0101}_{-0.0128}$	0.89 ± 0.05
$\|a_1(D_s^{*+}K^-)\|$	1.028	$1.059^{+0.018}_{-0.019}$	$1.078^{+0.009}_{-0.012}$	$1.069^{+0.010}_{-0.013}$	$1.0687^{+0.0103}_{-0.0125}$	0.79 ± 0.14

➢ **quasi-universal, with small process-dep. from non-fact. corrections.**

$$a_1(D^+K^-) = (1.069^{+0.009}_{-0.012}) + (0.046^{+0.023}_{-0.015})i\,,$$
$$a_1(D^+\pi^-) = (1.072^{+0.011}_{-0.013}) + (0.043^{+0.022}_{-0.014})i\,,$$
$$a_1(D^{*+}K^-) = (1.068^{+0.010}_{-0.012}) + (0.034^{+0.017}_{-0.011})i\,,$$
$$a_1(D^{*+}\pi^-) = (1.071^{+0.012}_{-0.013}) + (0.032^{+0.016}_{-0.010})i\,.$$

➢ **For a rough estimate:**

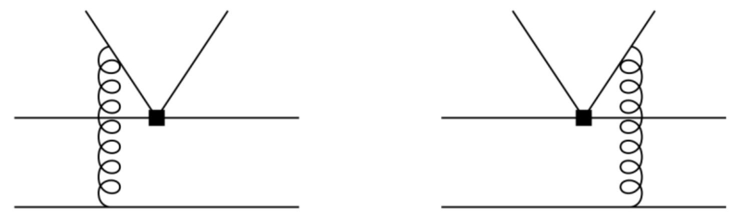
$$\frac{Br^{Exp.}}{Br^{SM}} = \frac{|a_1^{BSM}|^2}{|a_1^{SM}|^2} = 0.6 \Longrightarrow \frac{a_1^{BSM}}{a_1^{SM}} \simeq 0.77 = 1 - 0.23$$

$$= \frac{a_1^{SM} + \delta a_1^{BSM}}{a_1^{SM}} \simeq 1 + \frac{\delta a_1^{BSM}}{a_1^{SM}} \Longrightarrow \delta a_1^{BSM} \simeq -20\%$$

$B \to D^{(*)} L$ DECAYS

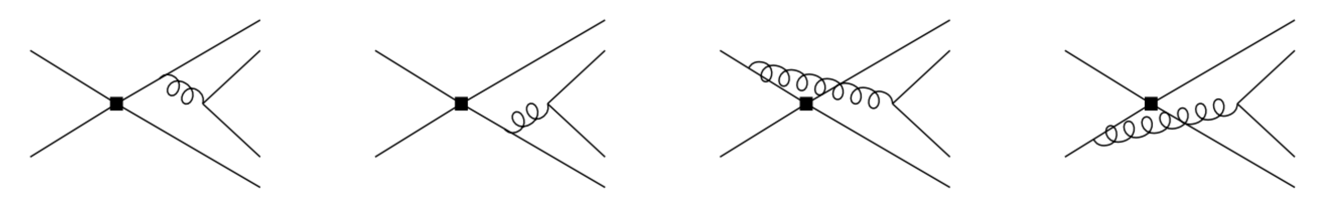
$$\langle D_q^{(*)+} L^- | \mathcal{Q}_i | \bar{B}_q^0 \rangle = \sum_j F_j^{\bar{B}_q \to D_q^{(*)}}(M_L^2) \times \int_0^1 du\, T_{ij}(u) \phi_L(u) + \mathcal{O}\left(\frac{\Lambda_{\rm QCD}}{m_b}\right)$$

- **Sources of sub-leading power corrections:** [Beneke, Buchalla, Neubert, Sachrajda '01; Bordone, Gubernari, Huber, Jung, van Dyk '20]
  - Non-factorizable spectator interactions;

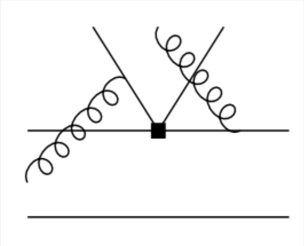


$\mathcal{O}\left(\frac{\Lambda_{\rm QCD}}{m_b}\right)$

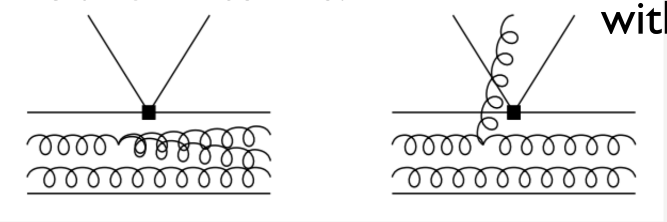
  - Annihilation topologies;



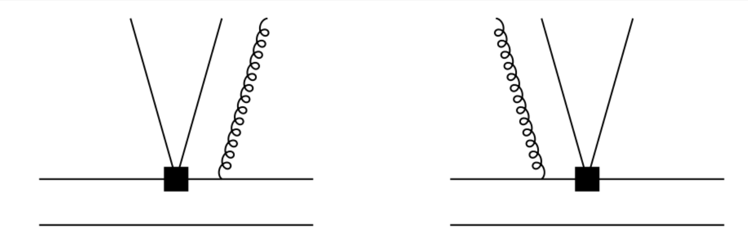
  - Non-leading Fock-state contributions;



included into FFs.



estimated with LCSR



$\mathcal{O}\left(\frac{\Lambda_{\rm QCD}}{m_b}\right)^2$

- **Scaling of the leading-power contribution:** [BBNS '01]

$$\mathcal{A}(\bar{B}_d \to D^+\pi^-) \sim G_F m_b^2\, F^{B\to D}(0)\, f_\pi \sim G_F m_b^2\, \Lambda_{\rm QCD}$$

- All ESTIMATED to be power-suppressed; not chirality-enhanced due to (V-A)(V-A) structure!
- The current exp. data can not be easily explained in the SM, at least within the QCDF/SCET framework.

$B \to D^{(*)}L$ DECAYS:

A puzzle in $\bar{B}^0_{(s)} \to D^+_{(s)}\{\pi^-, K^-\}$ decays and extraction of the f_s/f_d fragmentation fraction

Marzia Bordone (Siegen U.), Nico Gubernari (Munich, Tech. U.), Tobias Huber (Siegen U.), Martin Jung (Turin U. and INFN, Turin), Danny van Dyk (Munich, Tech. U.)

Eur.Phys.J.C 80 (2020) 10, 951 • e-Print: 2007.10338 • DOI: 10.1140/epjc/s10052-020-08512-8

Probing new physics in class-I B-meson decays into heavy-light final states

Fang-Min Cai (Hua-Zhong Normal U., LQLP), Wei-Jun Deng (Hua-Zhong Normal U., LQLP), Xin-Qiang Li (Hua-Zhong Normal U., LQLP), Ya-Dong Yang (Hua-Zhong Normal U., LQLP)

JHEP 10 (2021) 235 • e-Print: 2103.04138 • DOI: 10.1007/JHEP10(2021)235

Revisiting rescattering contributions to $\overline{B}_{(s)} \to D^{(*)}_{(s)}M$ decays

Motoi Endo (KEK, Tsukuba and Sokendai, Tsukuba and Tokyo U., IPMU), Syuhei Iguro (Tokyo U., IPMU), Satoshi Mishima (KEK, Tsukuba)

e-Print: 2109.10811

Using $B^0_s \to D^\mp_s K^\pm$ Decays as a Portal to New Physics

Robert Fleischer (NIKHEF, Amsterdam and Vrije U., Amsterdam), Eleftheria Malami (NIKHEF, Amsterdam)

e-Print: 2109.04950

Revealing New Physics in $B^0_s \to D^\mp_s K^\pm$ Decays

Robert Fleischer (Nikhef, Amsterdam and Vrije U., Amsterdam), Eleftheria Malami (Nikhef, Amsterdam)

e-Print: 2110.04240

Implications for new physics from a novel puzzle in $\bar{B}^0_{(s)} \to D^{(*)+}_{(s)}\{\pi^-, K^-\}$ decays

Syuhei Iguro (Nagoya U.), Teppei Kitahara (Nagoya U., IAR and KMI, Nagoya)

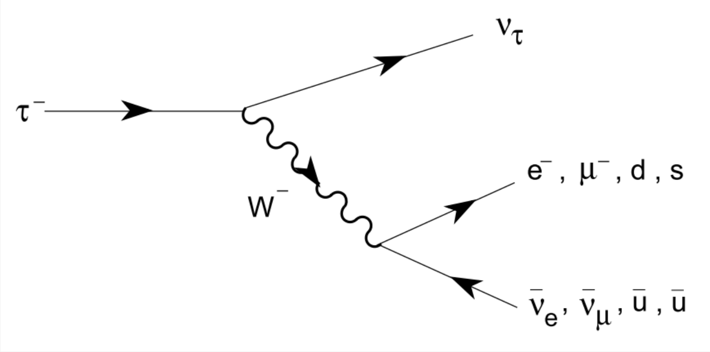
Phys.Rev.D 102 (2020) 7, 071701 • e-Print: 2008.01086 • DOI: 10.1103/PhysRevD.102.071701

New physics effects in tree-level decays?

several papers

TAU-LEPTON PHYSICS:

- 陶轻子 (m_τ= 1776.86MeV)够重，可纯轻也可半轻衰变，是研究低能QCD、强子共振态性质和寻找新物理的理想场所。

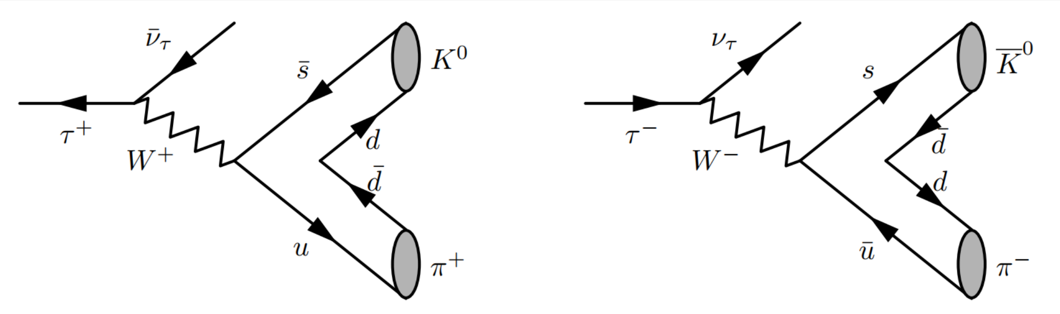


$$\sigma(e^+e^- \to b\bar{b}) = 1.1\ \text{nb}$$
$$\sigma(e^+e^- \to \tau^+\tau^-) = 0.9\ \text{nb}$$
$$@\sqrt{s} = 10.58\text{GeV}$$

- B介子工厂同样也是一个陶轻子工厂：

- 陶轻子物理也是Belle II、STCF和Tera-Z上的重要研究内容

- $\tau \to K_S \pi \nu_\tau$半轻衰变，是CP破坏和新物理的敏感探针



TAU-LEPTON PHYSICS:

PRD 85 (2012) 031102

◻ SM下，CP破坏来源于$K^0-\bar{K}^0$混合，但与BABAR结果不符:

$$A_{CP} \equiv \frac{\Gamma(\tau^+ \to [\pi^+\pi^-]_{``K_S"}\pi^+\bar{\nu}_\tau) - \Gamma(\tau^- \to [\pi^+\pi^-]_{``K_S"}\pi^-\nu_\tau)}{\Gamma(\tau^+ \to [\pi^+\pi^-]_{``K_S"}\pi^+\bar{\nu}_\tau) + \Gamma(\tau^- \to [\pi^+\pi^-]_{``K_S"}\pi^-\nu_\tau)}$$

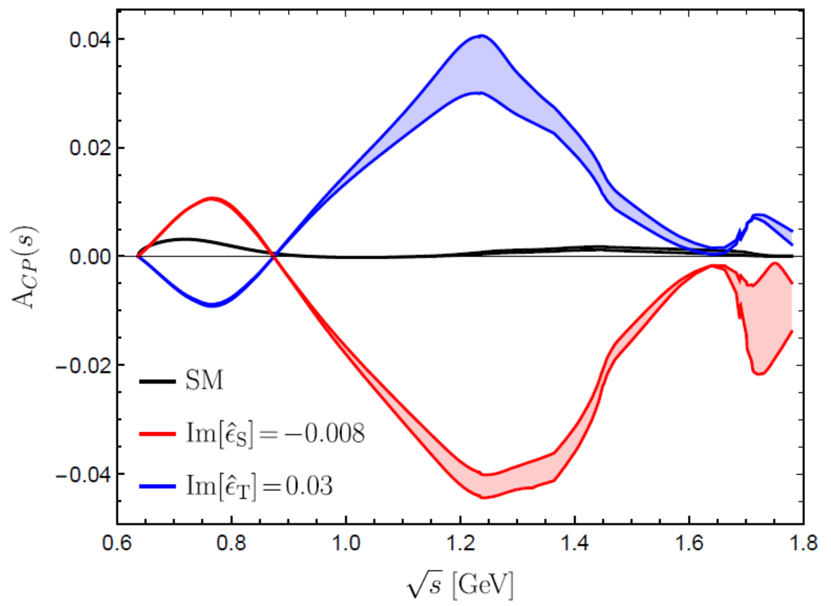
⇨ 2.8 σ 偏差

$$\begin{cases} A_{CP}^{\rm Exp} = (-3.6 \pm 2.3 \pm 1.1) \times 10^{-3} \\ A_{CP}^{\rm SM} = (3.6 \pm 0.1) \times 10^{-3} \end{cases}$$

➢ 只能来自张量新物理算符:

$$\mathcal{L}_{\rm eff} = -\frac{G_F V_{us}}{\sqrt{2}}(1+\epsilon_L+\epsilon_R)\Big\{\bar{\tau}\gamma_\mu(1-\gamma_5)\nu_\tau \cdot \bar{u}[\gamma^\mu - (1-2\hat{\epsilon}_R)\gamma^\mu\gamma_5]s + \bar{\tau}(1-\gamma_5)\nu_\tau \cdot \bar{u}[\hat{\epsilon}_S - \hat{\epsilon}_P\gamma_5]s + 2\hat{\epsilon}_T\bar{\tau}\sigma_{\mu\nu}(1-\gamma_5)\nu_\tau \cdot \bar{u}\sigma^{\mu\nu}s\Big\} + {\rm h.c.}$$

Feng-Zhi Chen, Xin-Qiang Li, Ya-Dong Yang and Xin Zhang, Phys.Rev.D 100 (2019) 11, 113006



➢ 由于$K^0-\bar{K}^0$混合，角分布中存在非零的CPV

Feng-Zhi Chen, Xin-Qiang Li, Ya-Dong Yang, JHEP 05 (2020) 151

$$A_i^{CP} = \frac{\int_{s_{1,i}}^{s_{2,i}}\int_{-1}^{1}\cos\alpha\left[\frac{d^2\Gamma(\tau^-\to K_S\pi^-\nu_\tau)}{ds\,d\cos\alpha} - \frac{d^2\Gamma(\tau^+\to K_S\pi^+\bar{\nu}_\tau)}{ds\,d\cos\alpha}\right]ds\,d\cos\alpha}{\frac{1}{2}\int_{s_{1,i}}^{s_{2,i}}\int_{-1}^{1}\left[\frac{d^2\Gamma(\tau^-\to K_S\pi^-\nu_\tau)}{ds\,d\cos\alpha} + \frac{d^2\Gamma(\tau^+\to K_S\pi^+\bar{\nu}_\tau)}{ds\,d\cos\alpha}\right]ds\,d\cos\alpha}$$

Belle Collaboration, PRL 107 (2011) 131801

OTHER INTERESTING TOPICS:

☐ QED effects in B decays:

Power-enhanced leading-logarithmic QED corrections to $B_q \to \mu^+\mu^-$
Martin Beneke (Munich, Tech. U.), Christoph Bobeth (Munich, Tech. U.), Robert Szafron (Munich,
Published in: *JHEP* 10 (2019) 232 • e-Print: 1908.07011 [hep-ph]

$B_{d,s} \to \gamma\ell\bar{\ell}$ decay with an energetic photon
Martin Beneke (Munich, Tech. U.), Christoph Bobeth (Munich, Tech. U.), Yu-Ming Wang (Nankai U.) (
Published in: *JHEP* 12 (2020) 148 • e-Print: 2008.12494 [hep-ph]
pdf DOI cite

QED factorization of non-leptonic B decays
Martin Beneke (Munich, Tech. U.), Philipp Böer (Munich, Tech. U.), Jan-Niklas Toelstede (Munich, Tec
U.) (Aug 24, 2020)
Published in: *JHEP* 11 (2020) 081 • e-Print: 2008.10615 [hep-ph]

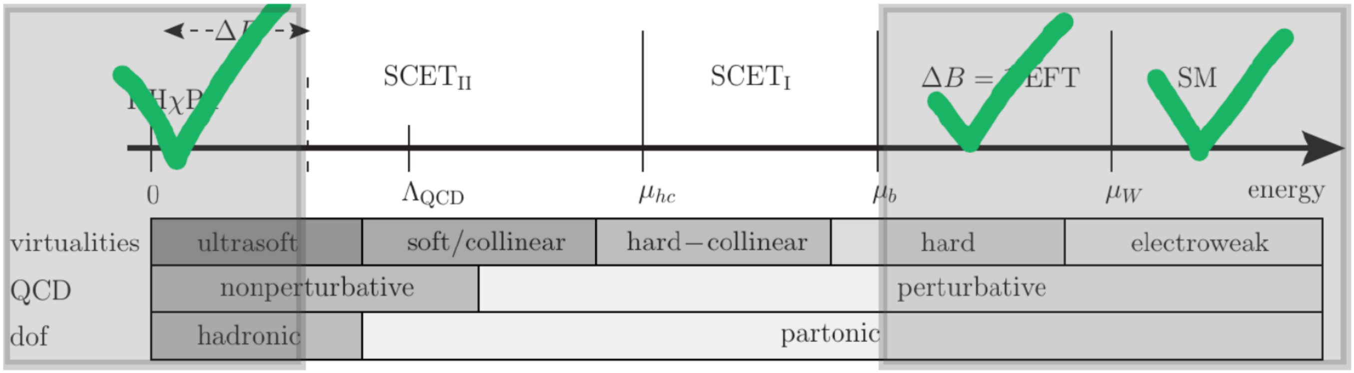
QED factorization of two-body non-leptonic and semi-leptonic B to charm decays
Martin Beneke (Munich, Tech. U.), Philipp Böer (Munich, Tech. U.), Gael Finauri (Munich, Tech. U.), K. Keri Vos (
Published in: *JHEP* 10 (2021) 223 • e-Print: 2107.03819 [hep-ph]
pdf DOI cite

Light-cone distribution amplitudes of light mesons with QED effects
Martin Beneke (Munich, Tech. U.), Philipp Böer (Munich, Tech. U.), Jan-Niklas Toelstede (Munich, Tech. U.), K. Keri Vos (
12, 2021)
Published in: *JHEP* 11 (2021) 059 • e-Print: 2108.05589 [hep-ph]
pdf DOI cite

Multiple scales: $m_W,\ m_b,\ \sqrt{m_b\Lambda_{\rm QCD}},\ \Lambda_{\rm QCD},\ m_\mu,\ \Delta E$

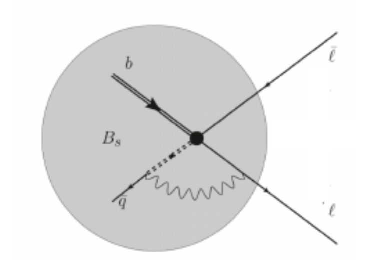
Short-distance QED at $\mu \gtrsim m_b$ can be included in the usual weak effective Lagrangian (extended Fermi theory) + renormalization group.

Far IR (ultrasoft scale) described by theory of point-like hadrons.



Goal: Theory for QED corrections between the scales m_b and $\Lambda_{\rm QCD}$ (structure-dependent effects).

QED factorization for the leptonic B meson decays 周四红



☐ Higher-order power-corrections:

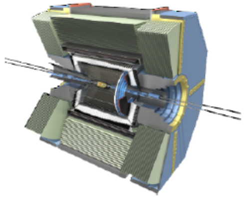
QCD calculations of radiative heavy meson decays with subleading power corrections
Hua-Dong Li (Beijing, Inst. High Energy Phys.), Cai-Dian Lü (Beijing, Inst. High Energy Phys. and Beijing, GUCAS), Chao Wang (N
U.), Yan-Bing Wei (Nankai U.) (Feb 10, 2020)
Published in: *JHEP* 04 (2020) 023 • e-Print: 2002.03825 [hep-ph]

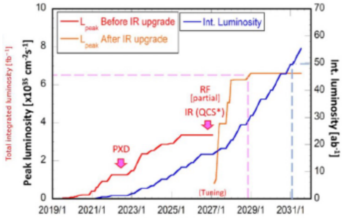
VERY PROMISING FUTURE:

2018	2021	2025	2027	2030	2035

Belle II: $220 fb^{-1}$ (2021) → $50\ ab^{-1}$ (2030)

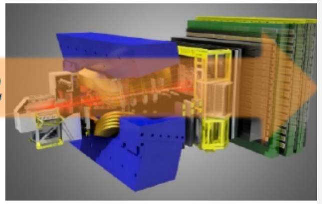
$\approx 55\times10^{9}\ B\bar{B}$ pairs





LHCb ($9\ fb^{-1}$) → **LHCb Upgrade 1** → **Phase I** (May/2022-Dec/2024, $\sim 23\ fb^{-1}$) → **Phase 1b Upgrade** → **Phase 1b** ($\sim 50\ fb^{-1}$) → **Phase 2 Upgrade** (proposed) → **Phase 2** ($300\ fb^{-1}$)

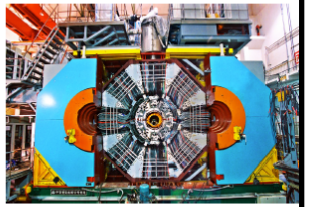
$\approx 3\times10^{12}\ b\bar{b}$ pairs



BES III

Continue to run for 5-10 years

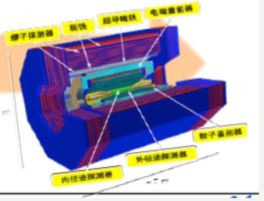
Increase E_{cm} => 5.6 GeV



Prepare → **Construction?** → **STCF?**

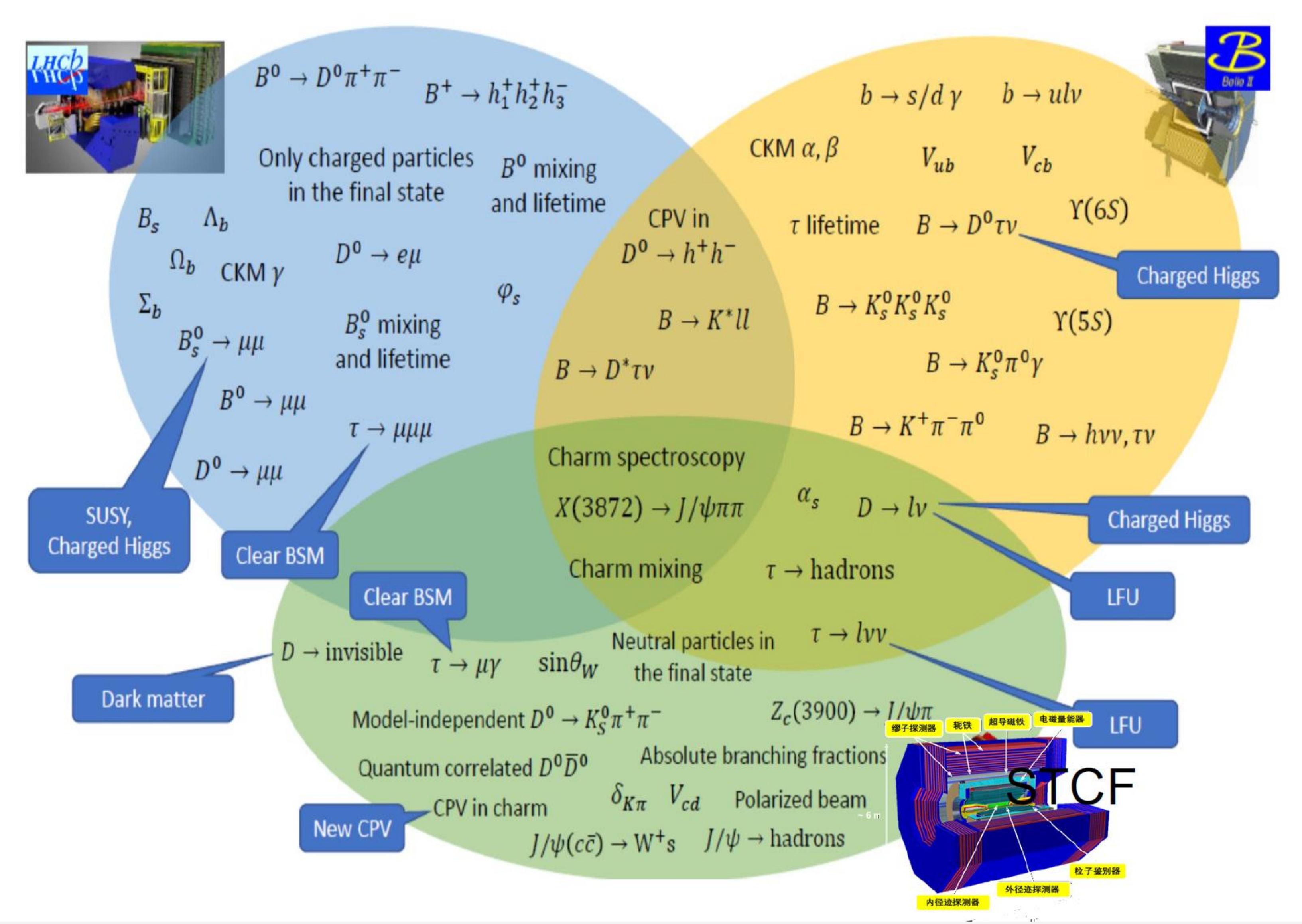
E_{cm} = 2-7 GeV

L_{peak}= 0.5~1.0 $x10^{35}/cm^2s$



Flavour physics dedicated exps.

VERY PROMISING FUTURE:



Complementary exp. data

⇓

Lattice QCD + theory progress

⇓

Answers to many key issues!

Exciting Times are just ahead of us !!!

感谢暨南大学和会务组的精心准备和辛勤付出

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让我们明年相聚
南京师大!