Isospin $B \to K^{(*)} l_+ l_-$ in and beyond the SM

a) Generic remarks $B \to K^{(*)} l_+ l_-$ and isospin

b) What drives isospin violation

c) Isospin asymmetries in and beyond SM

d) Remarks on low recoil region (high q^2)

CP^3 - Origins

Particle Physics & Origin of Mass

The Higgs Centre for Theoretical Physics

Roman Zwicky

Higgs-centre for theoretical physics -- Edinburgh University

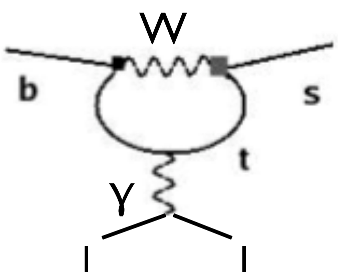
in collaboration James Lyon & (Maria Dimou)

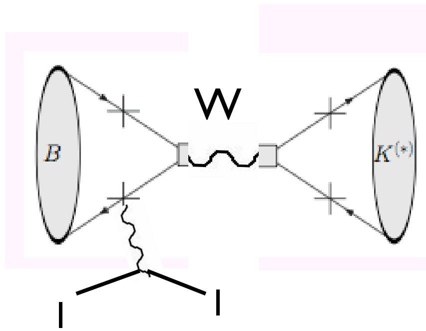
Challenges in Flavour pHYSICS --- 15-18 April 2013 Portoroz

Note: corresponds to arXiv.1304.479 (appeared after talk)
later includes $B \to \rho\gamma/ll$ isospin analysis as well
as some further aspects on phenomenology aspects.

Why $B \to K^{(*)} l_+ l_-$? And what it is.

- 1) It's an FCNC ($b \to s$ -transition); thus loop suppressed in SM
  2) It's measured at experimental facilities (currently LHCb future KEK2 past: Belle/BaBar/CDF)





Wilson coefficient *(UV-physics SM & BSM?)* → $C^i(\mu_F)$

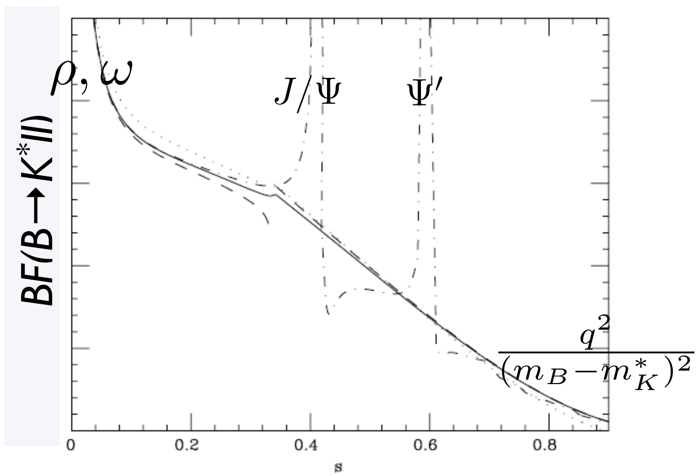
operator *(IR-physics)* → $O^i(\mu_F)$

$$H_{\rm eff} = \sum_i C^i(\mu_F) O^i(\mu_F)$$

$$\mathcal{A} = \langle V l l | H_{\rm eff} | B \rangle = \sum_i C_i(m_b) \langle V l l | O_i(m_b) | B \rangle$$

Amplitude

non-perturbative



low q^2 (large recoil) $E_{K^*} >> \Lambda_{QCD}$

- ⇒ light-cone dynamics
- QCD-factorization/SCET & LCSR -- form factor LCSR

this talk

high q^2 (low recoil) $E_{K^*} \approx \Lambda_{QCD}$

- OPE (*Grinstein,Pirjol'04, Beylich et al'11*) $1/m_b \sqrt{q^2}$
- form factors Lattice

comments end

Definition of isospin asymmetries

Lyon & RZ'13

- Experimental definition (Recall: **q²** lepton pair momentum squared)

$K^*\gamma$, Kll analoguous

$$\frac{dA_I^{\bar{0}-}}{dq^2} \equiv \frac{d\Gamma[\overline{B}^0 \to \overline{K}^{*0} l^+ l^-]/dq^2 - d\Gamma[B^- \to K^{*-} l^+ l^-]/dq^2}{d\Gamma[\overline{B}^0 \to \overline{K}^{*0} l^+ l^-]/dq^2 + d\Gamma[B^- \to K^{*-} l^+ l^-]/dq^2}$$

- In terms of K^*-helicity (0,±) & $(\bar{l}l)_{V,A}$

$$\frac{dA_I^{\bar{0}-}}{dq^2}[B \to K^* l^+ l^-] = \frac{\sum_{i=\{0,\pm\}} \mathrm{Re}\big[h_i^{V,0}(q^2)\Delta_i^{V,d-u}(q^2)\big]}{\sum_{i=\{0,\pm\}} \Big[|h_i^{V,0}(q^2)|^2 + \big|h_i^A(q^2)\big|^2\Big]} + \mathcal{O}([\Delta_i^{V,d-u}(q^2)]^2, m_l)$$

$$\Delta_i^{V,d-u}(q^2) \equiv \left(h_i^{V,d}(q^2) - h_i^{V,u}(q^2)\right).$$

- above isospin linear effect -- interference with isospin neutral part
  a) compute SM asymmetry
  b) extend the basis to include most generic isospin sensitive dimension 6 operators
  (N.B. do not extend SM isospin neutral part; as "know" to be small by rate)

How do we extend the basis?

What “drives” sizeable isospin asymmetries?

- **Not QCD** as effects known to be small: m(K^{*-})/m(K^{*0}) = 0.995

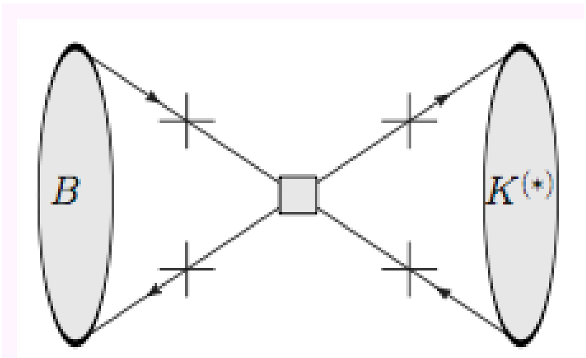
UV IR

- Recall: $\mathcal{A} = \langle Vll | H_{\rm eff} | B \rangle = \sum_i C_i(m_b) \langle Vll | O_i(m_b) | B \rangle$

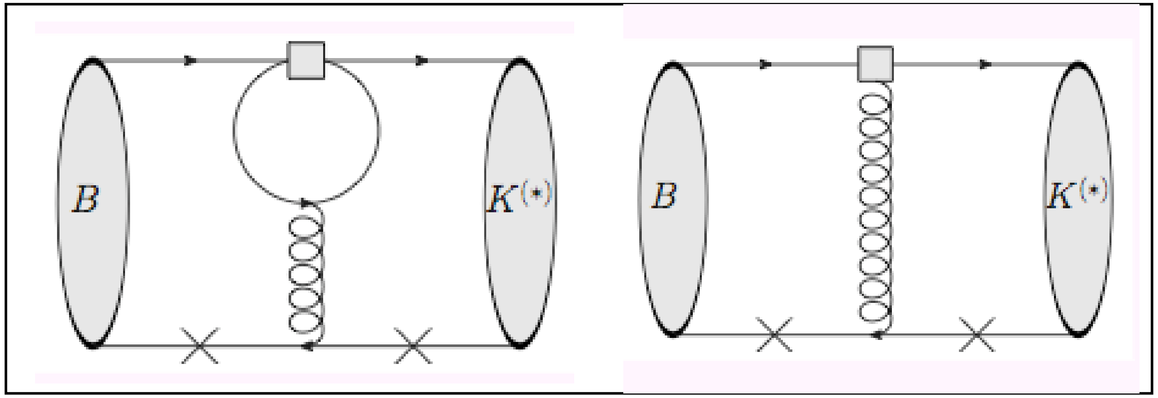
Weak Annihilation (WA)

Quark-loop spectator scattering (QLSS)

Chromomagnetic-operator (O_8)



spectator is not a spectator
(sensitive to UV isospin violation)



resemble each other
(e.g. - if loop massive shrinks to a point & mix under RG)

Answer title: IR **QED**-effects & **BSM UV isospin violation** manifested in WA

- very specific operators ⇒ answers the question: **“why isospin asymmetries?”**

A rough overview of what we did.

- **WA:** 1) extend (*Khodj.&Wyler, Ali&Braun'95*) to $q^2 \neq 0$ within Light-cone sum rules

  2) introduce most general dimension 6 H^{eff} at $O(\alpha_s^0)$

10(20) operators

$$\mathcal{H}^{\mathrm{WA,q}} = -\frac{G_F}{\sqrt{2}}\lambda_t \sum_{i=1}^{10} a_i^q O_i^{\mathrm{WA}}$$

$$O_9^{\mathrm{WA}} \equiv \bar{q}\sigma_{\mu\nu}b\,\bar{s}\sigma^{\mu\nu}q \quad O_{10}^{\mathrm{WA}} \equiv \bar{q}\sigma_{\mu\nu}\gamma_5 b\,\bar{s}\sigma^{\mu\nu}q$$

$$O_1^{\mathrm{WA}} \equiv \bar{q}b\,\bar{s}q \quad O_2^{\mathrm{WA}} \equiv \bar{q}\gamma_5 b\,\bar{s}q \quad O_3^{\mathrm{WA}} \equiv \bar{q}b\,\bar{s}\gamma_5 q \quad O_4^{\mathrm{WA}} \equiv \bar{q}\gamma_5 b\,\bar{s}\gamma_5 q$$

$$O_5^{\mathrm{WA}} \equiv \bar{q}\gamma_\mu b\,\bar{s}\gamma^\mu q \quad O_6^{\mathrm{WA}} \equiv \bar{q}\gamma_\mu\gamma_5 b\,\bar{s}\gamma^\mu q \quad O_7^{\mathrm{WA}} \equiv \bar{q}\gamma_\mu b\,\bar{s}\gamma^\mu\gamma_5 q \quad O_8^{\mathrm{WA}} \equiv \bar{q}\gamma_\mu\gamma_5 b\,\bar{s}\gamma^\mu\gamma_5 q$$

- **QLSS:** extend (*Feldmann & Matias '02*) to include most general dimension 6 H^{eff} at $O(\alpha_s^0)$

  We resort to QCDF as LCSR involves 2-loops and complicated analytic structure ..

$$\mathcal{H}^{\mathrm{QLSS}} = -\frac{G_F}{\sqrt{2}}\lambda_t \sum_{x,\chi,f} s^f_{x\chi} Q^{4f}_{x\chi}\,, \quad x = 1,2\,,\ \chi = L,R\,,\ f = SU(3)_F, c, b$$

10 operators (m_q=0)

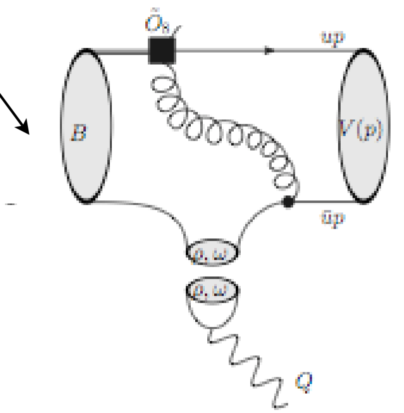
$$Q^{4f}_{1L(R)} \equiv \bar{f}t^a\gamma_\mu f\,\bar{s}_{L(R)}t^a\gamma^\mu b\,, \quad Q^{4f}_{2L(R)} \equiv \bar{f}t^a\sigma_{\mu\nu} f\,\bar{s}_{L(R)}t^a\sigma_{\mu\nu} b\,, \quad Q^{4SU(3)_F}_{xL(R)} \equiv \sum_{q=u,d,s} Q^{4q}_{xL(R)}$$

> N.B. $10(20)_{\mathrm{WA}}$ & $10_{\mathrm{QLSS}(mq=0)}$ are not orthogonal but linearly independent

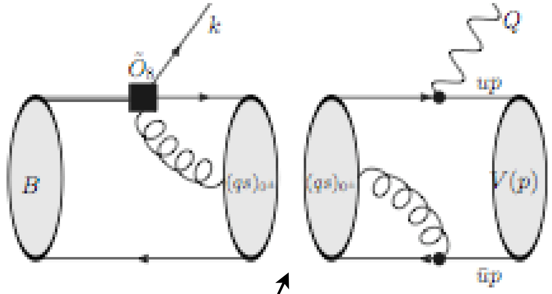
- **O_8:** earlier work (*Dimou, Lyon & RZ '12*) BSM: flipped chirality ⇒ trivial

Hadronic contributions & strong phases

- e.g. ρ,ω-thresholds when photon emitted from light-quark -- seen O_8, WA not in (QLSS as LO QCDF)



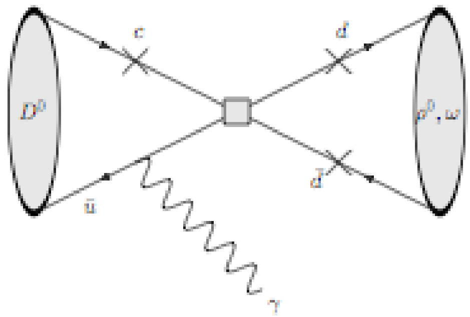
rong phases



- Multihadron state $(\bar{s}q)_{0^\pm}$ q-number and momentum squared m_B^2

Quick comment (un)related topic: $A_{CP}[D^0 \to \rho^0\gamma]$

- Strong phase of O_8 and WA (dominant) interfere to CP-violation in $D^0 \to \rho^0\gamma$



x $\mathrm{Im}[C_8]O_8$

LD $e^{i\delta(\mathrm{strong})}$ x $\mathrm{Im}[C_8]O_7$

RG-mixing

Lyon & RZ 12

First: Isidori & Kamenik 12

main difference: IK: LD not specified depends sizeable strong phase
LZ: LD=WA no strong phase at leading order -- strong phase through O_8

Fun with dispersion relations

- Main tool for sum rules (besides LC-OPE) is the construction of a dispersion relation:

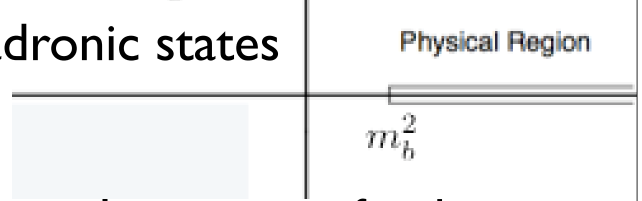
$$g_i(p_B^2, ..) = \int_\Gamma \frac{ds g_i(s, ..)}{s - p_B^2 - i0}$$

Cauchy's thm

1) Γ: path encircles singularities $\mathcal{C}_{p_B^2}$

2) Γ: chosen s.t. relates hadronic states

"usually"



- Investigate singularities Landau equations: leading Landau singularities **s±** of a three point function appearing in the computation has got two complex solutions.

- Are they on the physical Riemann sheet (PRS)?

  For real singularities its relatively straightforward to answer not for complex ones!

- Found 4 ways to show/convince ourselves that one is present on PRS

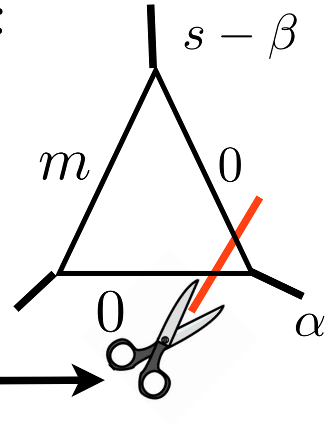
  1) Kallen-Wightman paper '59 ananlytic properties three pts fcts (axiomatic approach)

  2) 6-dimensional projective geometry (did not do finally)

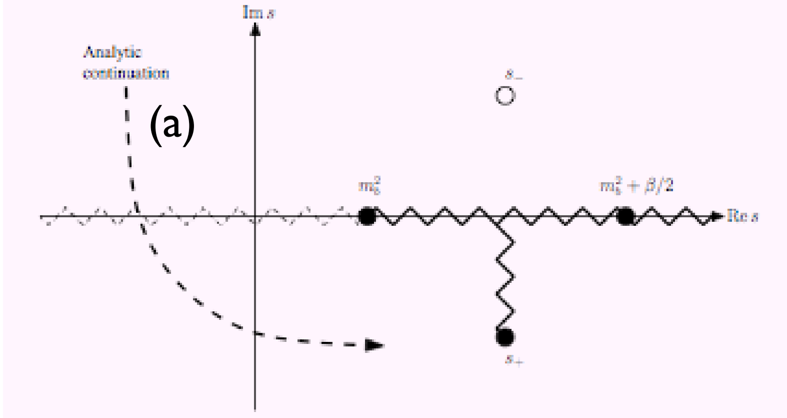
  3) deformation from non-complex case (tricky in case at hand)

  4) "invented method" using Feynman parameter integral (next slide)

Passarino-Veltman reduction C_0:
➢ study analytic continuation



ρ/ω-thresholds &
$(\bar{s}q)_{0^\pm}$-mutiparticle threshold



❶ Real line: $C_0(s) = C_0^F(s) \equiv \int_0^1 dx \int_0^{1-x} dy((1-x-y)(xs+y(s-\beta)-m^2)....+xy\alpha+i0]^{-1}$

❷ Real α,β,m C_0^F no singularities upper half plane ➢ valid analytic continuation & **s-** ∉ PRS

❸ Lower half plane -- analytic continuation via (a) -- unphysical branch cut s < m^2

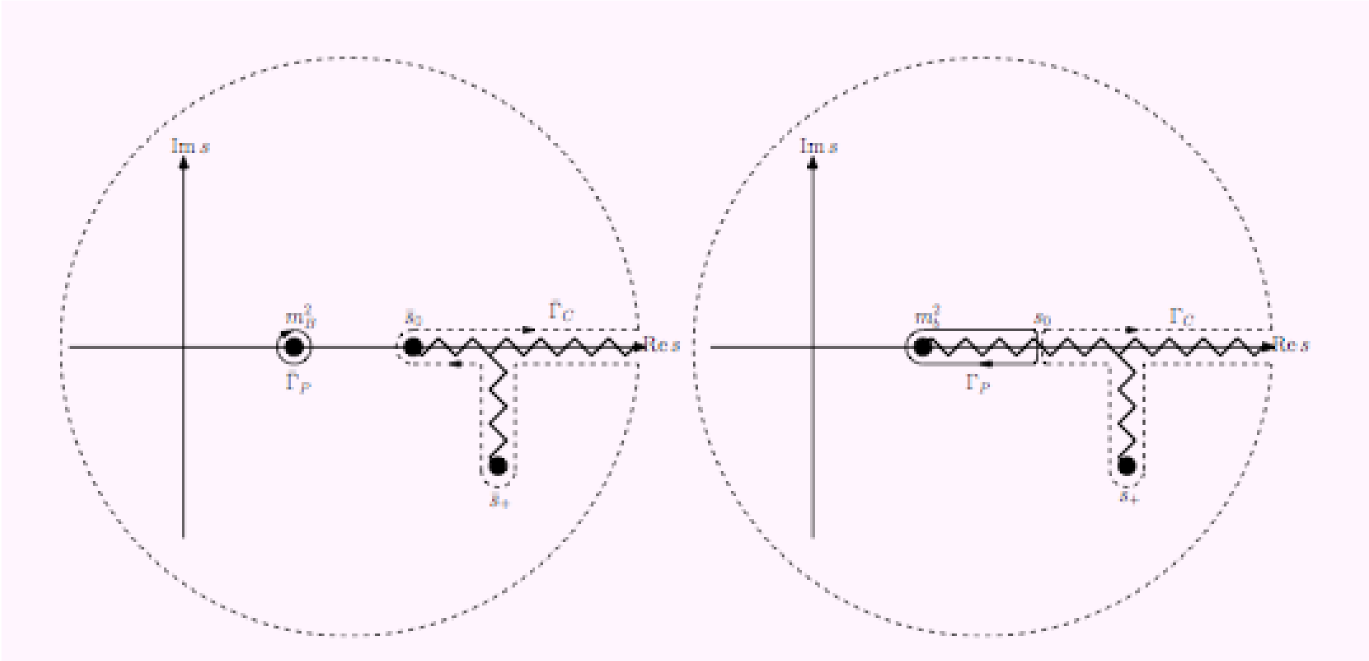
❹ **Principle: impose continuity across real line s<m^2 ➢ eliminate branch cut**

$$Im[s] \neq 0: \quad [C_0^F(s^*)]^* = C_0^F(s) \text{ Reflection principle}$$

$$C_0(s) = \begin{cases} C_0^F(s) & \text{Im}[s] > 0 \\ C_0^F(s^*)^* + C_0^{\text{rem}}(s) & \text{Im}[s] < 0 \end{cases} \qquad C_0^{\text{rem}}(s) = Im[C_0^F(s)] \quad Im[s] = 0$$

is continuous and thus the unique analytic continuation! N.B. $[C_0(s^*)]^* \neq C_0[s]$

❺ Inspect C_0^{rem} note **s+** ∈ PRS!! Know how to choose path appropriately very briefly the analytic structure in full QCD and in partonic QCD



- leading Landau singularities (anomalous thresholds) are not related to insersion of a hadronic state(s).

- Essence for sum rules is that the branch cut from **s₋** is above continuum states and therefore will be exponentially Borel suppressed

end of technical excursion

Selection rules

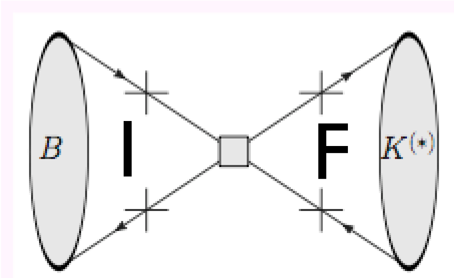
- **General:** a) $B[0^-] \to K[0^-](\gamma^*[1^-] \to ll[1^-]) \quad \Rightarrow \quad$ p-wave; i.e. $l = 1$,

  induced by parity conserving interacton $\quad \ldots(1 - \gamma_5)s$

  b) other way around for K*(0-helicity = longitidinal polarisation)

- **WA:** more stringent selection rules ground of Lorentz-invariance etc (at least at the level of the factorisable contribution)

		Twist	Operator O_n^{WA}									
			1	2	3	4	5	6	7	8	9	10
$B \to K$	cov. (α_s^0)		✗	✗̲	✗̲		✗	✗̲	✗̲		✗	✗̲
	χ-even (ϕ_K)	2								I,F		
	χ-odd $(\phi_{P,\sigma})$	3				I,F						
	cov. $(\alpha_s^n, n > 0)$		✓	✗̲	✗̲	✓	✓	✗̲	✗̲	✓	✓	✗̲
$B \to K^*$	cov. (α_s^0)		✗		✗				✗	✗		
	χ-even $(g_\perp^{(v)}, g_\perp^{(a)})$	3					I,F	I,F				
	χ-odd $(\phi_\perp)$	2		F		F					I	I
	χ-odd $(h_\parallel^{(t)}, h_\parallel^{(s)})$	3		F								I
	cov. $(\alpha_s^n, n > 0)$		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓



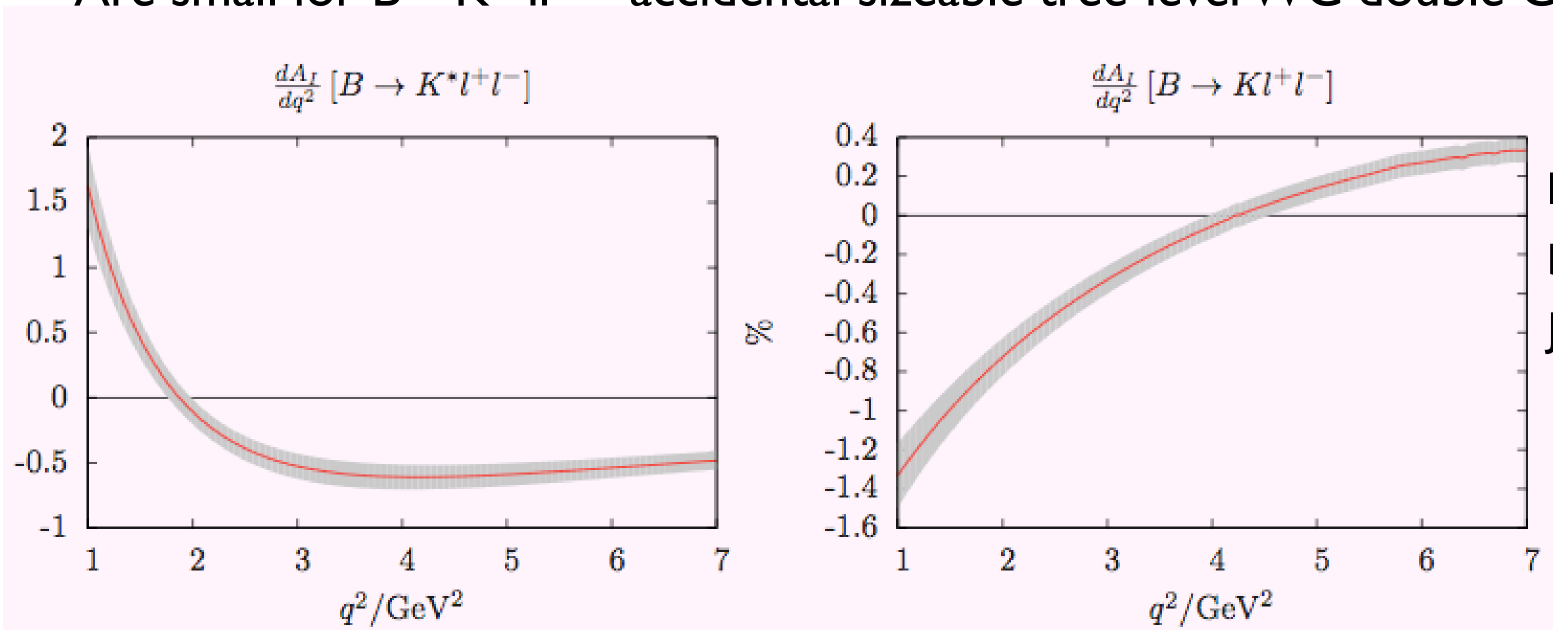
I(inital) & F(inal) state radiation

"the K-meson contribution corresponds to the longitudinal part of K*-meson"

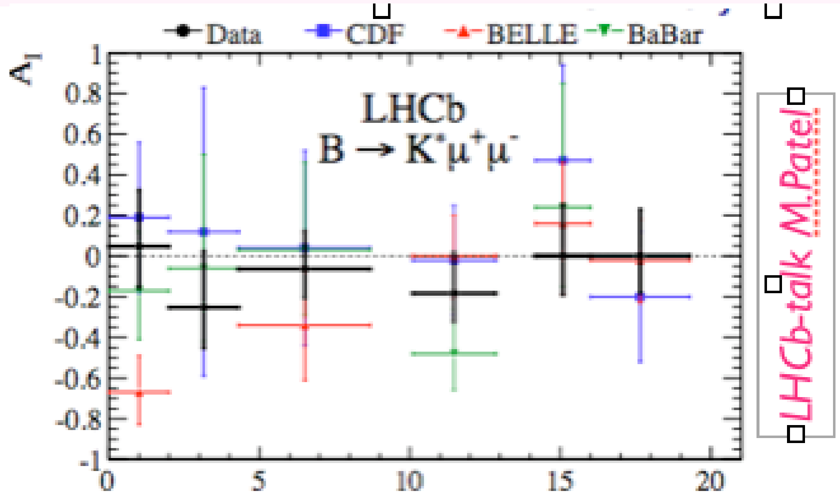
true leading twist in the SM where V-A imposes $a_6 = -a_8$; V+A not true

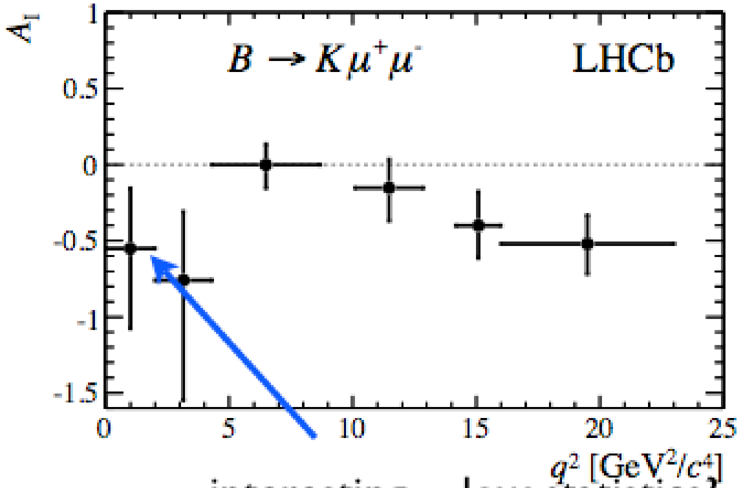
Isospin asymmetries in the SM

- Are small for $B \to K^{(*)}ll$ -- accidental sizeable tree-level WC double Cabibbo suppressed



lower and upper boundaries: ρ,ω & J/ψ, ψ(2s) resonances



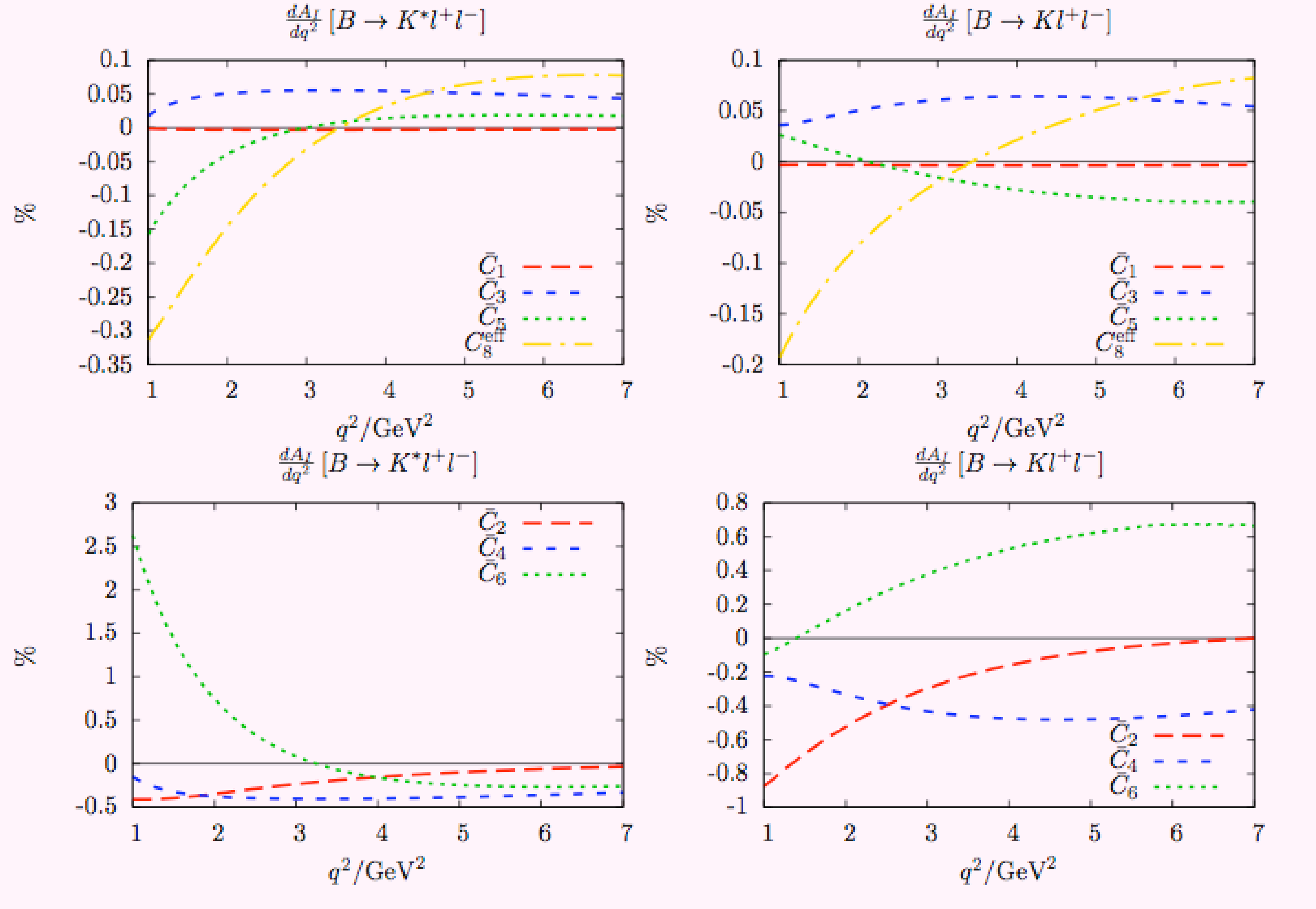


interesting -- low statistics?

- Larger for $B \to K^{(*)}\gamma$

$$a_I^{\bar{0}-}(K^*\gamma)_{\mathrm{LZ}} = 7\% \ , \qquad a_I^{\bar{0}-}(K^*\gamma)_{\mathrm{HFAG}} = 5.2(2.6)\%$$

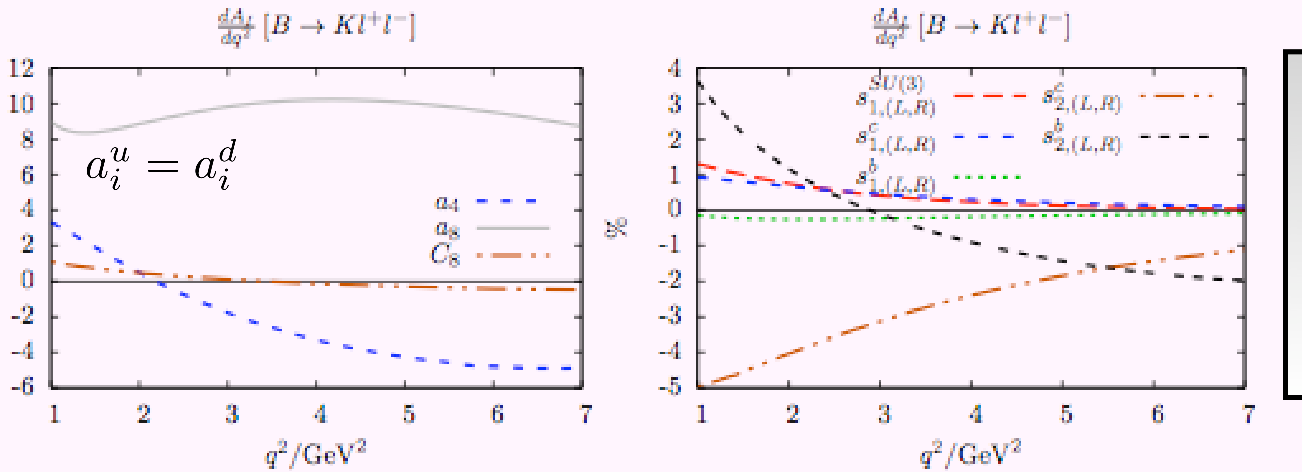
The breakdown in the SM....



Isospin asymmetries BSM

- After selection rules:
  still <u>many</u> operators!

	$C_8^{(\prime)}$	WA		QLSS		total
K^*	2[1]	12[3]	$a^q_{2,4,5,6,9,10}$	10[3]	all no i=2,f=SU(3)	24[7]
K	1[1]	4[3]	$a^q_{4,8}$	5[3]	idem no $\chi = A$	10[7]



- K^* even more ".. by the laws of probability cancellation ought to be the rule rather than the exception."
- *Or a new principle for flavour physics)*
- q^2-spectrum ought to help can't be unlucky all the way

N.B. all BSM WCs set to unity (paper a_i^q=0.1)

- Are there **constraints?** a) non-leptonic decays (large hadronic uncertainties)
  to be seen: some constraint not all as selection rules differ
  isospin & non-leptonic decays might marry to constrain bsqq's
  b) isospin asymmetry in $B \to K^* \gamma$ of course

Take $a_i \neq 0$ others zero then to be within 2σ of $a_I^{\bar{0}-}(K^*\gamma)_{\mathrm{HFAG}} = 5.2(2.6)\%$

$$0 > a_2 > -3 \cdot 10^{-1}\,, \quad 0 > a_4 > -3 \cdot 10^{-1}\,, \quad 0 < a_5 < 5 \cdot 10^{-1}$$
$$0 > a_6 > -7 \cdot 10^{-1}\,, \quad 0 < a_9 < 6 \cdot 10^{-2}\,, \quad 0 < a_{10} < 6 \cdot 10^{-2}\,.$$

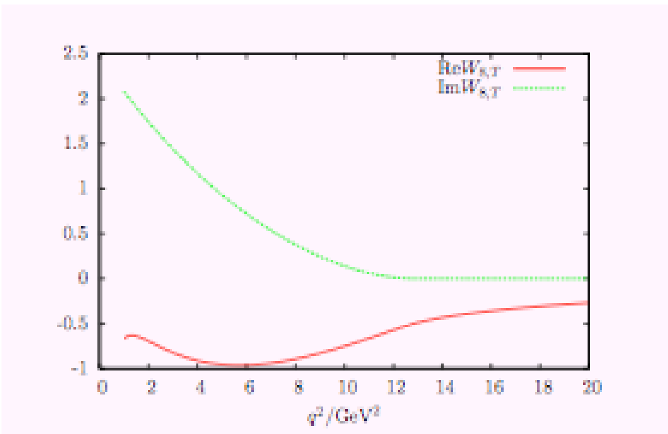
indicative constraints

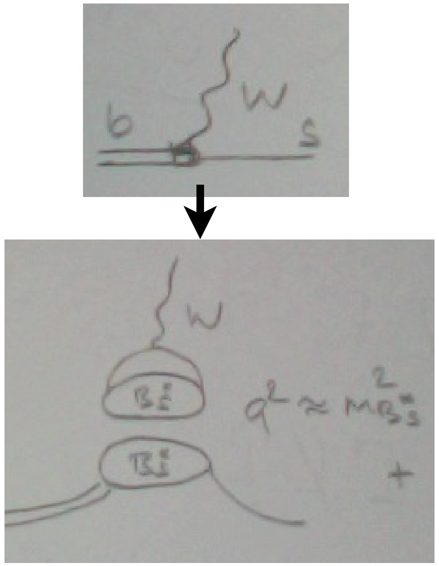
Comments on high q^2

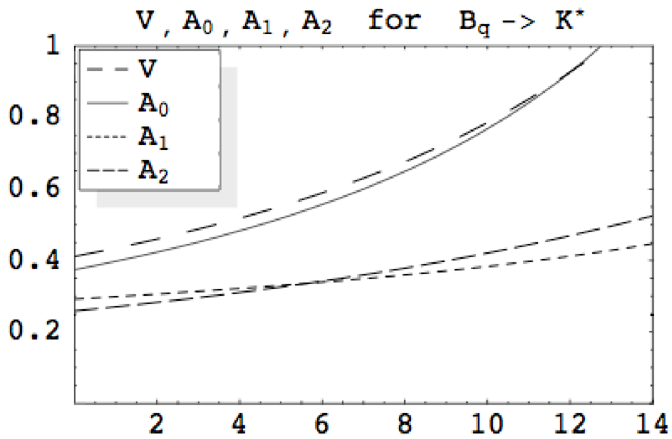
1) Generic remarks

- Isospin violation: - through photon ➢ enhanced through photon pole low q^2
  ➢ isospin asymmetry has to decrease (module conspiracy) at high q^2 as rate dominated by Z-penguins and boxes (e.g. $C_9^{eff..}$)

- On top of that isospin transitions (IT) compete with penguin form factors who show increase, at high q^2, due to nearby t-channel $B_s^*[1^+]$ poles and alike whereas IT have no such enhancements (at least at leading order)







2) OPE language: form factors dim 3 operators
isospin violation dim 5,6

•*Beylich, Buchalla, Feldmann'11*

... Epilogue

- Isospin asymmetry driven by QED-effects & Weak Annihilation

- SM isospin accidentally small as large WC is doubly Cabibbo suppressed

- Difficult to see how isospin asymmetry can be large at high q^2
  Isospin symmetric WC as well as matrix element (form factors) raise

- BSM many operators contribute
  - Is by the laws of probability cancellation the rule rather than the exception
  - This is where q^2-spectrum ought to help - can't be unlucky everywhere in q^2

- Theoretical improvement
  SM: compute WA at $O(\alpha_s)$ -- presumably difficult -- important charm $D \to V\gamma$
  BSM: compute QLSS with LCSR

thanks for your attention!