A strategy to determine the C'_{78910} Wilson coefficients using Parity Doubling

CP³ Origins
Cosmology & Particle Physics

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Implications of LHCb measurements 16th of Oct 2018

work presented based on

Gratrex RZ' 1804.09006 JHEP 1808 (2018) 178
1807.01643 Moriond proceedings

more refs on the topic in the backup pages

Outline

- SM: **V-A-chirality** [SU(2)$_L$] ⇒ traces in **polarisations** [angular dist.]
  Relativistic limit: **chirality** ⇔ **helicity** e,g, $\mathbf{B_s \to \phi}\gamma$ ($b \to s$) @LHCb

1) **Right-handed Currents** (RHC) and $\mathbf{H_{eff}}$	[1 slide]
2) The **Trouble** with RHC - Hadronic m-elements	[1 slide]
3) **Parity Doubling,** as proposed Solution	[3 slides]
4) Beyond the Doubling limit (real world)	[2 slides]
5) Outlook on **B→VII**	[1 slide]
6) Summary and Conclusions	[2 slides]

1. RHC and H$_{eff}$

$$H_{eff}^{b\to s\gamma} = C\bar{s}_L \Gamma b O_r + \boxed{C'\bar{s}_R} \Gamma b O_r$$

Right-handed current (RHC)

$$\left.\frac{C'}{C}\right|_{SM} = \frac{m_s}{m_b}, tiny \qquad \Rightarrow \qquad \delta C' = \text{BSM-RHC visible?}$$

- Hadronic matrix-element can perturb this structure ….

2. The trouble with RHC - hadronic m-elements

Form Factor (SD)*

Long distance (LD)
(4-quark operators)

$$A_L^{B_s\to\phi\gamma_L} = \mathcal{N}(1 + \epsilon_L(C, C'))$$

$$A_R^{B_s\to\phi\gamma_R} = \mathcal{N}(\frac{m_s}{m_b} + \delta\hat{C}' + \epsilon_R(C, C'))$$

Problem: distinguishing RHCs from LD-terms induced by large C$_{\text{Wilson}}$

(assuming we can measure A$_{\text{R}}$)

⇒ non-perturbative **QCD** (LD) can **blur RHC** and **LHC** in amplitudes

....

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* $\gamma_5\sigma_{\mu\nu} = \frac{i}{2}\epsilon_{\mu\nu\mu'\mu'}\sigma^{\mu'\nu'}$ $\Rightarrow T_1(0) = T_2(0)$ [exact relation]

Parity-doubling as proposed solution

- **Chiral** symmetry **restoration** limit:

  $$m_q, \langle \bar{q} q \rangle, \ldots \to 0$$

restored flavour-symmetry

$$SU(N_f)_V \times \mathbf{SU(N_f)_A} \times \text{"}\mathbf{U(1)_A}\text{"}$$

Global symmetries ⇒ mass-degeneracy e.g. *isospin* ⊂ $\mathrm{SU(N_f{=}3)_V}$

supersymmetry, …

$SU(N_f = 3)_A$: mass degneracy in 1^{--} and 1^{++} states

We **propose degeneracies** in full **amplitudes :**

$$A^{B_s \to \phi\gamma}(C, C') = A^{B_s \to f_1(1420)\gamma}(-C, C')$$

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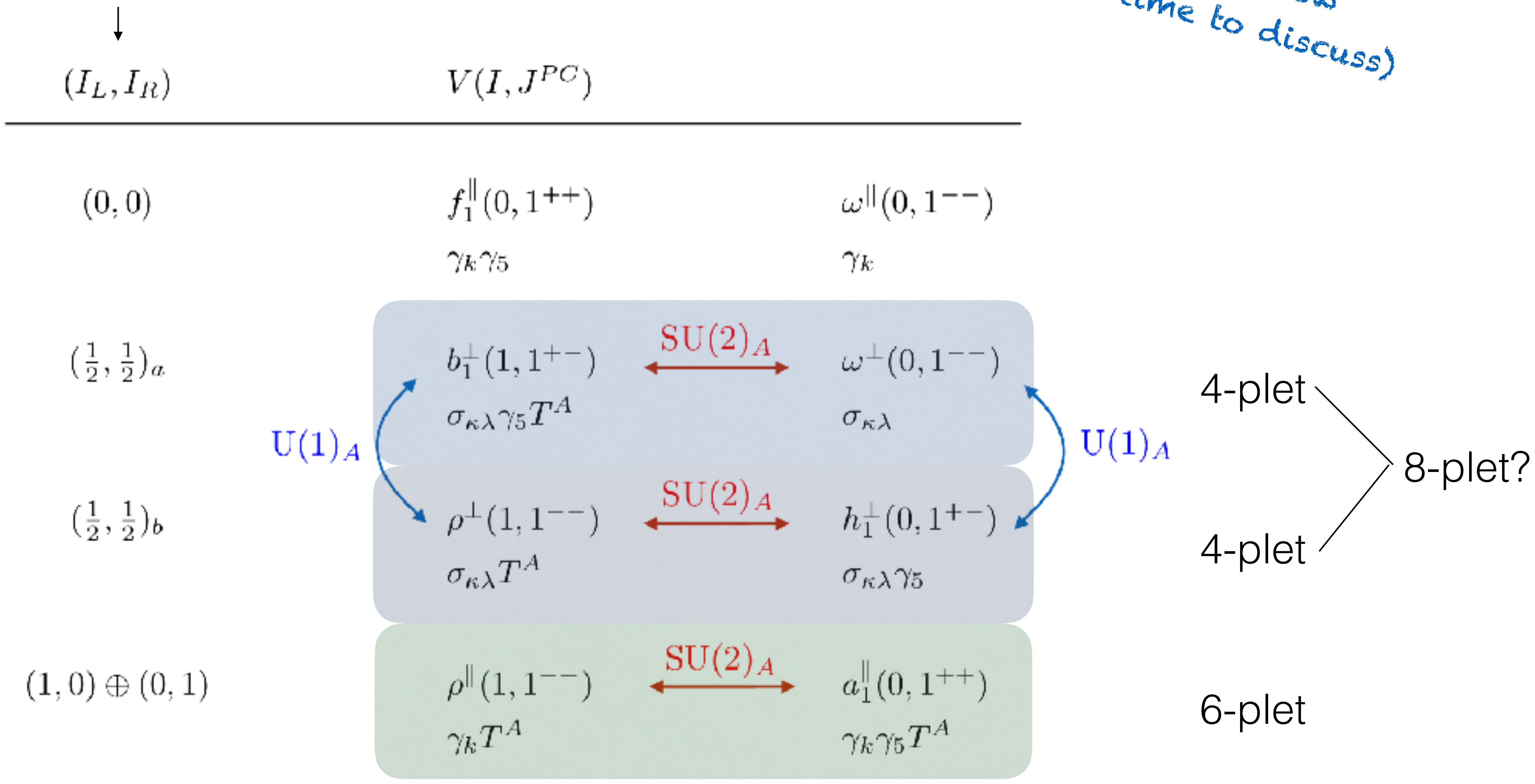
* Afonin'07 (history) - tested on the lattice hight T Glozman, Lang, Cossu, KEK-collab. '14

How the symmetries work for N_f=2

briefly show
(no time to discuss)



(I_L, I_R)	$V(I, J^{PC})$	
$(0,0)$	$f_1^{\parallel}(0,1^{++})$ $\gamma_k\gamma_5$	$\omega^{\parallel}(0,1^{--})$ γ_k
$(\frac{1}{2},\frac{1}{2})_a$	$b_1^{\perp}(1,1^{+-})$ $\sigma_{\kappa\lambda}\gamma_5 T^A$	$\omega^{\perp}(0,1^{--})$ $\sigma_{\kappa\lambda}$
$(\frac{1}{2},\frac{1}{2})_b$	$\rho^{\perp}(1,1^{--})$ $\sigma_{\kappa\lambda}T^A$	$h_1^{\perp}(0,1^{+-})$ $\sigma_{\kappa\lambda}\gamma_5$
$(1,0)\oplus(0,1)$	$\rho^{\parallel}(1,1^{--})$ $\gamma_k T^A$	$a_1^{\parallel}(0,1^{++})$ $\gamma_k\gamma_5 T^A$

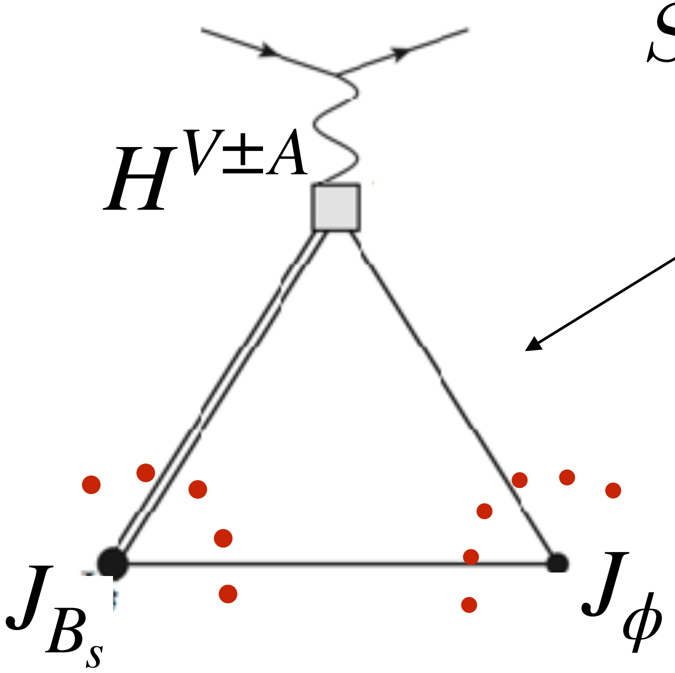
Proof of amplitude relation (symmetry limit)

- Any $B_s \to \phi\gamma$ matrix elements ⊂ 3-pt function:

$$\langle T J_{B_s}(x) J_\phi(y) H^{V\pm A}(0) \rangle =$$

$$\int DG_\mu \det(D + im) e^{iS(G)} \times$$

“as in lattice QCD (here Mink. space)”

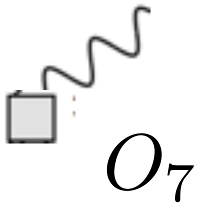


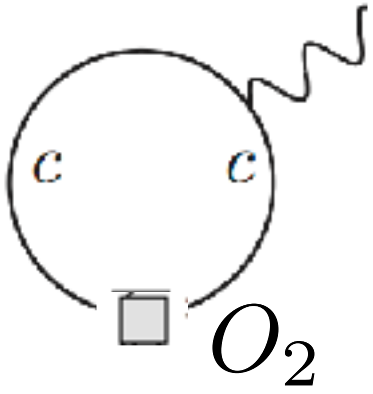
$$S_G(x,y) = \langle x | \frac{1}{\not{D}} | y \rangle$$

$H^{V\pm A}$ either be

local operator (=SD=FF)

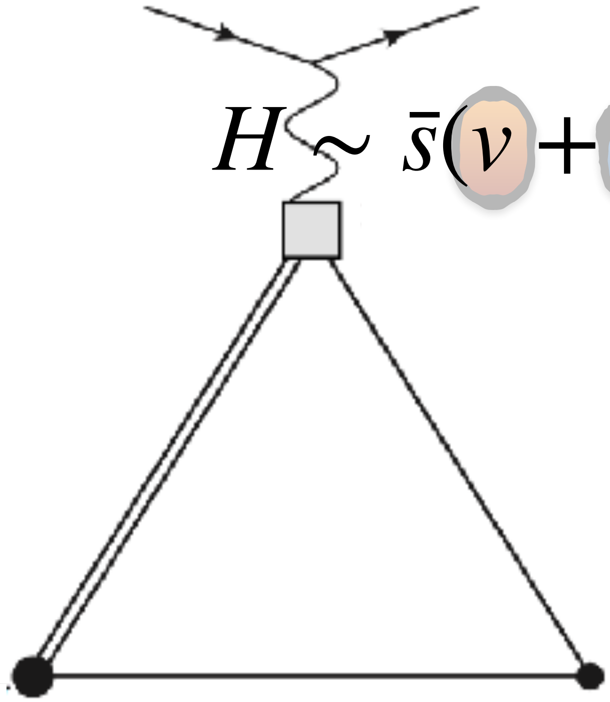
charm loop





An exact equality in the symmetry limit

$B_s \to \phi\gamma$



$H \sim \bar{s}(v + a\gamma_5)\Gamma b$

J_{B_s}

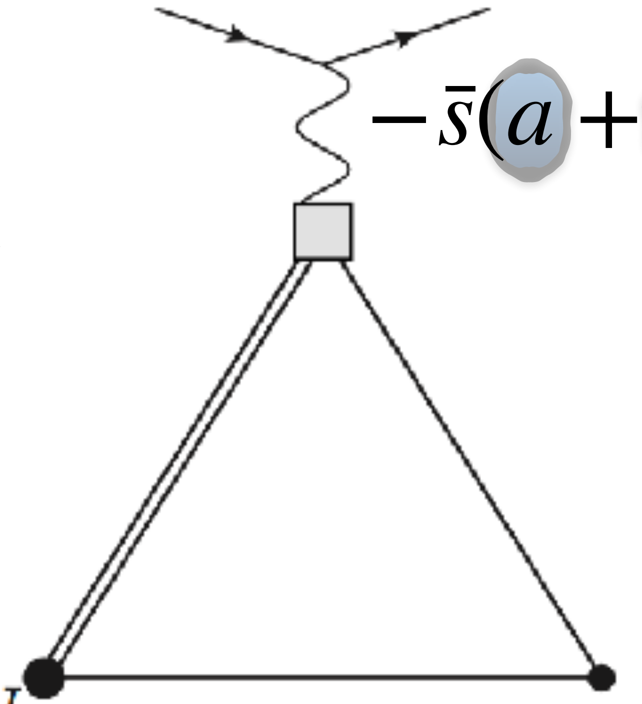
$\phi_\mu \doteq \bar{s}\gamma_\mu[\gamma_5^2]s$

$$\gamma_5 S_G^{(q)} = -\, S_G^{(q)}\gamma_5$$

↓

$$=$$

$B_s \to f_1(1420)\gamma$



$-\bar{s}(a + v\gamma_5)\Gamma b$

J_{B_s} J_B

$(f_1)_\mu = \bar{s}\gamma_\mu\gamma_5 s$

Since: $C(C') \leftrightarrow (v, a) = (1, \mp 1)$

$$\Rightarrow \quad \boxed{A^{B_s\to\phi\gamma}(C, C') = A^{B_s\to f_1(1420)\gamma}(-C, C')}$$

(4) In practice beyond the symmetry limit

- Right-handed amplitude (crucial sign)

$$A_R^{B_s \to \phi[f_1]\gamma_R} = -\mathcal{N}_{\phi[f_1]}\left(\frac{m_s}{m_b} + \delta\hat{C}' \pm \epsilon_R^{\phi[f_1]}(C)\right)$$

What to do with it?

… there are observables linear in A_R!

[1] Normalisation $\mathcal{N}$ drops in asymmetries e.g. time-dependent rate*

Experiment

$$H_{B_s\to\phi\gamma} + H_{B_s\to f_1\gamma} = -2\mathrm{Re}[\epsilon_R^{\phi} + \epsilon_R^{f_1}] \;= -2\mathrm{Re}[\epsilon_R^{\phi}](1+\mathbb{R}_{\phi f_1})$$

⇒ sum of LD contribution RH-amplitude measurable

[2] Compute ratio (improved situation) then “know everything”

Theory

$$\mathbb{R}_{\phi f_1} = \frac{\mathrm{Re}[\epsilon_R^{f_1}]}{\mathrm{Re}[\epsilon_R^{\phi}}] \simeq 1.3(1) = 1 + O(m_q, \langle\bar{q}q\rangle, \ldots)$$

tentative

⇒ crucial error (0.1) and not deviation from unity (0.3)

work
in progress

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* $H_{B_s\to\phi\gamma} = -0.98(50)(20)$ @LCHb'16 - $H_{B_s\to\phi\gamma} = 0.047(25)$ Muheim,Xie,RZ PLB08

(5) Outlook on B→Vll

- Go from 2 to 3 helicity amplitudes. The new **0-helicity** amplitude can be **avoided** in certain angular moments.

$$\text{Moments: } \mathbb{G}_{m}^{l_K\, l_\ell} \; ; m = \text{helicity-difference} \;\; \Rightarrow \;\; m = 2$$

One recovers well-known observables sensitive to RHC

$$P_1 = A_T^{(2)} \sim \text{Re}[\mathbb{G}_2^{2,2}] \, , \quad P_3 \sim \text{Im}[\mathbb{G}_2^{2,2}]$$

- helicity FF, won't be degenerate $T_1(0) = T_2(0)$, but continue to be controlled at low q^2 due to LEL/SCET/EOM and all that

⇒ opens the door in settling uncertainty in $C'_{9,10}$

Conclusions & outlook

- **Relativistic regime: assess RHCs** via parity doublers

$$\begin{array}{cccc|cc}
C_7' & C_8' & - & - & B \to V(A)\gamma & \Lambda_b \to \Lambda(\tilde{\Lambda})\gamma \\
C_7' & C_8' & C_9' & C_{10}' & B \to V(A)\ell\ell & \Lambda_b \to \Lambda(\tilde{\Lambda})\ell\ell
\end{array}$$

- **Assessing opposite parity** - data-driven (1.) theory (2.) program

1. measure Re$[\epsilon_R^V + \epsilon_R^A] =$ LD-part(=non-FF) to RH-amplitude
2. predict ratio: Re$[\epsilon_R^A]$/Re$[\epsilon_R^V]$ [in progress] ⇒ "full info"

e.g. computing doubler-ratio to 20% ⇒ ε_R 10% accuracy

improved situation
order of magnitude

- Assessing RH-Long-distance contribution is important:

  a) 1/2 LD-input into P_5' prediction [possibility to crosscheck]

  b) argued to be large in other context [we can test]

- Should be **useful elsewhere e.g. D-physics** (K-physics less obvious)

Thanks for your attention!

BACKUP

A few references

- Paper arguing charmloops could be large

  Grinstein, Grossman, Ligeti, Pirjol'04 [based on inclusive decay]
  Fedele, Franco, Ciuchini, Mishima, Paul, Silvestrini,.Vialli. JHEP'16

- Papers extracting information on LD from experiment

  Lyon, RZ'14, LHCb'16

- Papers with concrete computation on charmloops

  Ball, RZ PLB'06, Ball, Jones & RZ'PRD'07 Khodjamirian, Mannel, Pivovarov, Wang JHEP'10

- Papers aiming to eliminate the hadronic contribution

  Atwood, Gershon, Hazumi, Soni PRD'05

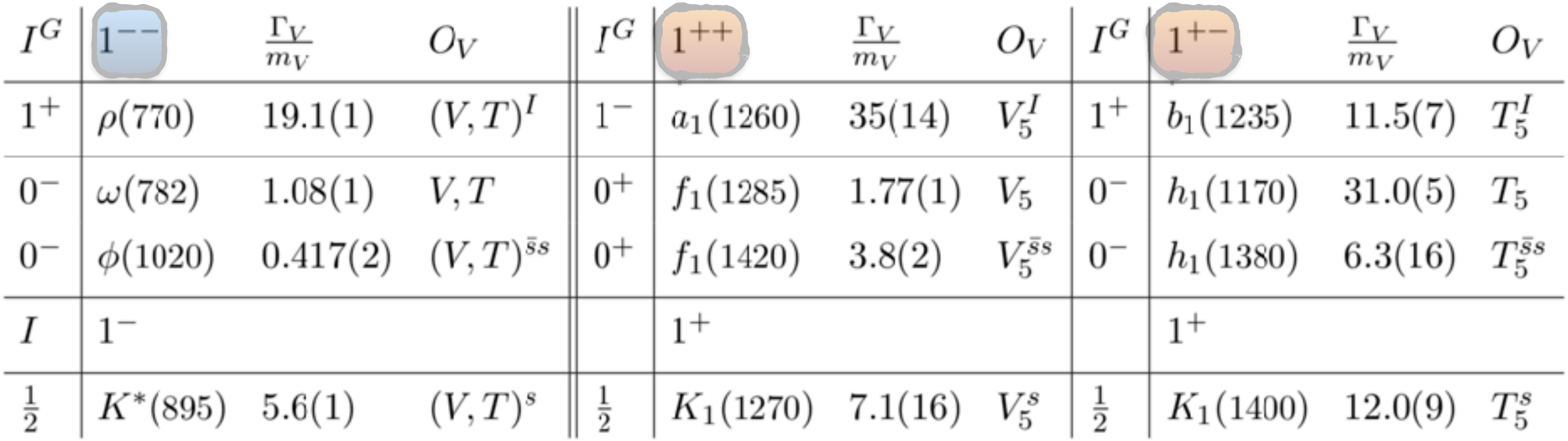
- Authors investigating RHC in bs-transitions (incomplete list)

  Kou, Becirevic, Hiller, Matias, Lunghi, Schneider, Mannel …..

- Authors parameterising LD-contributions (input-depdendent)

  Bobeth, Chrasz, vDyk, Virto

Table of “parity doublers”



I^G	1^{--}	$\frac{\Gamma_V}{m_V}$	O_V	I^G	1^{++}	$\frac{\Gamma_V}{m_V}$	O_V	I^G	1^{+-}	$\frac{\Gamma_V}{m_V}$	O_V
1^+	$\rho(770)$	19.1(1)	$(V,T)^I$	1^-	$a_1(1260)$	35(14)	V_5^I	1^+	$b_1(1235)$	11.5(7)	T_5^I
0^-	$\omega(782)$	1.08(1)	V,T	0^+	$f_1(1285)$	1.77(1)	V_5	0^-	$h_1(1170)$	31.0(5)	T_5
0^-	$\phi(1020)$	0.417(2)	$(V,T)^{\bar{s}s}$	0^+	$f_1(1420)$	3.8(2)	$V_5^{\bar{s}s}$	0^-	$h_1(1380)$	6.3(16)	$T_5^{\bar{s}s}$
I	1^-				1^+				1^+		
$\frac{1}{2}$	$K^*(895)$	5.6(1)	$(V,T)^s$	$\frac{1}{2}$	$K_1(1270)$	7.1(16)	V_5^s	$\frac{1}{2}$	$K_1(1400)$	12.0(9)	T_5^s

Going back to example of $B_s \to \phi\gamma$
& beyond symmetry limit (QCD)

Quick summary: experiment & theory numbers

- **Experiment:**

- $S_{K^*\gamma}$ and $S_{\rho\gamma}$ good @ B-factories

$S_{B\to K^*\gamma}$ = -0.16(22)
$S_{B\to\rho\gamma}$ = -0.83(65)(18)

Belle, Babar
(HFAG-values)

- $H_{\phi\gamma}$ feasible @ LHCb

Muheim, Xie, RZ'08

$H_{Bs\to\phi\gamma}$ = -0.98(50)(20)

LHCb'16

- **Theory:**

$$S_{K^*\gamma} = -\frac{m_s}{m_b}\sin(2\beta) + \mathrm{LD} = -2.3(16)\%$$

$$S_{\rho\gamma} = \frac{m_d}{m_b} + \mathrm{LD} = 0.2(16)\%$$

$$H_{\phi\gamma} = \frac{m_s}{m_b} + \mathrm{LD} = 4.7(25)\%$$

Ball, Jones, RZ'06

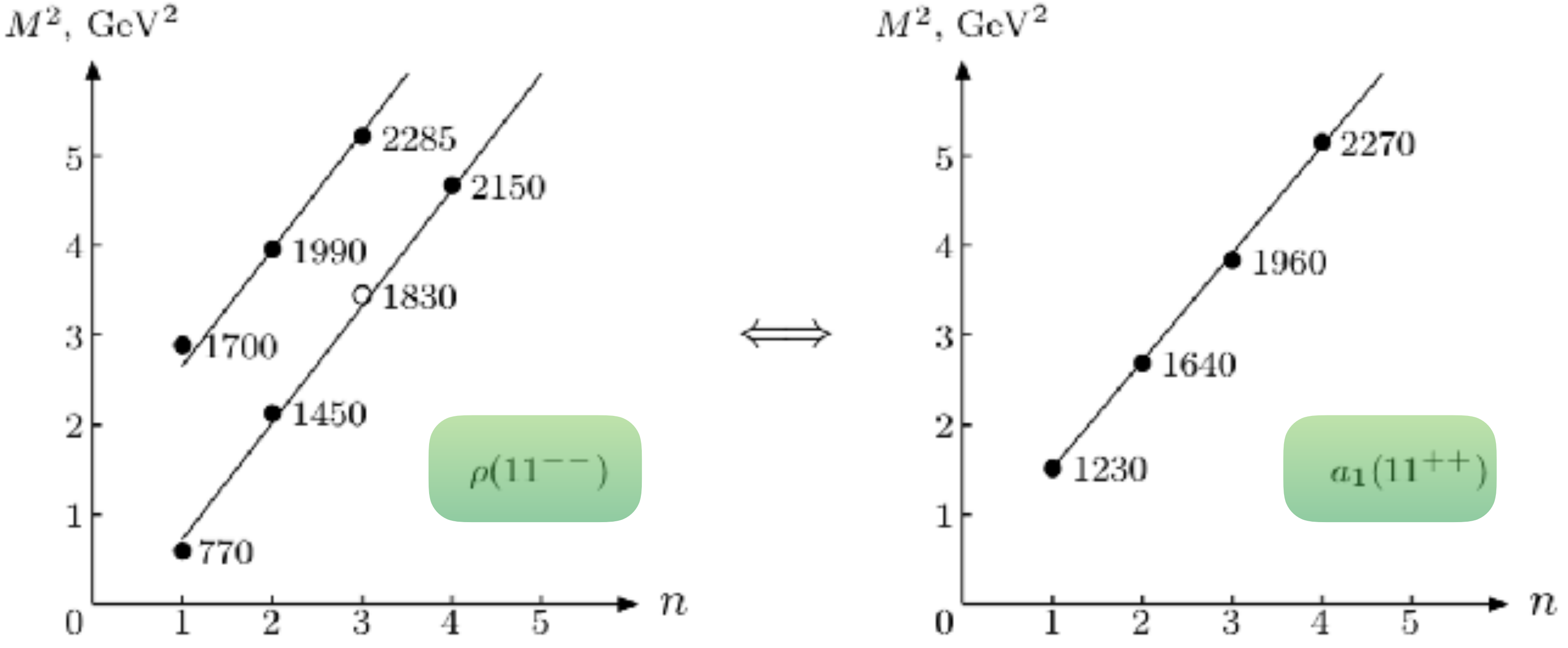
show for completeness

$$\mathrm{BelleII@50}ab^{-1}:\ \Delta S_{K^*\gamma} = 3\%\ , \Delta S_{\rho^0\gamma} = 6\%$$

So what's the trouble (besides statistics)?

2. Parity Doubling* - Global Symmetries

- QCD is parity symmetric - (parity not spontaneously broken Vafa, Witten'84)
- Parity discrete symmetry: Z_2 with irreps **1** and **1'**
  particles parity-eigenstates - either **singlet** or **doublet** of parity
- Reality-check: Anisovich'04



Doubling pattern but not exact. Need a little help from ……

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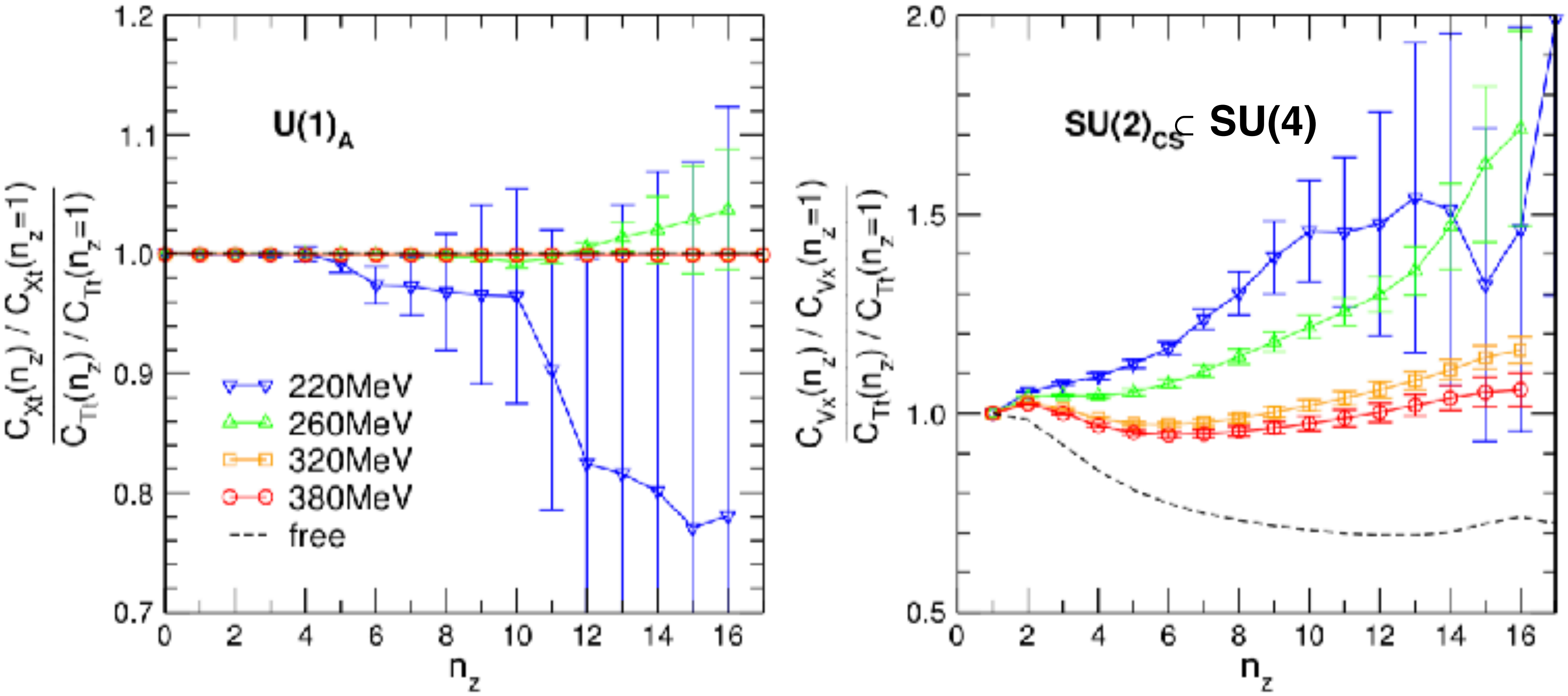
* **Parity Doubling:** 50 years history Afonin'07 motivated by Regge theory, bootstrap models,..

Intermezzo: test of Symmetry on the Lattice

- Tested on lattice: $T>T_\chi$ Rohrhofer, Aoki, Cossu, Fukaya, Glozman, Hashimoto, Lang. Prelovsek'17
  truncate low Dirac eigenmodes Denissenya, Glozman,Lang '14'15

- 1st $U(1)_A$ restores $T>T_\chi$ (8-plet) Cossu, Aoki, Fukaya, Hashimoto, Kaneko, Matsufuru, J.-I. Noaki,'13

- 2nd Even higher **(emergent) symmetry** a 15-plet!



$U(1)_A$ restoration **$SU(2)$Chiral Spin emergence!**

Weinberg Sum Rules - parity splitting controlled by condensates

- combining **dispersion relations** and **group theory**

Weinberg'67

$$\Pi_{LR}^{ab} \sim \begin{cases} \int_0^\infty ds \frac{\rho_V(s)-\rho_A(s)}{s-q^2-i0} \\ \frac{\langle \bar{q}\gamma_\mu T^a \lambda^i q_L \bar{q}\gamma^\mu T^b \lambda^i q_R\rangle}{q^6} + \ldots \end{cases}$$

$$\rho_A(s) = F_\pi^2 \delta(s-m_\pi^2) + F_{a_1}^2 \delta(s-m_{a_1}^2) + \ldots \qquad \rho_V(s) = F_\rho^2 \delta(s-m_\rho^2) + \ldots$$

massless quarks

$$(\Pi_{LR}^{a,b})_{\mu\nu}(q^2) = i \int d^4x e^{iq\cdot x} \langle T J_\mu^{a,L}(x) J_\nu^{b,R}(x)\rangle = (q_\mu q_\nu - q^2 g_{\mu\nu}) \Pi_{LR}^{a,b}(q^2) \;,$$

- Assuming perturbation theory to dominate above a₁-meson:

2-Weinberg sum rules:

$$F_\rho^2 - F_\pi^2 - F_{a_1}^2 = 0 \,,$$

$$m_\rho^2 F_\rho^2 - m_{a_1}^2 F_{a_1}^2 = 0 \,,$$

3rd sum rule:

$$m_\rho^4 F_\rho^2 - m_{a_1}^4 F_{a_1}^2 = (c\alpha_s + \ldots)\, \underbrace{\langle \bar{q}..q_L q..q_R\rangle}_{\simeq \langle \bar{q}q\rangle^2} \;.$$