Isospin B → $K^{(*)} l_+ l_-$ 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)

-- CHARM-INTERMEZZO --

CP^3 - Origins

Particle Physics & Origin of Mass

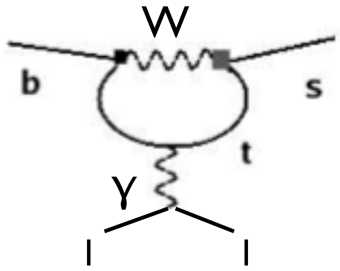
The Higgs Centre
for Theoretical Physics

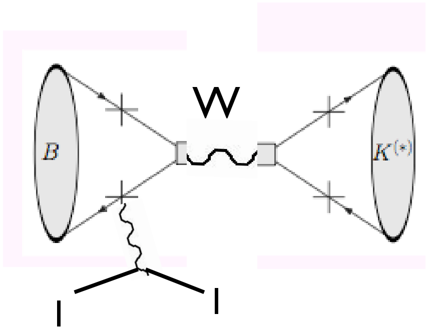
Roman Zwicky
Higgs-centre for theoretical physics -- Edinburgh University
in collaboration James Lyon & Maria Dimou

UK flavour workshop --- 5-7 Sep 2013 Durham IPPP

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

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





Wilson coefficient *operator*
(UV-physics SM & BSM?) *(IR-physics)*

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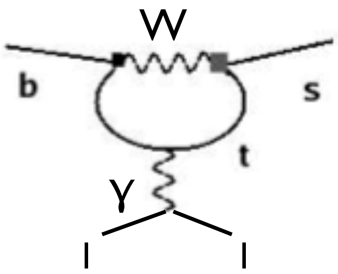

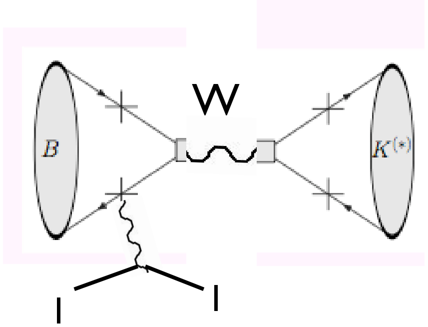

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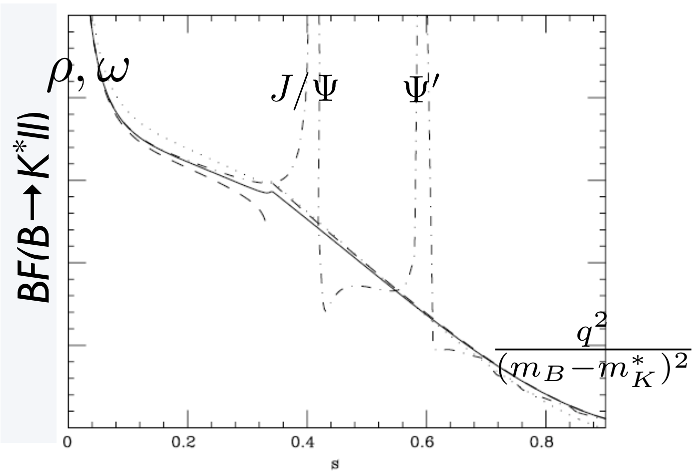
non-perturbative



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: **q^2** lepton pair momentum squared)

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  a) compute SM asymmetry
  b) extend the basis to include most generic isospin sensitive dimension 6 operators
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How do we extend the basis?

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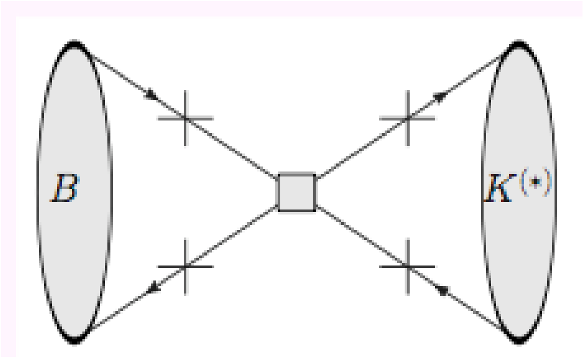
Quark-loop spectator scattering (QLSS)

Chromomagnetic-operator (O8)



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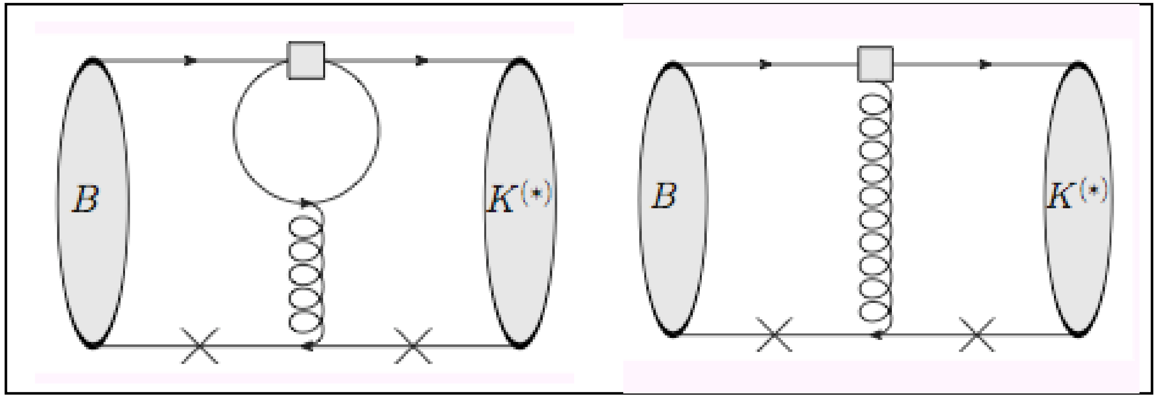

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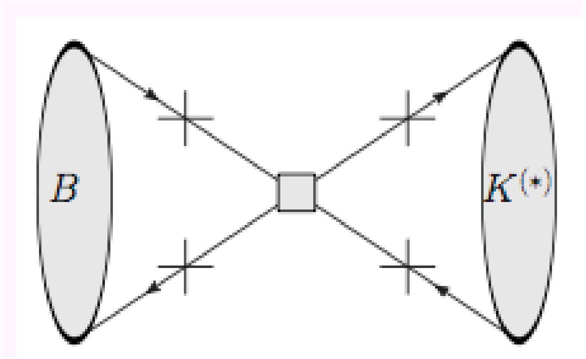

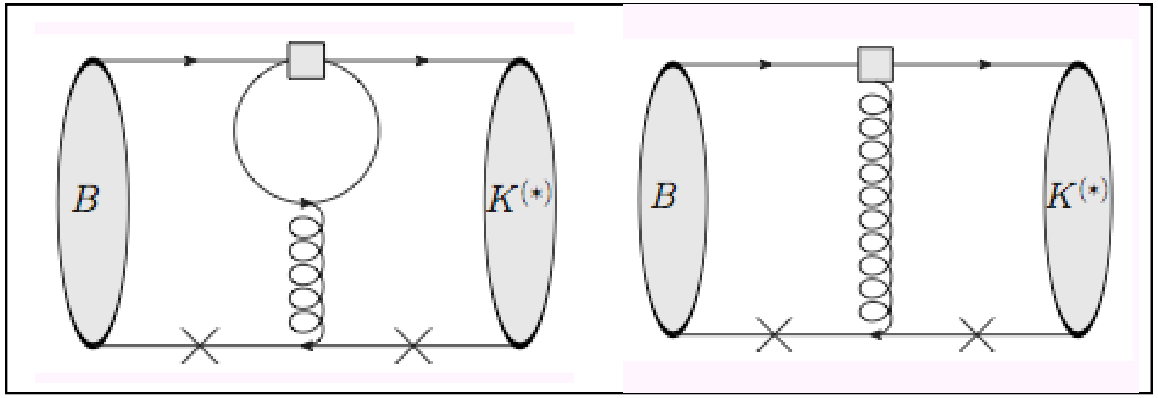

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Answer title Q: IR **QED**-effects & **BSM UV isospin violation** manifested in WA

- 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

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

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

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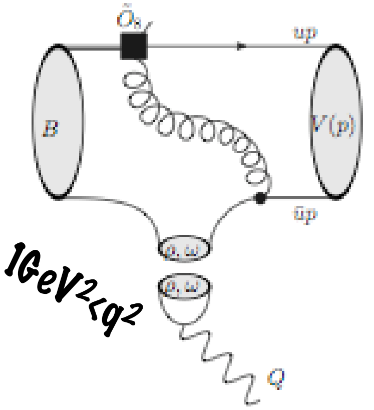
- **O_8:** earlier work (*Dimou, Lyon & RZ '12*) BSM: flipped chirality ⇒ trivial

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)



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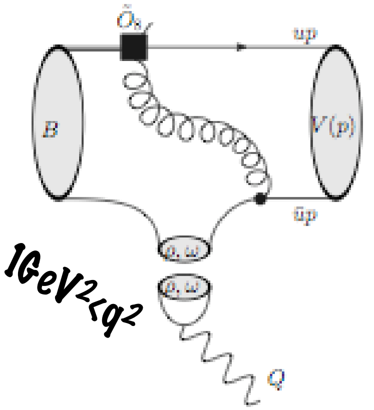

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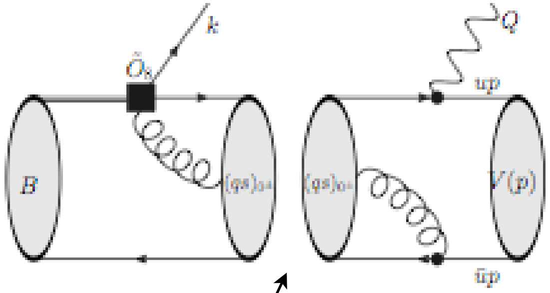

ok as cut at m_B^2
not in resonance region

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

Charm-physics intermezzo

- recent interest $\Delta A_{CP}(D \to KK/\pi\pi)$ ---
  one suspect: enhanced chromomagentic operator new weak phase

Isidori,Kamenik,Ligeti,Perez et al '11

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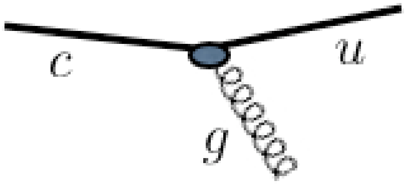

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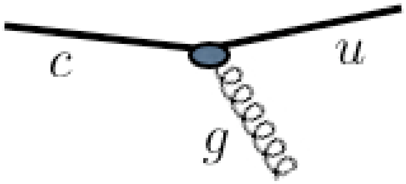

- Appears in $A_{CP}[\, D\rightarrow V\gamma]$ *Isidori,Kamenik'12* ....

$D\Rightarrow V\gamma$ under the microscope

- Consensus: $B\Rightarrow V\gamma$ short distance (SD) dominated (penguin)

  $D\Rightarrow V\gamma$ long distance (LD) dominated

our view

Why? -CKM-hierarchies
-large top mas

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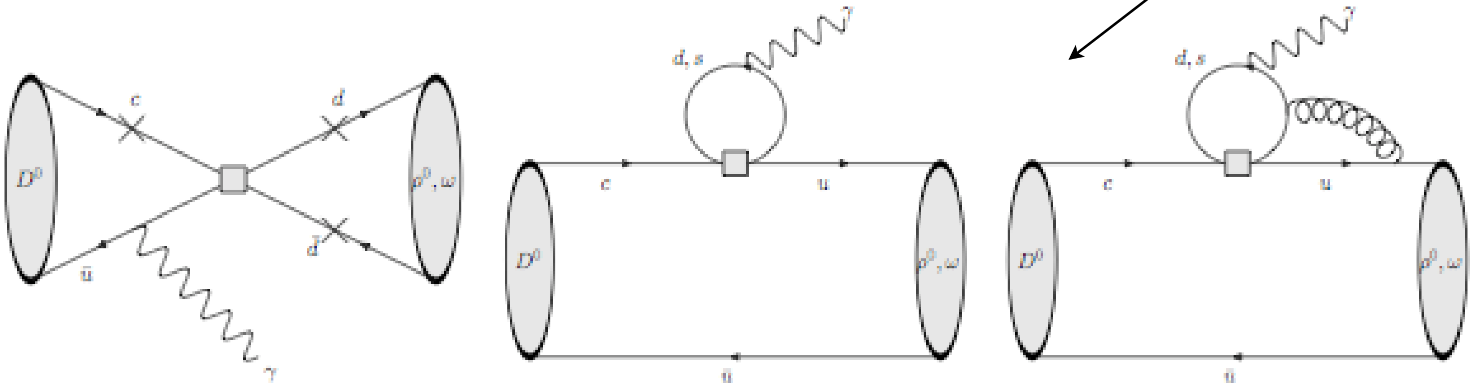

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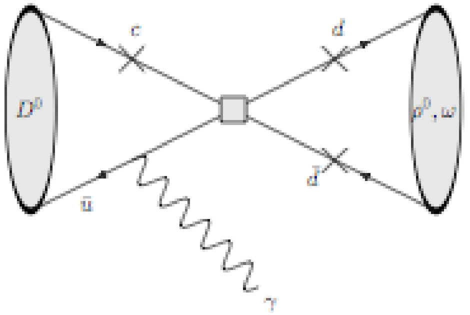

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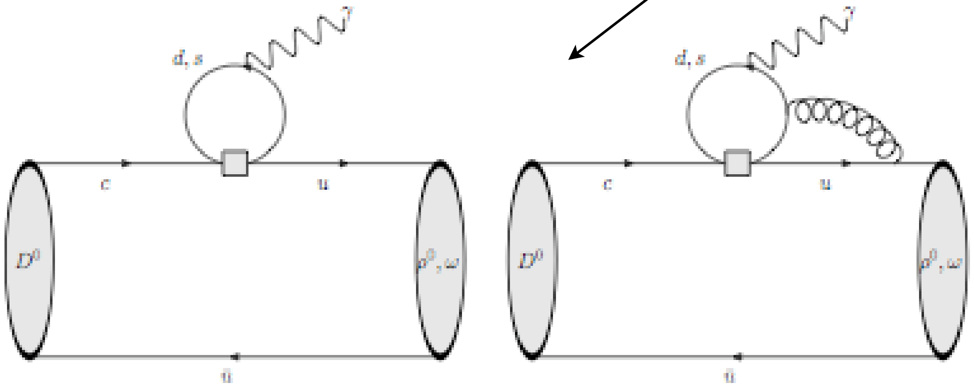

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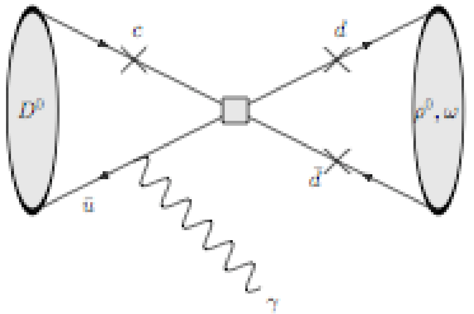
B) Computation LO α_s WA: 1) approx. saturates known rates $D^0 \Rightarrow \bar{K}^{*0}\gamma$, $D^0 \Rightarrow \phi\gamma$

2) chiral limit & no strong phase by virtue of $\partial \cdot J_{weak} = 0$

delicate colour suppressed
(enhanced NLO?)

Comment 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

END OF Charm-physics intermezzo

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 $\mathcal{C}_{p_B^2}$

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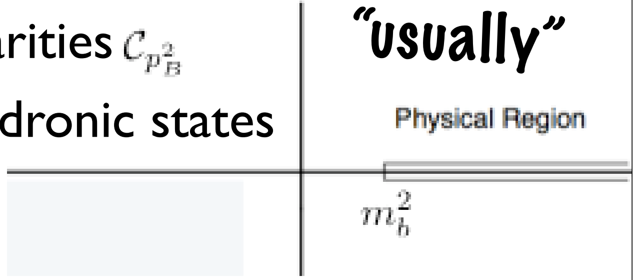

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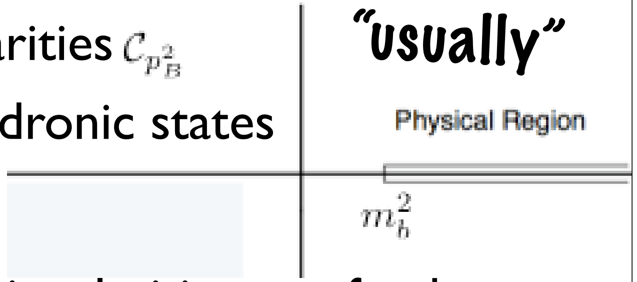

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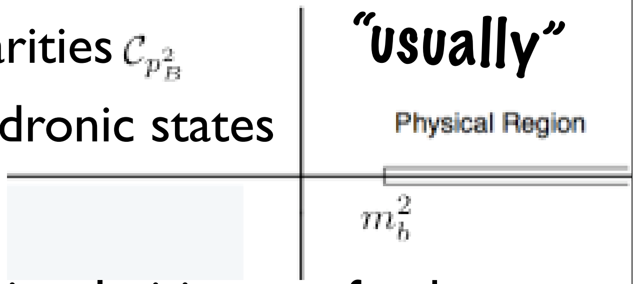

- Investigate singularities Landau equations: leading Landau singularities **s±** of a three point function appearing in the computation has got two complex solutions.

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

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

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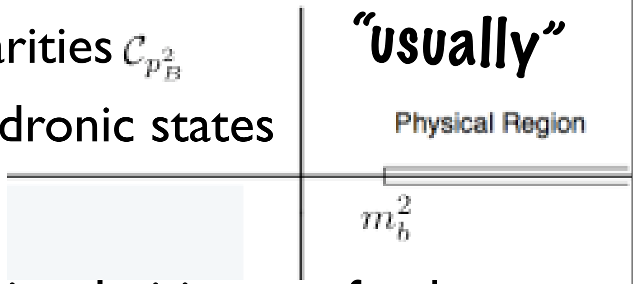
Cauchy's thm

1) Γ: path encircles singularities $\mathcal{C}_{p_B^2}$
2) Γ: chosen s.t. relates hadronic states



"usually"

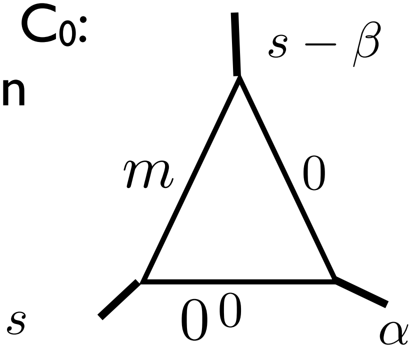
- Investigate singularities <u>Landau equations</u>: leading Landau singularities **s±** of a three point function appearing in the computation has got two <u>complex solutions</u>.

- 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 C₀:

➢ study analytic continuation



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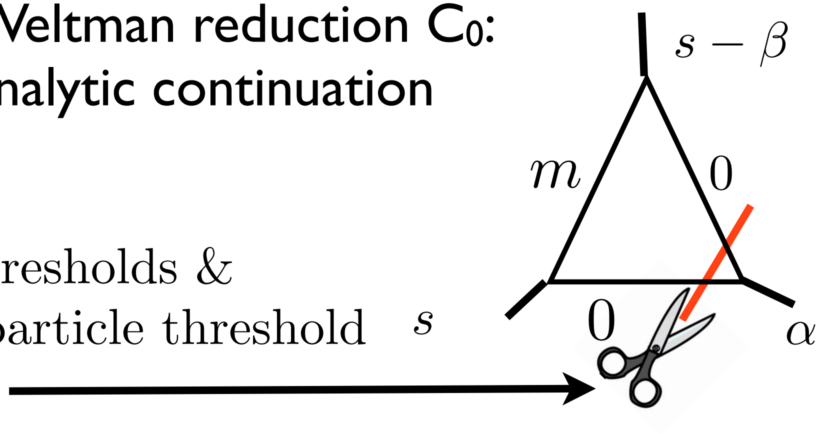

ρ/ω-thresholds &
$(\bar{s}q)_{0^\pm}$-mutiparticle threshold

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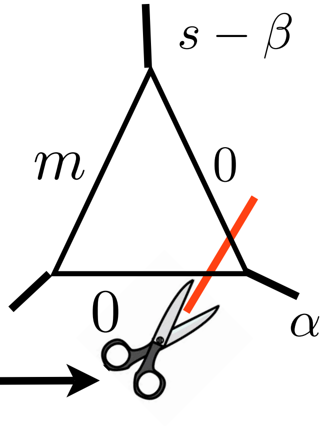

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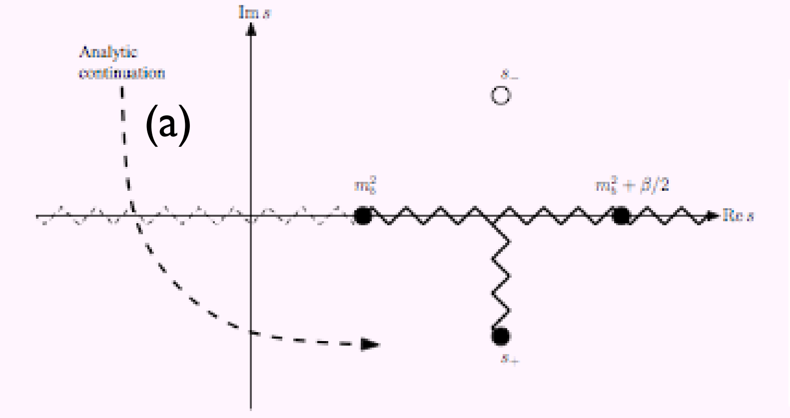

❶ **Real line:** $C_0(s) = C_0^F(s) \equiv \int_0^1 dx \int_0^{1-x} dy((1{-}x{-}y)(xs{+}y(s{-}\beta){-}m^2)....{+}xy\alpha{+}i0]^{-1}$

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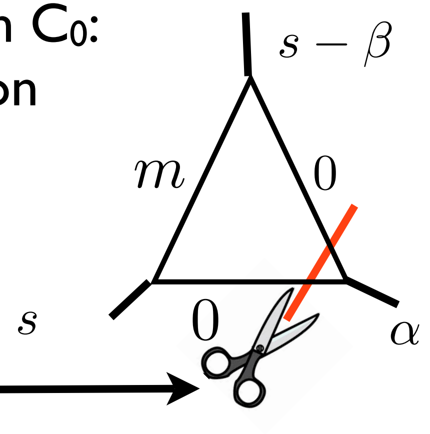

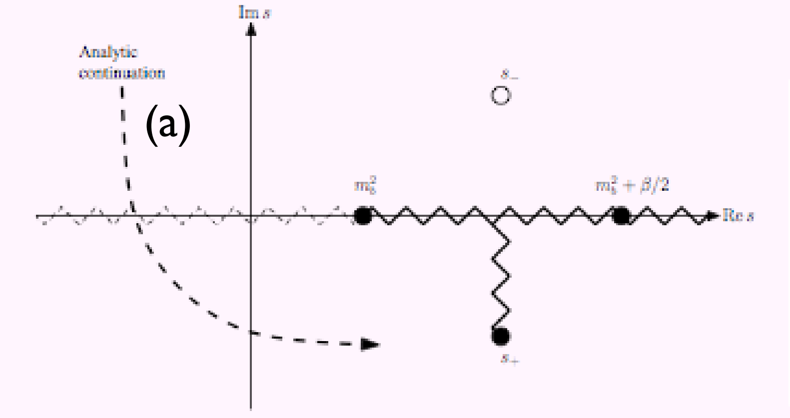

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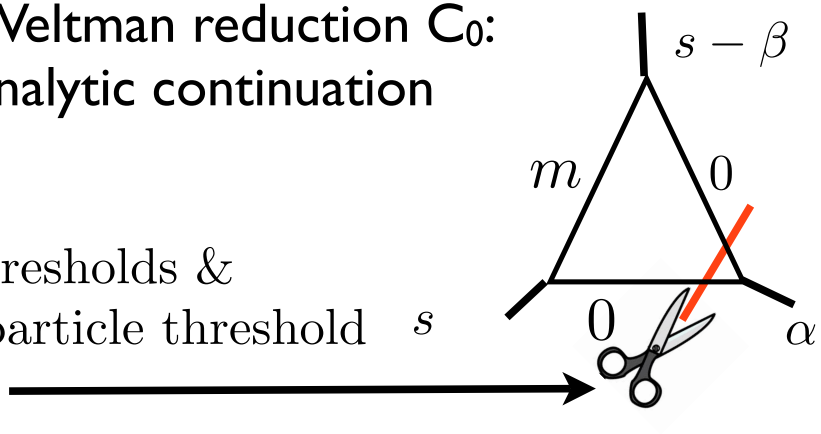

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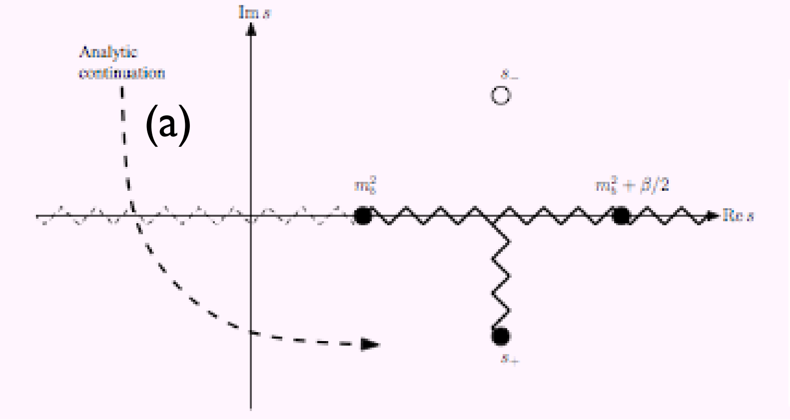

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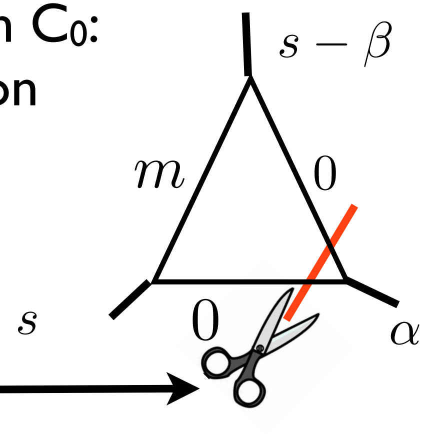

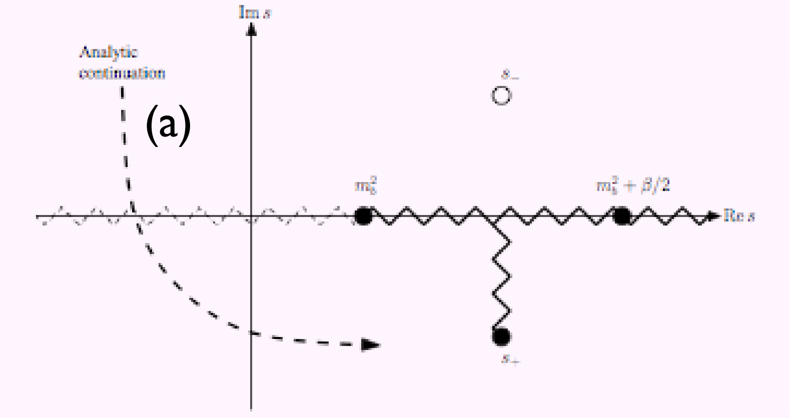

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$$Im[s] \neq 0: \quad [C_0^F(s^*)]^* = C_0^F(s) \text{ Reflection principle}$$

$$C_0(s) = \begin{cases} C_0^F(s) & \text{Im}[s] > 0 \\ C_0^F(s^*)^* + C_0^{\text{rem}}(s) & \text{Im}[s] < 0 \end{cases} \qquad C_0^{\text{rem}}(s) = 2i Im[C_0^F(s)] \quad Im[s] = 0$$

not obey

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

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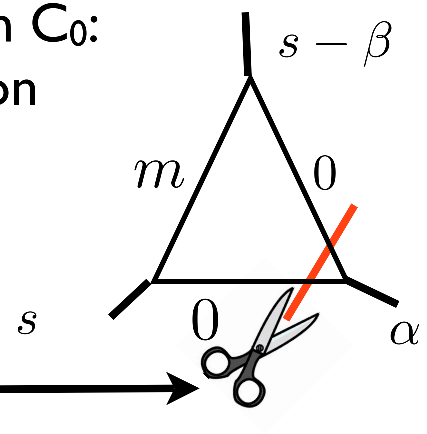

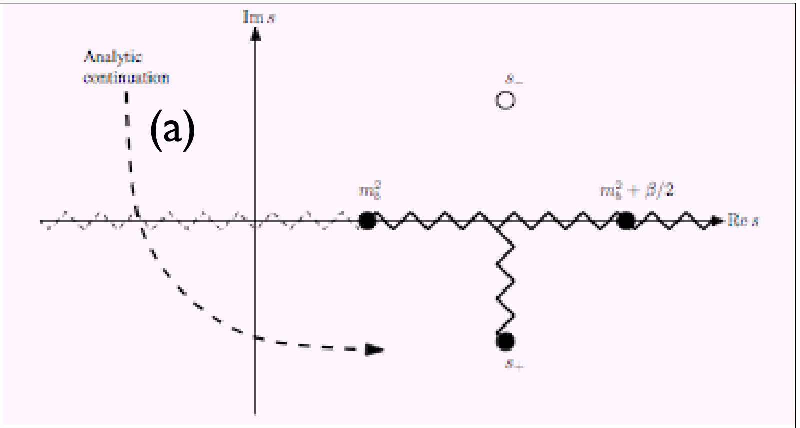

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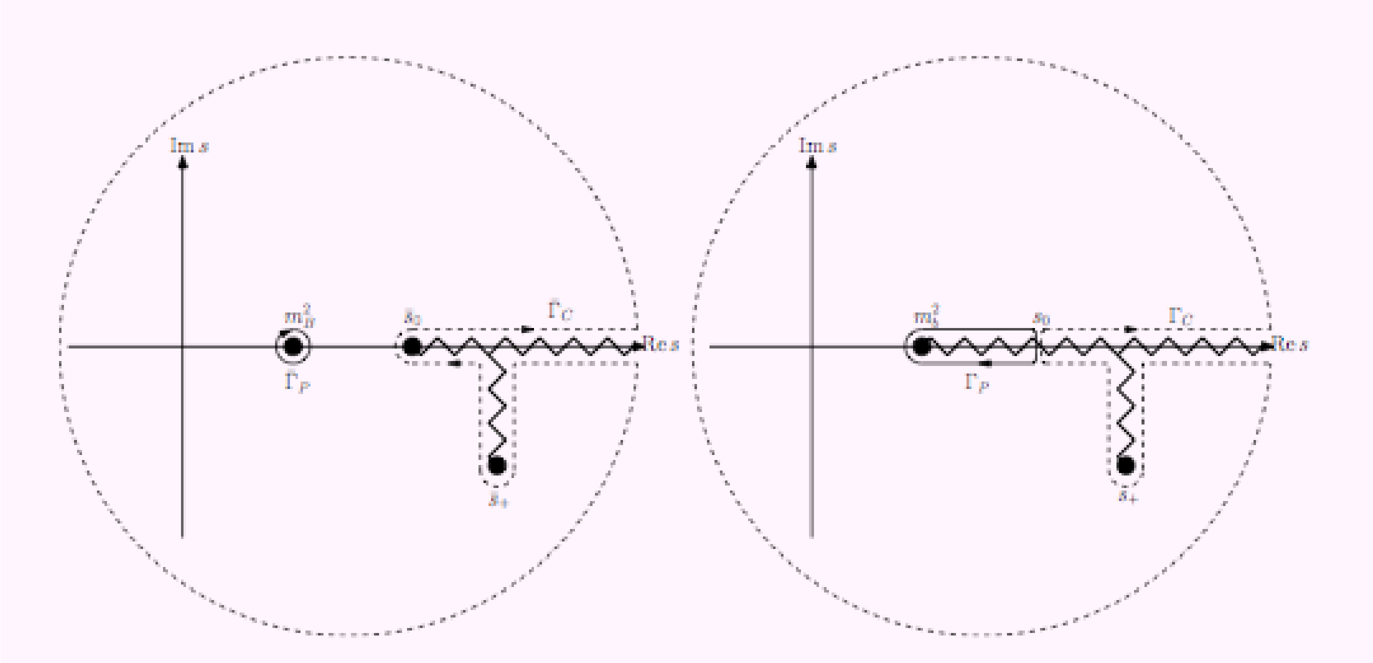
❺ Analyze C$_0^{\text{rem}}$ note **s$_+$** ∈ PRS!! ⇒ *Know how to choose path appropriately*

very briefly the analytic structure in full QCD and in partonic QCD



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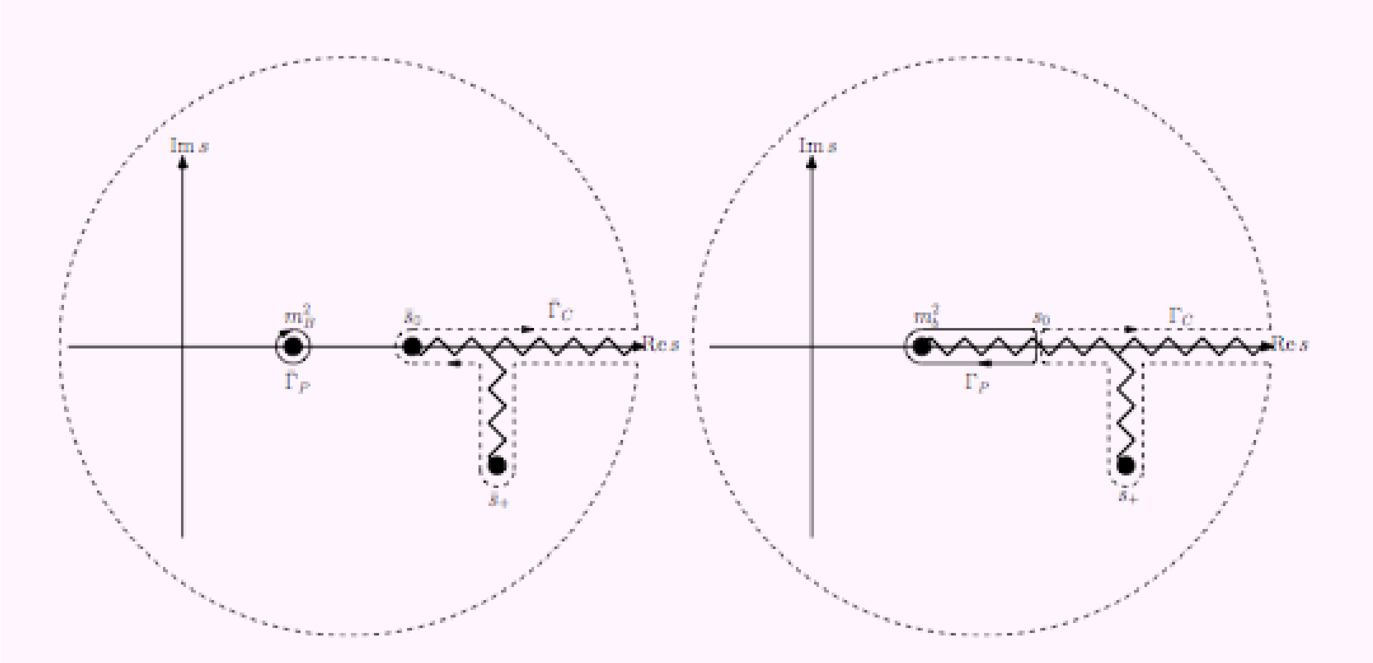

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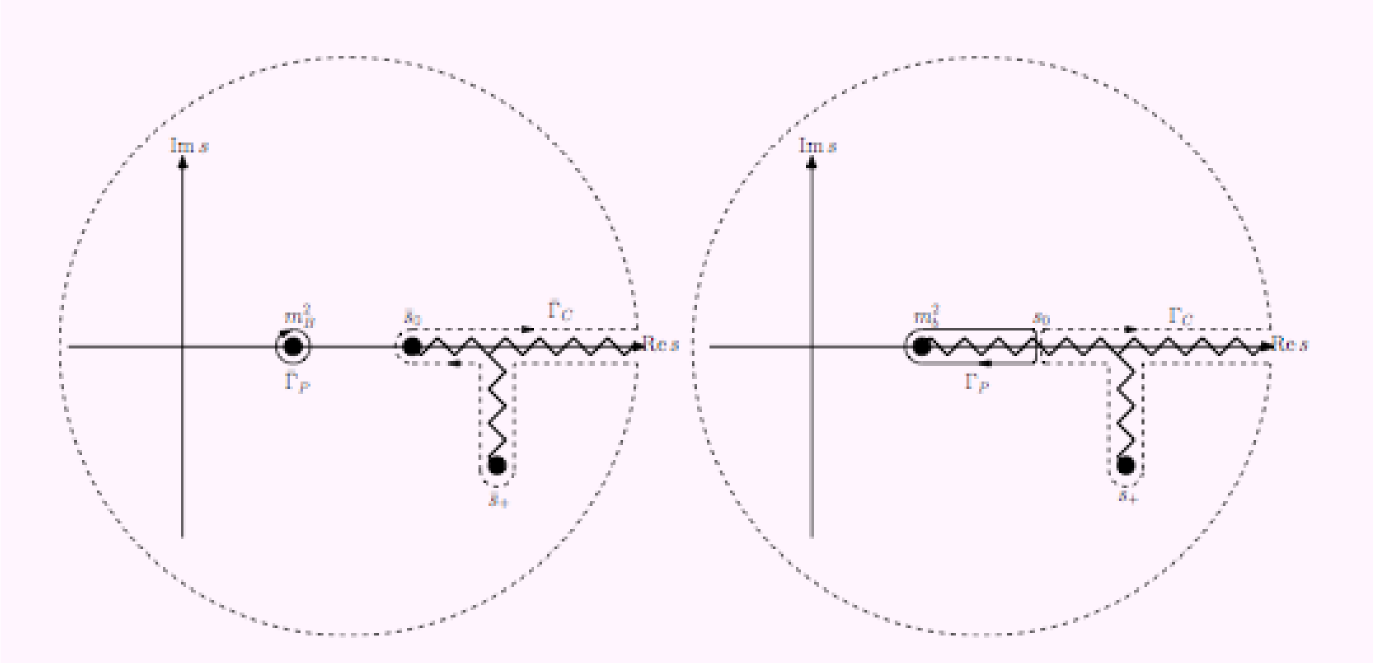
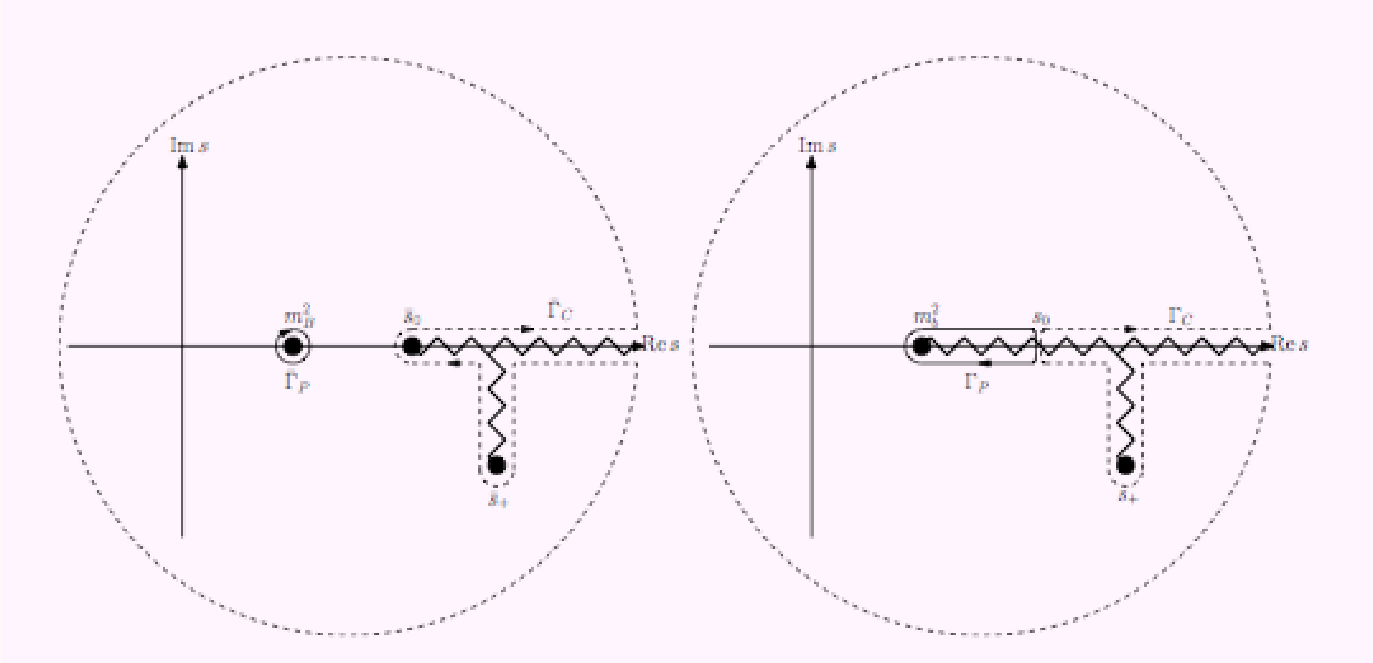


- leading Landau singularities (anomalous thresholds) are not related to insersion of a hadronic state(s).

- Essence for sum rules is that the branch cut from $\mathbf{s_-}$ is above continuum states and therefore will be exponentially Borel suppressed very briefly the analytic structure in full QCD and in partonic QCD



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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 $\quad \ldots(1 - \cancel{\gamma_5})s$

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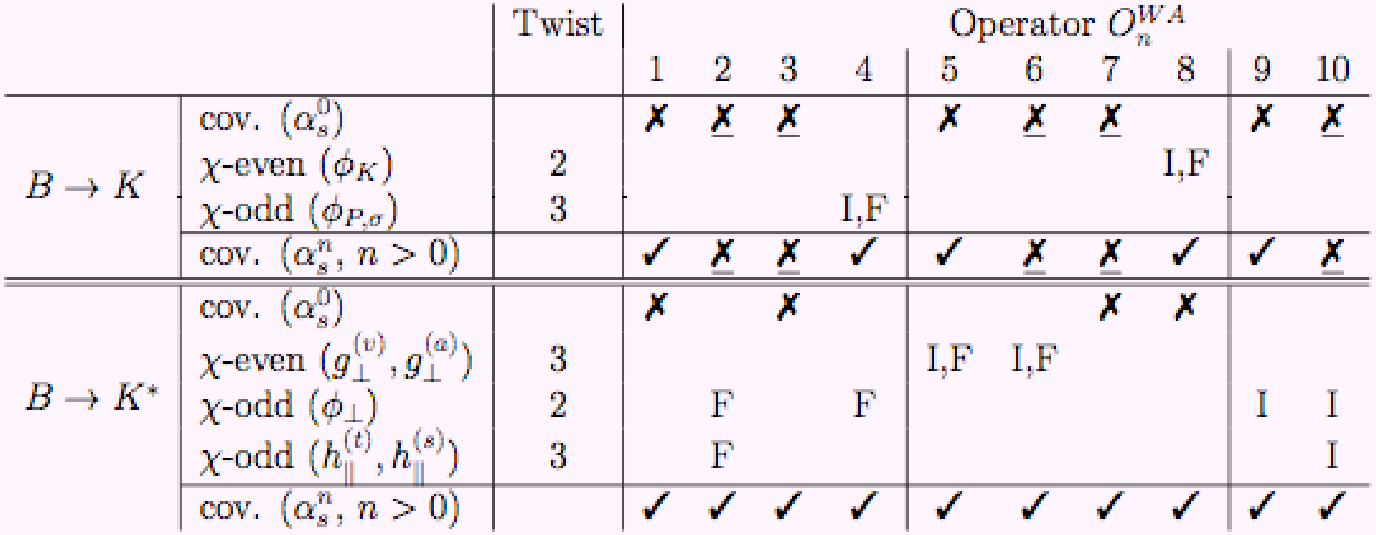
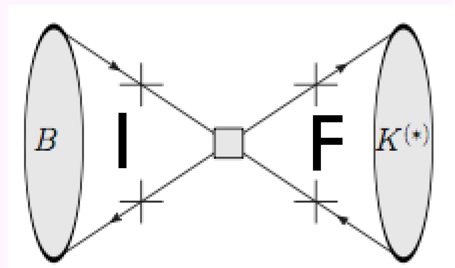
- **WA:** more stringent selection rules ground of Lorentz-invariance etc (at least at the level of the factorisable contribution)



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



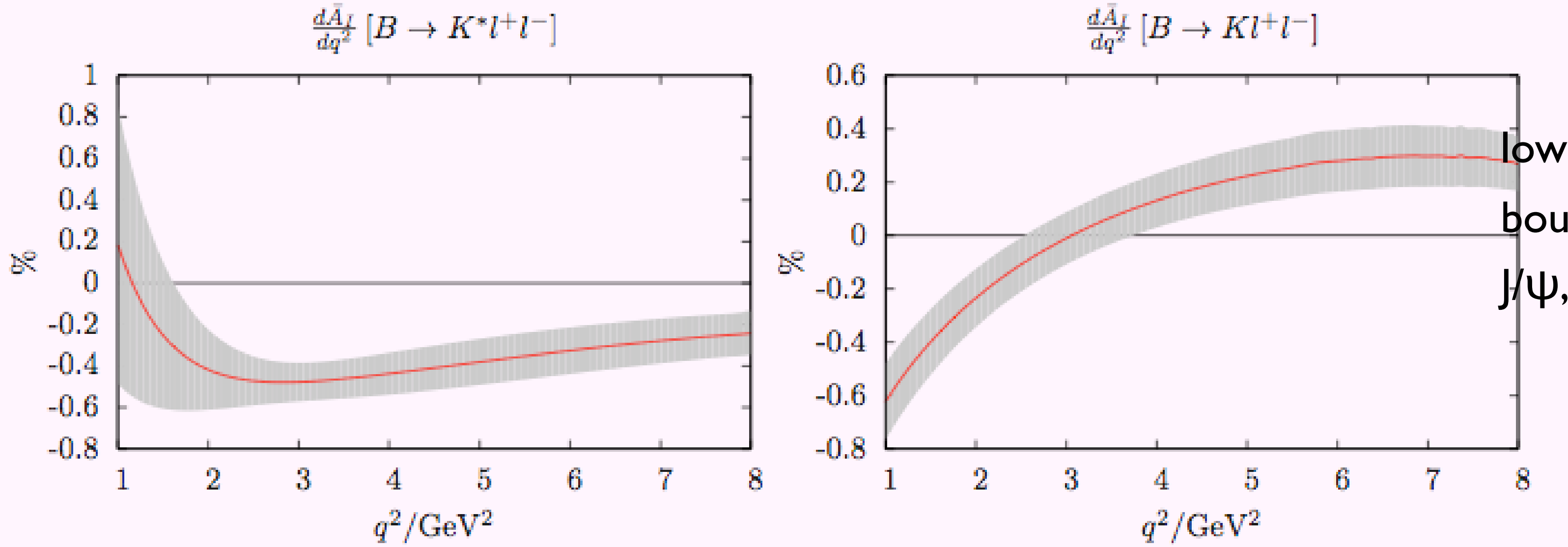
I(inital) & F(inal) state radiation

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

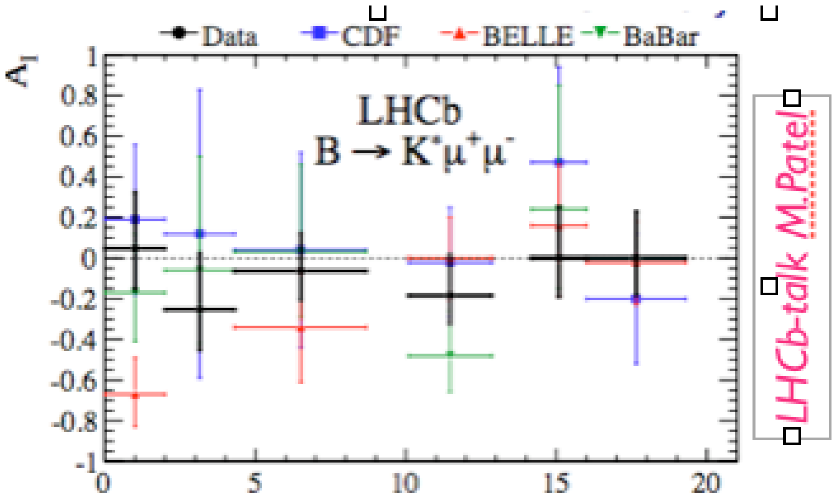
true leading twist in the SM where V-A imposes $a_6 = -a_8$; V+A not true

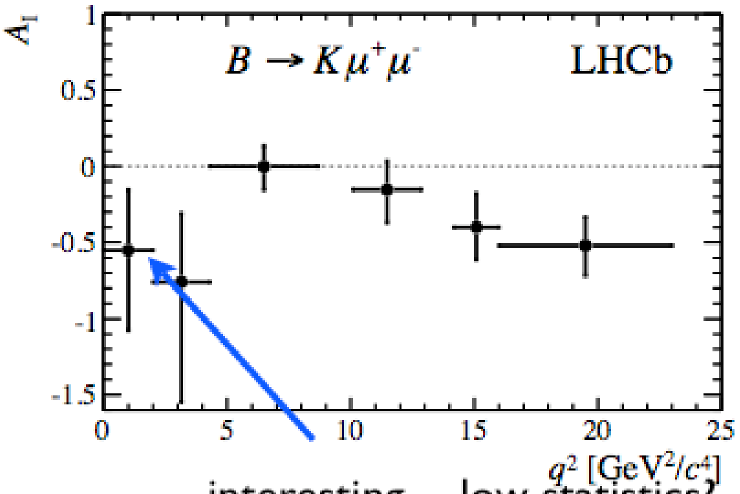
Isospin asymmetries in the SM

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



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



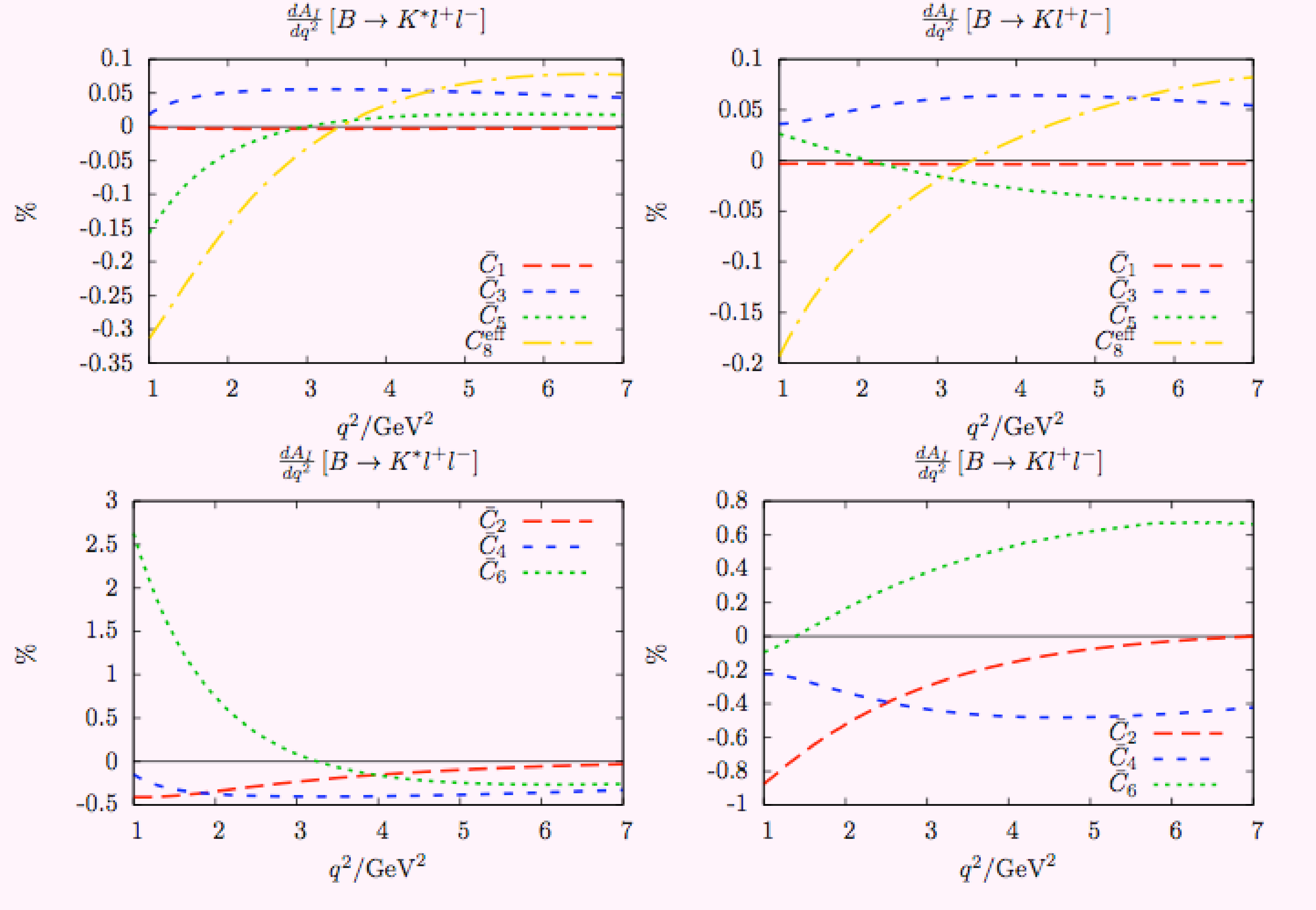


interesting -- low statistics?

- Larger for B→K$^{(*)}$γ

$$\bar{a}_I(K^*\gamma)_{\mathrm{HFAG}} = 5.2(2.6)\%\,, \qquad \bar{a}_I(K^*\gamma)_{\mathrm{LZ}} = 4.9(2.6)\%\,.$$

The breakdown in the SM....

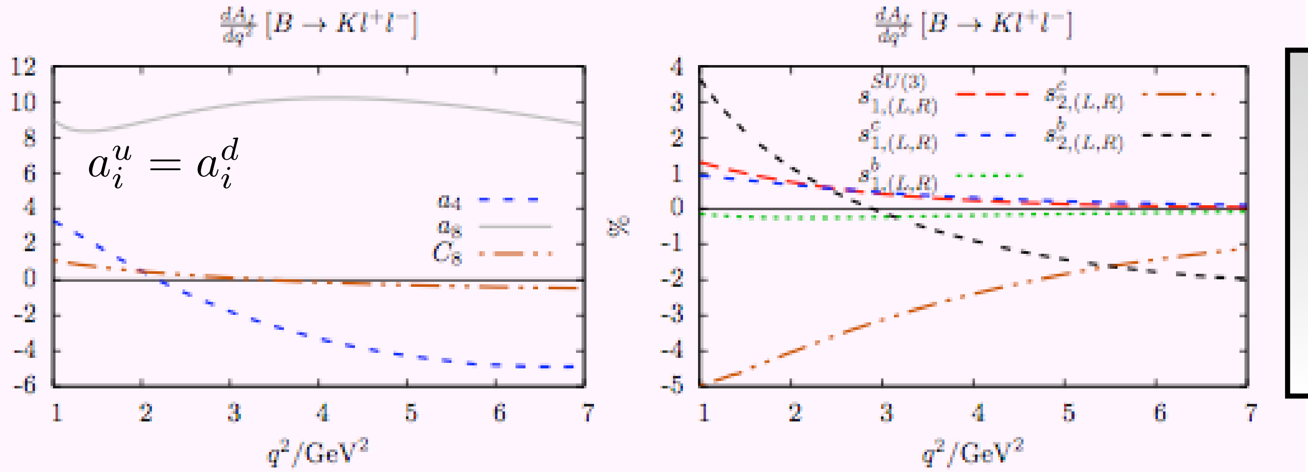


Isospin asymmetries BSM

- After selection rules:

  still <u>many</u> operators!

	$C_8^{(')}$	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)

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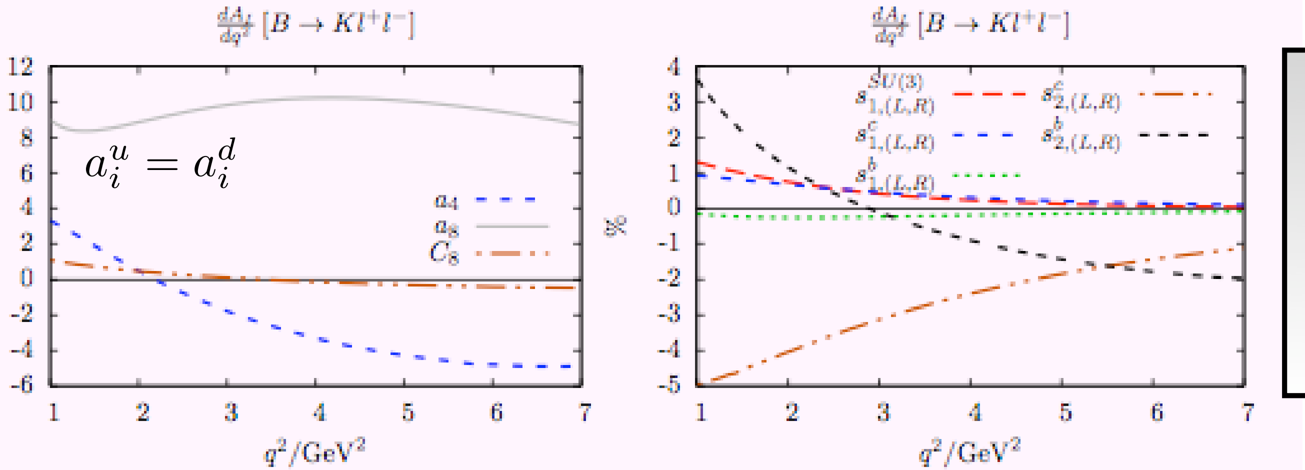

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  isospin & non-leptonic decays might marry to constrain bsqq's
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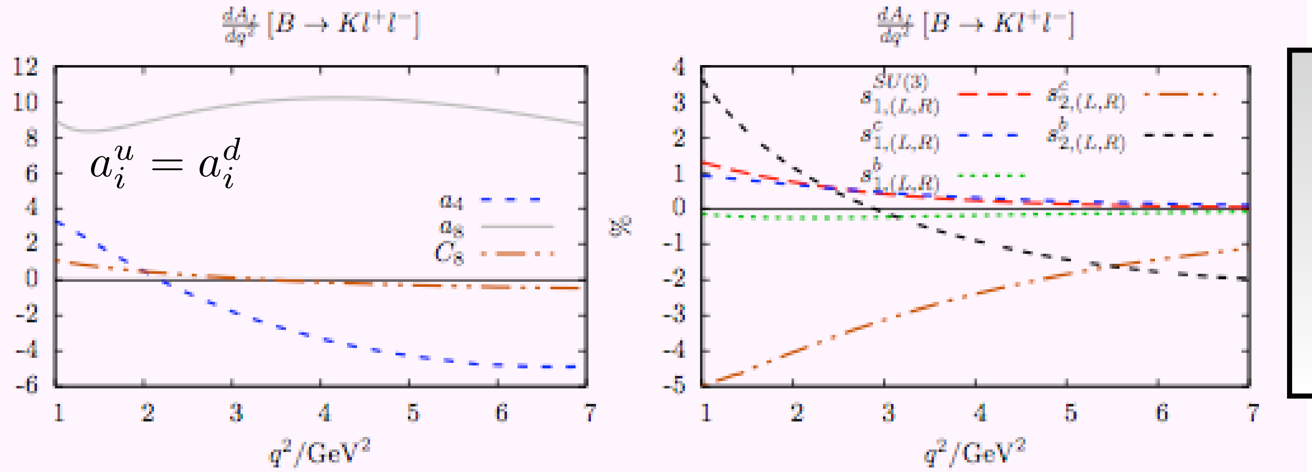

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Take $a_i \neq 0$ others zero then to be within 2σ of $a_I^{\bar{0}-}(K^*\gamma)_{\mathrm{HFAG}} = 5.2(2.6)\%$

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

indicative constraints

Comments on high q^2 (isospin)

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. $C_9^{\text{eff..}}$)

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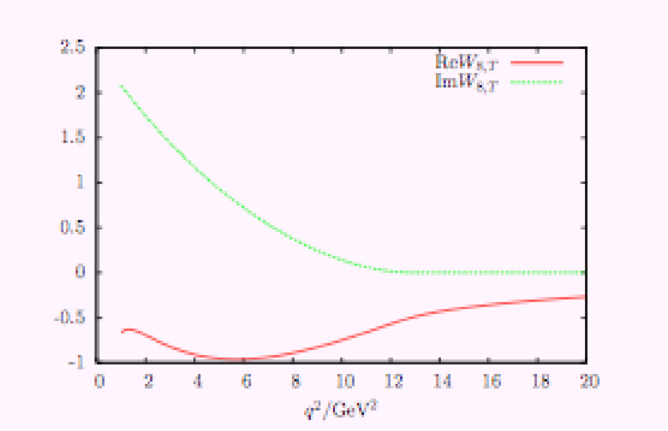

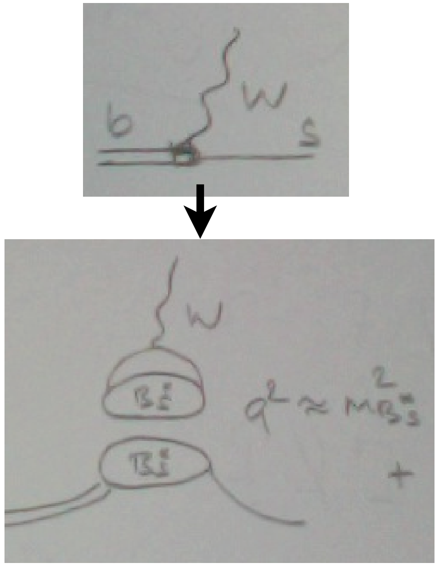

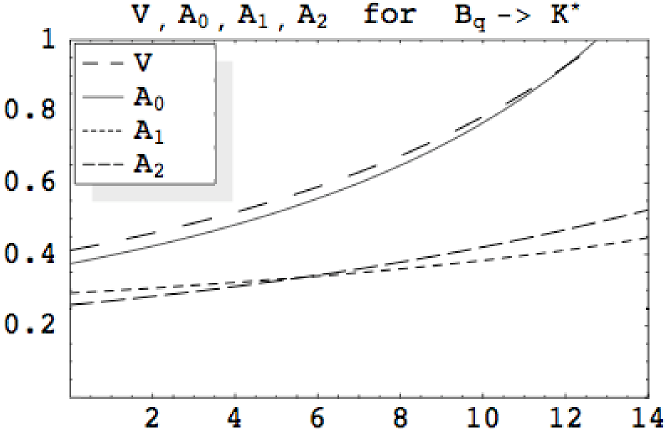

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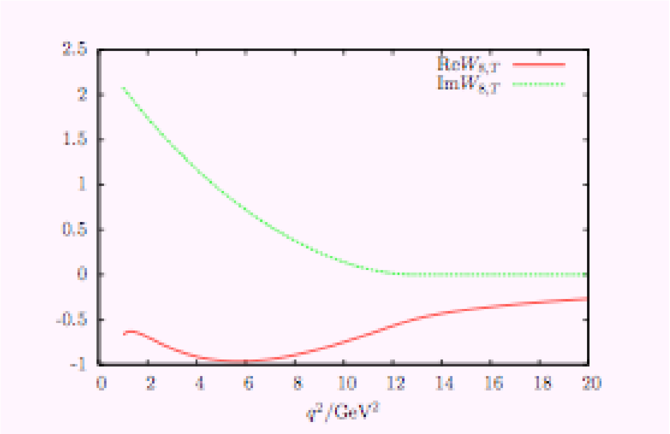

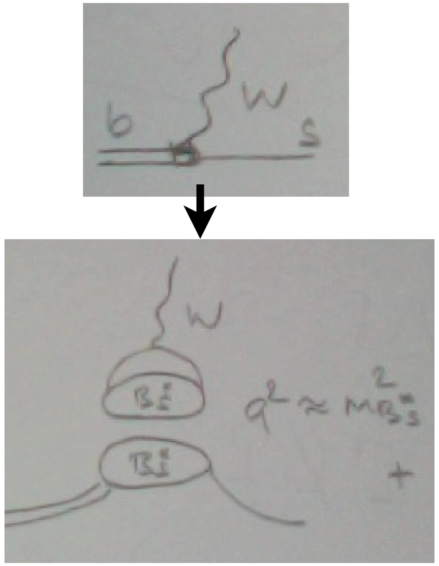

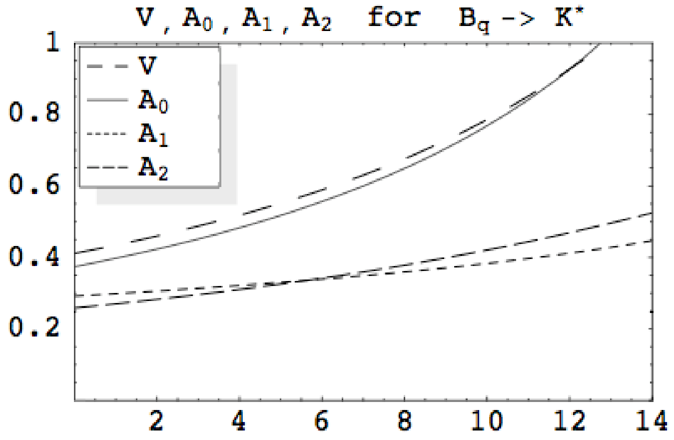

2) <u>OPE language</u>: form factors dim 3 operators
isospin violation dim 5,6

•*Beylich, Buchalla, Feldmann'11*

Comments on high q^2 --charm resonances

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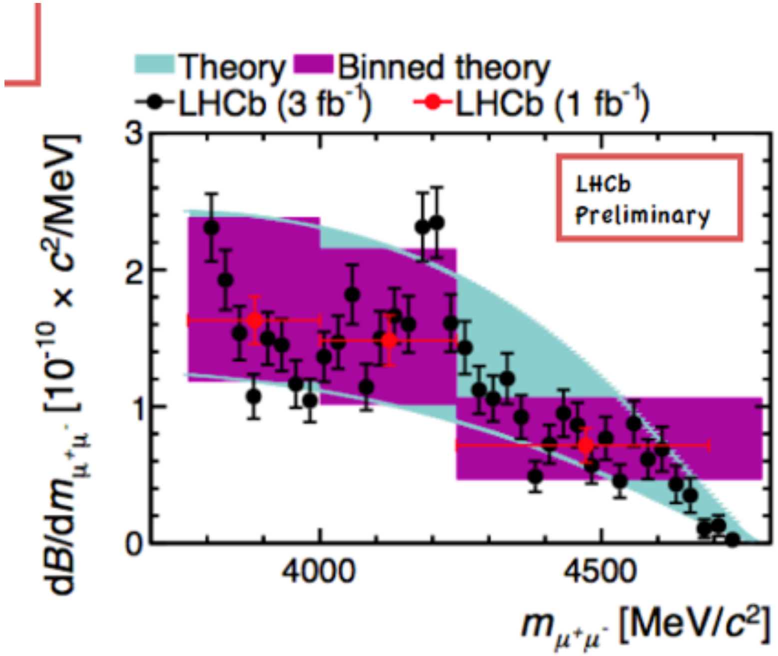

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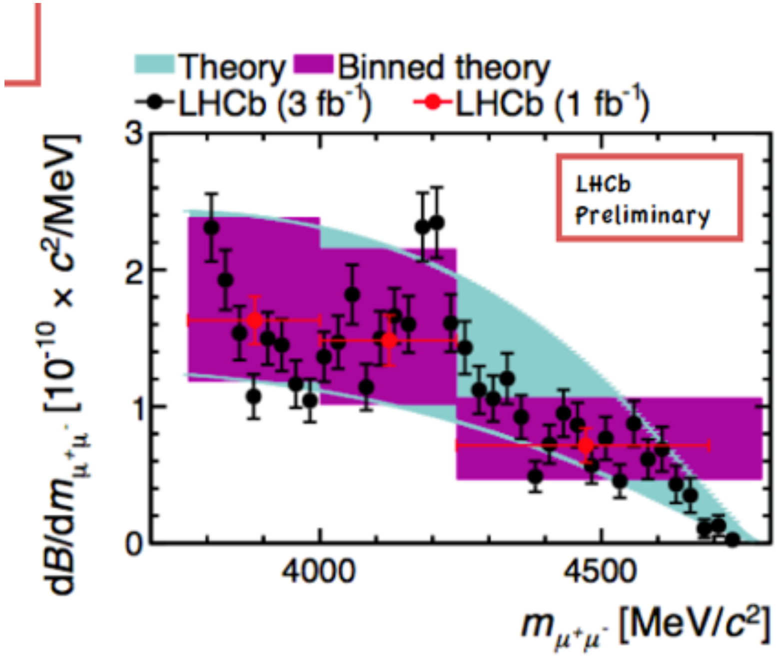

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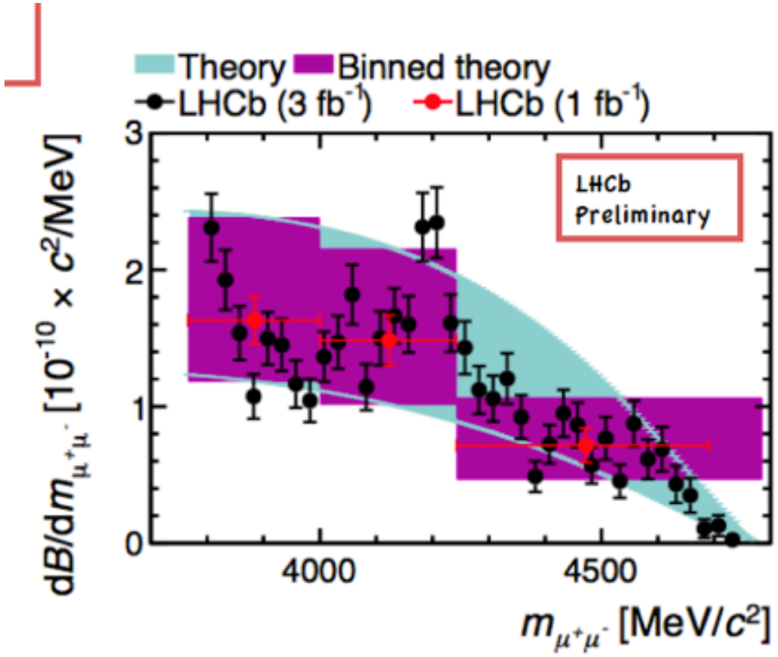
- This is why fitting form factors ratios for high q^2 from $A^{(2)}{}_T$, F_L, P_4' is ok (up to non-fac. corrections)
  Hambrock, Hiller, Schacht, RZ 1308.4379



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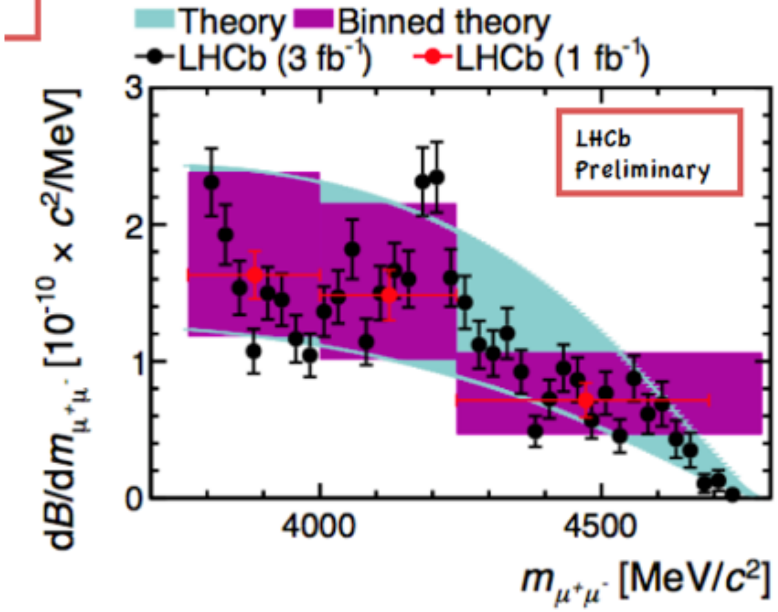
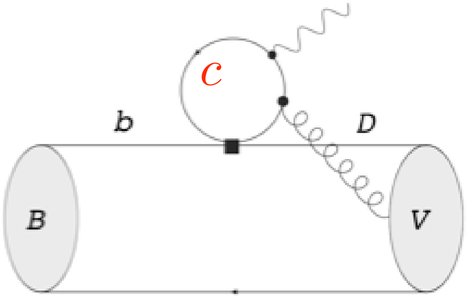
- This is why fitting form factors ratios for high q^2 from $A^{(2)}_T$, F_L, P_4' is ok (up to non-fac. corrections)
  Hambrock, Hiller, Schacht, RZ 1308.4379



- Important to estimate (high q2) non-factorizable contributions, which are helicity dependent e.g.



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- $D \to Vll$ charm physics has potential -- need charged modes to check theory

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