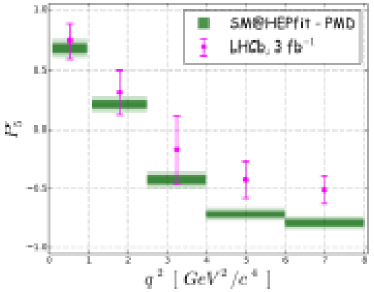
Charm-loop effects



Marco Ciuchini

INFN ROMA TRE

- charm loops in B decays: a short history
- charm loops in semileptonic B decays
  - Theoretical estimates
  - Phenomenological approach

Towards the Ultimate Precision in Flavo

University of Warwick, 16-18 April 2018

Pomeriggio in ricordo di Enrico

Roma 23/5/2023

Charm loop in the effective theory

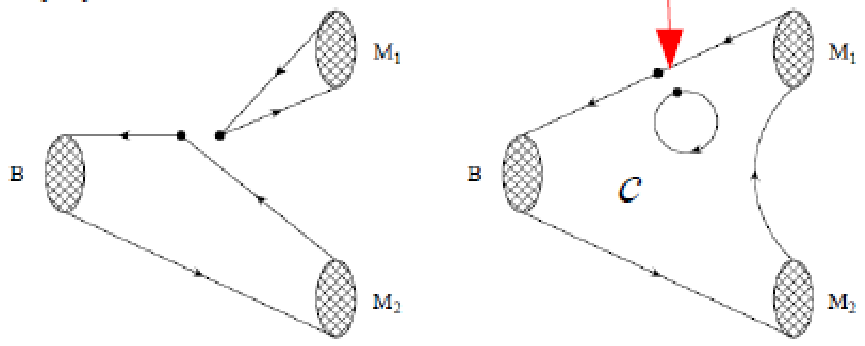
$$\mathcal{H}_{\text{eff}}^{\text{had}}(\Delta B = 1) = \frac{4G_F}{\sqrt{2}} \left\{ \lambda_u \left[C_1 \left(Q_1^u - Q_1^c \right) + C_2 \left(Q_2^u - Q_2^c \right) \right] - \lambda_t \left[C_1 Q_1^c + C_2 Q_2^c + \sum_{i=3}^{6} C_i Q_i + C_8 Q_{8g} \right] \right\}$$

top loops in the SM give rise to penguin operators

- non-perturbative matrix elements of local operators
- α_s suppressed matching conditions, small Wilson coefficients

charm (and up) loops appear as Wick contractions in the MEs

- dominated by the insertion of $Q_{1,2}$, namely O(1) Wilson coefficients
- easily produce intermediate real states, i.e. rescattering, non-local contributions, strong phases, etc.



Non-leptonic $b \to s$ decays: "charming" penguins

Colangelo, Nardulli, Paver, Riazuddin, Z.Phys. C45 (1990) 575
MC, Franco, Martinelli, Pierini, Silvestrini, hep-ph/9703353

Charm penguin is doubly Cabibbo-enhanced in $b \to s\bar{u}u$ transitions

- Threatened factorization of non-leptonic B decays in the infinite mass limit → tamed

  Beneke, Buchalla, Neubert, Sachrajda, hep-ph/0411171
  see also Bauer, Pirjol, Rothstein, Stewart, hep-ph/0401188

- Questioned the extraction of the CKM angle γ from $B \to K\pi$ decays (but helped to account for the $K\pi$ and $\pi\pi$ BRs and CP asymmetries)
- Challenged claims of NP sensitivity of various non-leptonic B decays

  → still to be tamed

  MC, Franco, Martinelli, Pierini, Silvestrini, hep-ph/0208048
  Beneke, Buchalla, Neubert, Sachrajda, hep-ph/0104110
  Fleischer, Matias, hep-ph/9906274, ...

Charming Penguins Saga

Marco Ciuchini

- **Episode I: *The penguin menace*** (1997) NPB501(1997)271
  - Lattice-inspired Wick contraction parameterization (*CE*, *DE*, *CP*, *DP*, ...)
  - Non-factorizable Cabibbo-enhanced contributions to $B \to K\pi$ decays
- **Episode II: *The neat hack of the clones*** (1998) NPB569(2000)3
  - Buras-Silvestrini RG-improved parameterization (E_1, E_2, P_1, P_2, ...)
- **Episode IV: *A new hope*** (1999) PRL83(1999)1914 (PRL74(1995)4388)
  - QCD (or pQCD) factorization holds in the $m_b \to \infty$ limit
- **Episode V: *Charming penguins strike back*** (2001) PLB515(2001)33
  - Charming penguins reinterpreted as $1/m_b$ corrections to factorization
- **Episode VI: *The return of factorization?*** (2002)
  - Are power-suppressed terms computable using factorization?

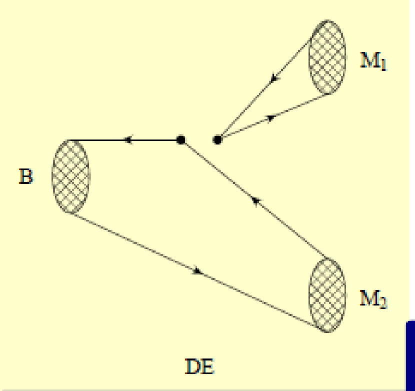
"Charming penguins" in $B \to K\pi$: Factorizable and non-factorizable contributions

It is instructive to start with an explicit example:

$$A(B_d \to K^+ \pi^-) = -V_{us} V_{ub}^* \times \{\boldsymbol{E_1}(s, u, u, B_d, K^+, \pi^-) - \boldsymbol{P_1^{GIM}}(s, u, B_d, K^+, \pi^-)\} + V_{ts} V_{tb}^* \times \boldsymbol{P_1}(s, u, B_d, K^+, \pi^-)$$

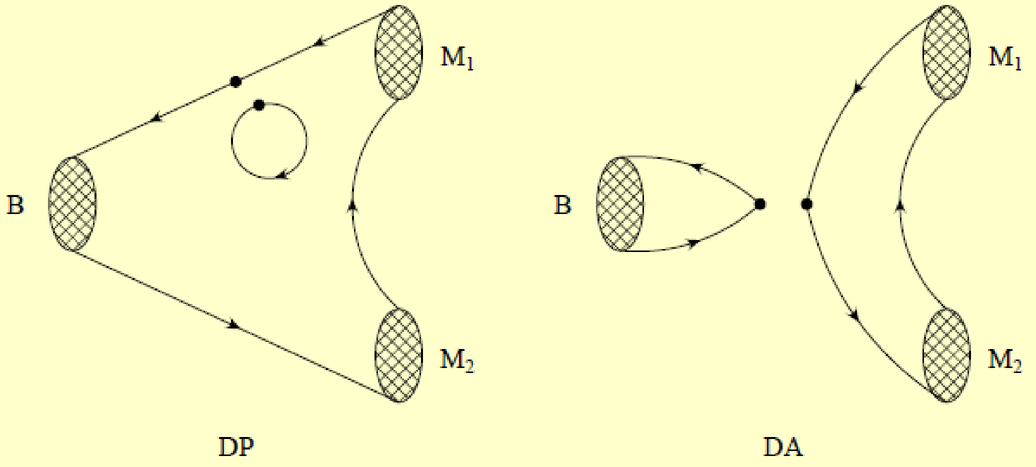
Called ***charming and GIM penguins*** in *MC et al.*, NPB501 (1997) 27
already discussed in *P. Colangelo et al.*, Z. Phys. C45 (1990) 575
see also *C. Isola et al.*, PRD64:014029,2001

N.B.: $V_{us} V_{ub}^* \sim \lambda^4$, $V_{ts} V_{tb}^* \sim \lambda^2$



Emission diagrams fully computed with QCD factorization

$$\boldsymbol{E_1}(s, u, u, B_d, K^+, \pi^-) \equiv C_1 \langle Q_1^u \rangle_{\mathbf{DE}} + C_2 \langle Q_2^u \rangle_{\mathbf{CE}} = a_1(K\pi) A_{\pi K}$$



The ***charming penguin*** parameter is split into a *factorizable contribution*, computed with QCD factorization, and a *genuine power-suppressed term* (denoted with a tilde), to be determined by a fit to the data

$$\boldsymbol{P}_1(s,u,B_d,K^+,\pi^-) \equiv C_1\langle Q_1^c\rangle_{\rm CP} + C_2\langle Q_2^c\rangle_{\rm DP} + \sum C_{2i-1}\langle Q_{2i-1}\rangle_{\rm CE} + C_{2i}\langle Q_{2i}\rangle_{\rm DE} + \sum C_i(\langle Q_i\rangle_{\rm CP} + \langle Q_i\rangle_{\rm DP}) + \sum C_{2i-1}\langle Q_{2i-1}\rangle_{\rm CA} + C_{2i}\langle Q_{2i}\rangle_{\rm DA} = a_4^c(K\pi)\,A_{\pi K} + \widetilde{\boldsymbol{P}}_1(s,u,B_d,K^+,\pi^-)$$

Similarly, the ***GIM penguin*** parameter can be split as:

$$\boldsymbol{P}_1^{GIM}(s,u,B_d,K^+,\pi^-) \equiv C_1(\langle Q_1^c\rangle_{\rm CP} - \langle Q_1^u\rangle_{\rm CP}) + C_2(\langle Q_2^c\rangle_{\rm DP} - \langle Q_2^u\rangle_{\rm DP}) = (a_4^c(K\pi) - a_4^u(K\pi))\,A_{\pi K} + \widetilde{\boldsymbol{P}}_1^{GIM}(s,u,B_d,K^+,\pi^-)$$

Experimental measurement (Moriond '02)

γ from UTA + charming penguins

Fitted assuming flavor SU(2)

$BR(K^0\pi^0) \times 10^6$	$BR(K^+\pi^0) \times 10^6$
8.8 ± 2.2	11.5 ± 1.5
$8.7 \pm 0.7 +0.1 -0.2$	$10.6 \pm 0.9 +0.1 -0.2$
$BR(K^0\pi^+) \times 10^6$	$BR(K^+\pi^-) \times 10^6$
18.5 ± 2.2	18.6 ± 1.1
$19.8 \pm 1.4 +0.2 -0.0$	$18.5 \pm 1.0 -0.1 +0.1$

Predicted assuming flavor SU(3)

$BR(\pi^+\pi^-) \times 10^6$	$BR(\pi^+\pi^0) \times 10^6$
5.2 ± 0.6	5.3 ± 1.7
$9.3 \pm 3.4 +0.2 -0.3$	$5.1 \pm 2.0 +0.1 -0.0$
$BR(\pi^0\pi^0) \times 10^6$	
–	
$0.37 \pm 0.08 -0.0 +0.1$	

Main results

- agreement in $B \to K\pi$ channels
- predicted $BR(B_d \to \pi^+\pi^-)$ too large

CP asymmetries (within large errors):

$A(K^0\pi^0) \sim A(K^0\pi^-) \sim 0$, $A(\pi^+\pi^-) \sim \pm 0.4$

$A(K^-\pi^+) \sim A(K^-\pi^0) \sim \pm 0.15$

$$\tilde{P}_1 \equiv G_F f_\pi F_\pi(0) g \, |B_1| \, e^{i\phi_1}$$

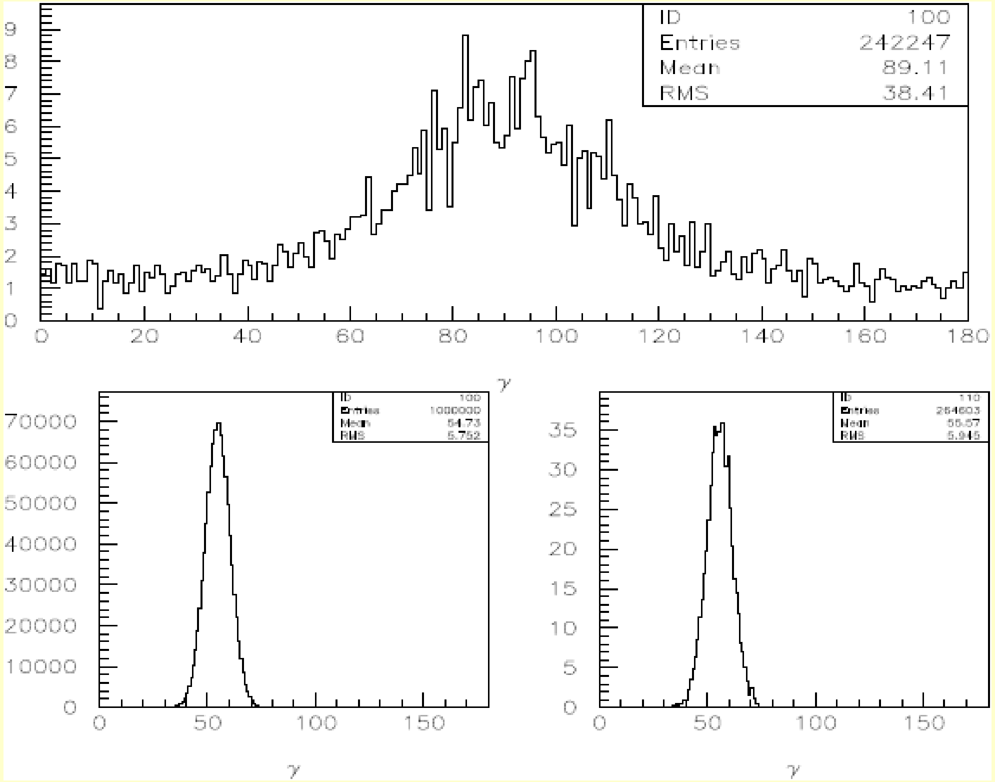
$$|B_1| = 0.12 \pm 0.02 \qquad \phi_1 = (185 \pm 73 \pm 5)^\circ$$

Natural size of Λ/m_b corrections $\sim$ 0.1-0.2

Information on γ are hindered by uncertainties on the phenomenological hadronic parameters

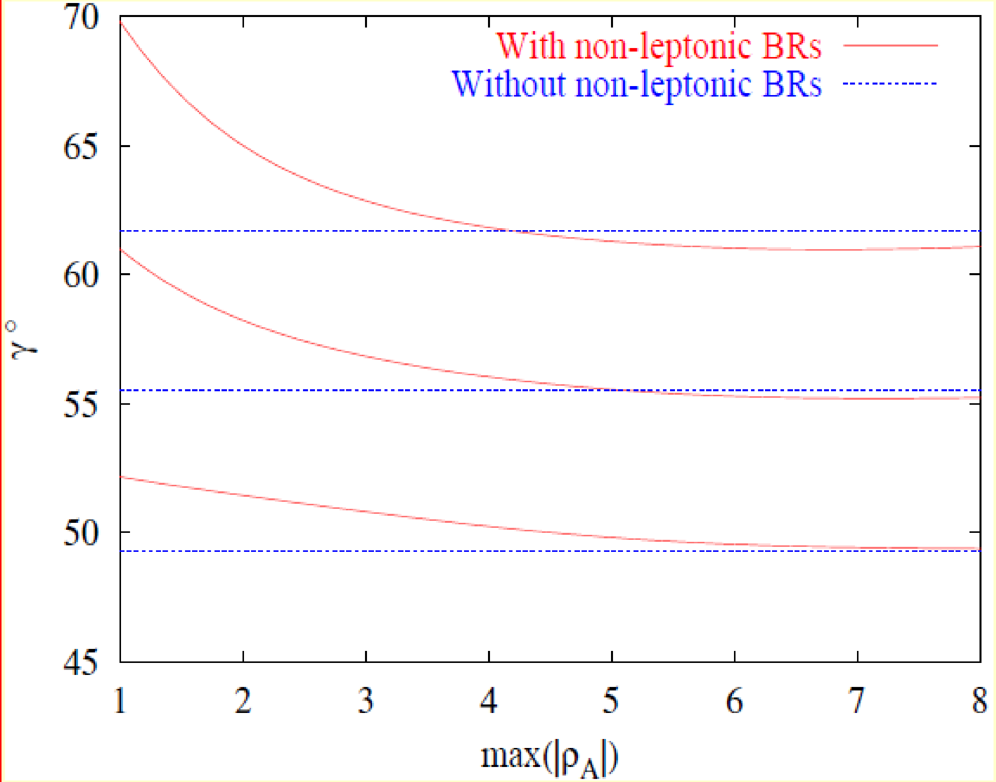
Fitting ***Kπ,ππ*** **with** ***charming penguins*** **+ γ :**

- ✗ poor determination of γ (preferred γ ~ 90°)
- ✗ negligible effect on the penguin parameters
- ✗ negligible effect on the UTA fit



Using BBNS approach to ***1/m$_b$*** **terms:**

- ✗ $|\rho_A| < 1$: γ larger than the UTA fit
- ✗ $|\rho_A| \geq 3$: γ unchanged (data prefer $|\rho_A| \sim 3$)



The "charming penguins" saga continues...

"Charming penguins" are a tool to study the effect of power-suppressed corrections based on:

- a complete parameterization
- dynamical assumptions to be checked on data

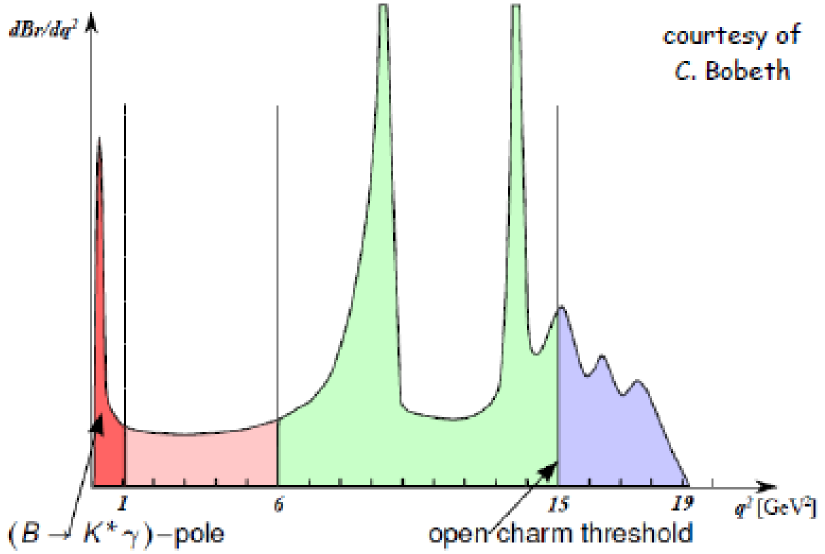
useful to check more specific approaches

Charming penguin parameter has been successfully extracted from $B \to K\pi$ data. More data are needed to check the consistency of the phenomenological picture and make predictions. For example:

- investigate further Λ/m_b terms in $B \to \pi\pi$ modes
- look for charming penguins effects in $B \to PV$ with transversely polarized vectors (vanishing in the factorization limit)

In any case: ***use the data, Luke!***

Charm loop in B→K*ℓℓ

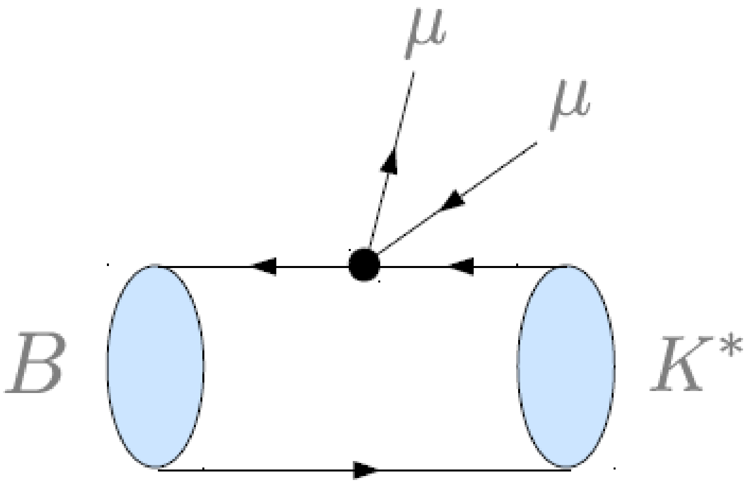


$$\mathcal{H}_{\rm eff}^{b\to s\ell\ell} = \mathcal{H}_{\rm eff}^{sl+\gamma} + \mathcal{H}_{\rm eff}^{\rm had}$$

$$\mathcal{H}_{\rm eff}^{sl+\gamma} = -\frac{4G_F}{\sqrt{2}}\lambda_t \left(C_7 Q_{7\gamma} + C_9 Q_{9V} + C_{10} Q_{10A}\right)$$

$$Q_{7\gamma} = \frac{e}{16\pi^2} m_b \bar{s}_L \sigma_{\mu\nu} F^{\mu\nu} b_R\,,$$
$$Q_{9V} = \frac{\alpha_e}{4\pi}(\bar{s}_L\gamma_\mu b_L)(\bar{\ell}\gamma^\mu \ell)\,,$$
$$Q_{10A} = \frac{\alpha_e}{4\pi}(\bar{s}_L\gamma_\mu b_L)(\bar{\ell}\gamma^\mu\gamma^5 \ell)\,.$$

Semileptonic decays have simpler hadronic MEs



Hadronic matrix elements of quark currents: **FORM FACTORS***

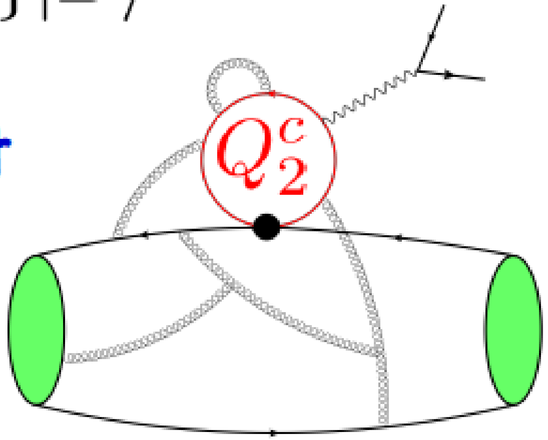
*not discussed here

BUT 4-quark operators also contribute to the ME. In the helicity amplitude formalism, they appear in

Jäger, Camalich, arXiv:1212.2263; Melikhov, Nikitin, Simula, hep-ph/9807464

$$\mathrm{H}_V{}^\lambda = \frac{4iG_F m_B}{\sqrt{2}} \frac{e^2}{16\pi^2} \lambda_t \left\{ C_9^{\rm eff} \tilde{V}_{L\lambda} + \frac{m_B^2}{q^2} \left[\frac{2m_b}{m_B} C_7^{\rm eff} \tilde{T}_{L\lambda} - 16\pi^2 h_\lambda \right] \right\}$$

$$h_\lambda(q^2) = \frac{\epsilon^*_\mu(\lambda)}{m_B^2} \int d^4x e^{iqx} \langle \bar{K}^* | T\{ j^\mu_{\rm em}(x) \mathcal{H}^{\rm had}_{\rm eff}(0)\} | \bar{B} \rangle$$



- At small values of $q^2 = m_{\ell\ell}^2$, the H^{had} matrix element factorizes in the infinite mass limit Beneke, Feldmann, Seidel, hep-ph/0106067
- Yet the "charming penguin" issues are present:
  - → how large is the genuine power-suppressed contribution?
  - → how much does it increase approaching the resonant region where factorization badly fails?

Taming the charm-loop monster…

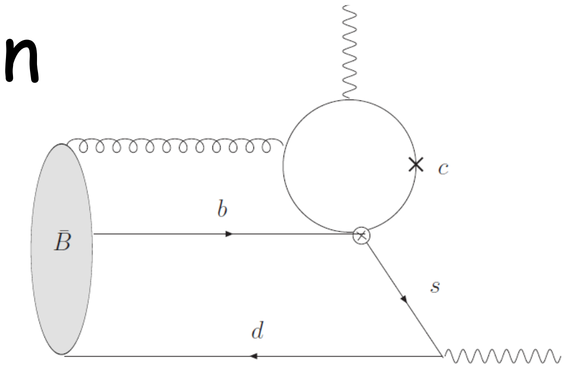
An estimate in 2 steps:

Khodjamirian, Mannel, Pivovarov, Wang, arXiv:1006.4945

1. at $q^2 \ll 4m_c^2$ the charm loop is dominated by light-cone dynamics

$$\left[\mathcal{H}_\mu^{(B\to K^{(*)})}(p,q)\right]_{nonfact} = 2C_1\langle K^{(*)}(p)|\widetilde{\mathcal{O}}_\mu(q)|B(p+q)\rangle\,, \qquad \widetilde{\mathcal{O}}_\mu(q) = \int d\omega\, I_{\mu\rho\alpha\beta}(q,\omega)\bar{s}_L\gamma^\rho\delta[\omega - \frac{(in_+\mathcal{D})}{2}]\widetilde{G}_{\alpha\beta}b_L$$

representing the 1^{st} subleading term of an expansion in $\Lambda^2/(4m_c^2-q^2)$ (single soft-gluon approximation)



step 1 ME is computed using light-cone sum rules

estimate of the hadronic contribution at small $q^2 <$ few GeV^2

<u>but</u> large uncertainties (100%? more?), no hard gluons, no phases, no scale and scheme dependence, ...

step 2 extend the previous result to larger q^2 using a dispersion relation, modelling the spectral function (2 physical $\Psi^{(')}$ + effective poles)

<u>but</u> model dependence, no pert. gluons and phases: uncertainty ?

Further attempts and improvements

Step 1: an hierarchy among contributions in the helicity basis has been found

$$h_+ \sim \mathcal{O}\left(\frac{\Lambda}{m_b}\right) h_-$$

Jäger, Camalich, arXiv:1212.2263

Step 2: attempts to gain more control over the q^2 dependence improving the dispersion relation approach

1. new phenomenological model using resonance data over the full dimuon spectrum

   Blake, Egede, Owen, Pomery, Petridis, arXiv:1709.03921

2. replace the dispersion relation with a z-expansion of h_λ, constraining the coefficients using analyticity and
   1. resonant $B \to \Psi^{(n)} K^*$ data (masses and amplitudes)
   2. LCSR + QCDF theoretical results at small/negative q^2

   Bobeth, Chrzaszcz, van Dyk, Virto, arXiv:1707.07305
   M. Chrzaszcz et al, arXiv:1805.06378
   Gubernari et al., arXiv:2011.09813
   …

Not yet fully satisfactory…

Melikov, arXiv:2208.04907
Ladisa, Santorelli, arXiv:2208.00080

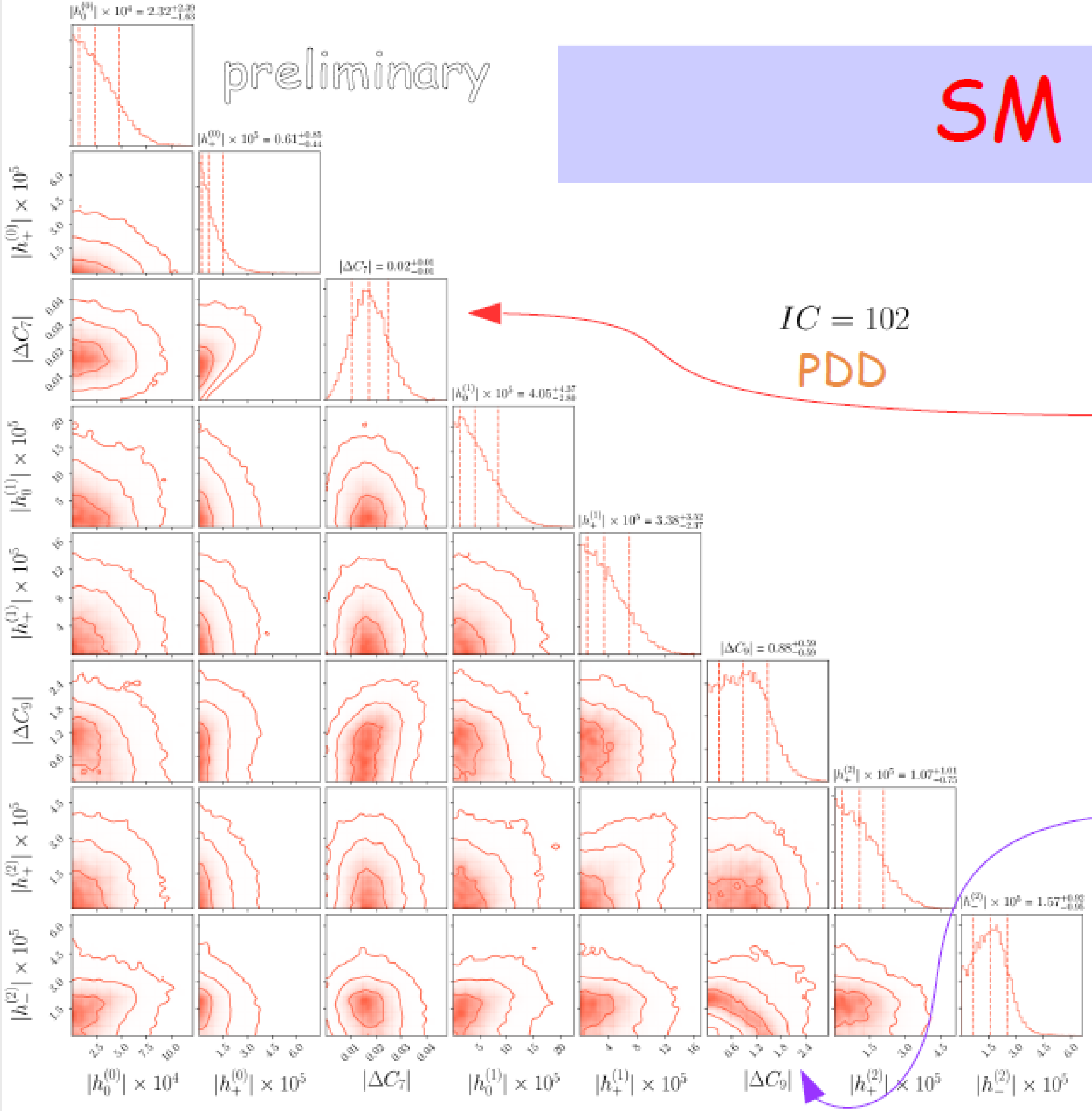
Parametrizing the charm loop

Jäger, Camalich, arXiv:1212.2263
MC, Fedele, Franco, Mishima, Paul, Silvestrini, Valli, arXiv:1512.07157
+ preliminary update

$$
\begin{aligned}
H_V^- &= -iN\left\{\left(C_9^{\rm eff}+h_-^1\right)V_{L-}+\frac{m_B^2}{q^2}\left[\frac{2m_b}{m_B}\left(C_7^{\rm eff}+h_-^0\right)T_{L-}-16\pi^2 h_-^2\, q^4\right]\right\}\\
H_V^0 &= -iN\left\{\left(C_9^{\rm eff}+h_-^1\right)\tilde{V}_{L0}+\frac{m_B^2}{q^2}\left[\frac{2m_b}{m_B}\left(C_7^{\rm eff}+h_-^0\right)\tilde{T}_{L0}-16\pi^2\left(\tilde{h}_0^0+\tilde{h}_0^1\, q^2\right)\right]\right\}\\
H_V^+ &= -iN\left\{\left(C_9^{\rm eff}+h_-^1\right)V_{L+}+\frac{m_B^2}{q^2}\left[\frac{2m_b}{m_B}\left(C_7^{\rm eff}+h_-^0\right)T_{L+}-16\pi^2\left(h_+^0+h_+^1\, q^2+h_+^2\, q^4\right)\right]\right\}
\end{aligned}
$$

$\Delta C_7^{(cc)} = h_-^0$ and $\Delta C_9^{(cc)} = h_-^1$ shift the corresponding Wilson coefficients (as NP contributions do), while the other parameters have no short-distance counterparts

SM fit of the h_λ's



$IC = 102$

PDD

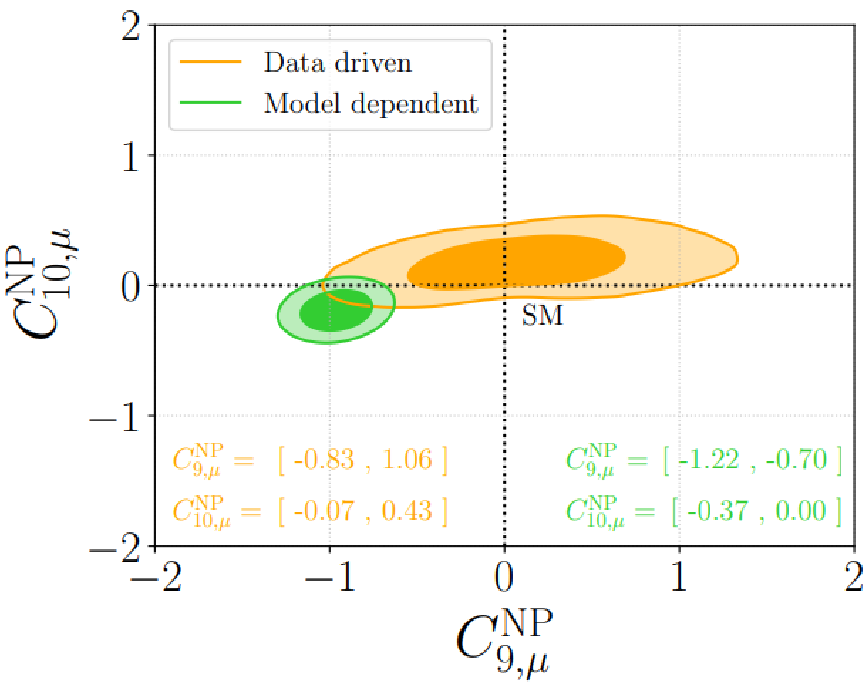
B→K*ℓℓ data accounted for by the hadronic contributions

$|\Delta C_7|$ fixed by the KMPW value at $q^2 = 0$

No clear evidence for other non-vanishing hadronic parameters but interesting correlation $|\Delta C_9|$ - $h_-^{(2)}$

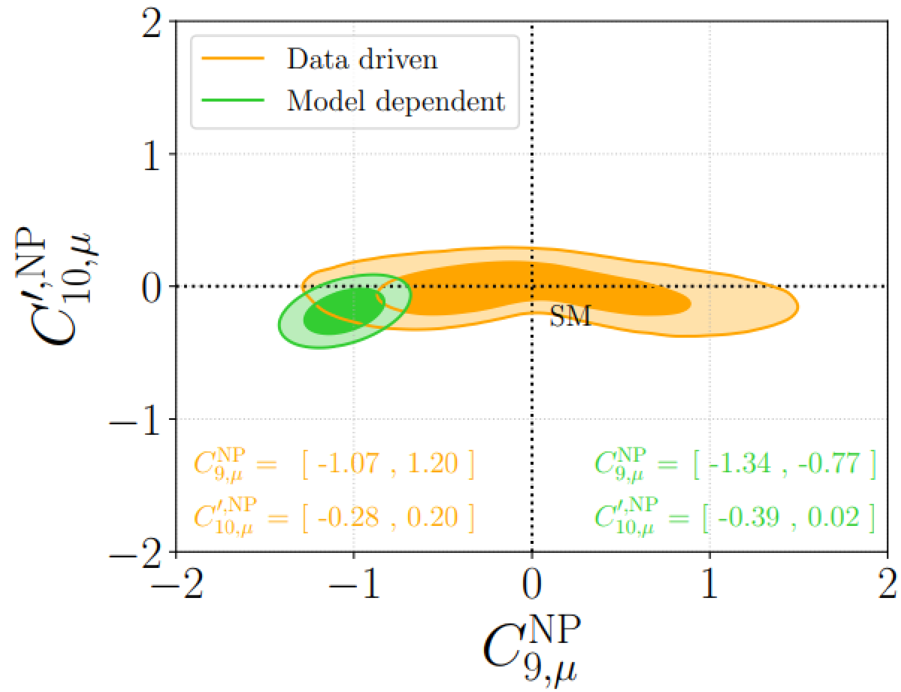
Future experimental uncertainties will be able to pin down the $h^{(2)}$'s

MC, Coutinho, Fedele, Franco, Paul, Silvestrini, Valli, in preparation

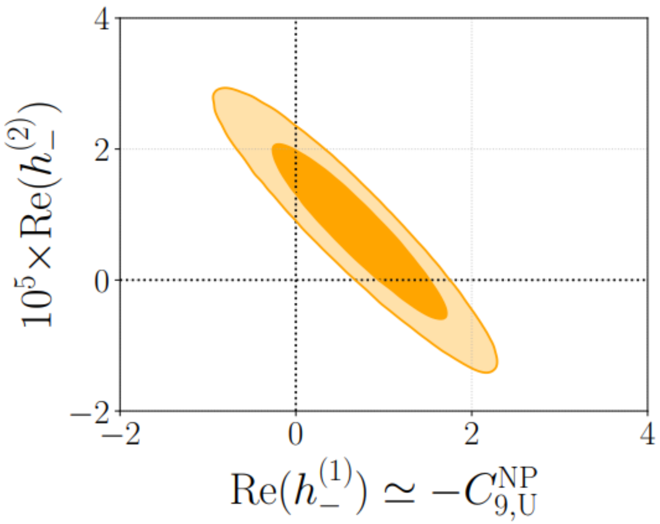


Today

	95% HPDI	ΔIC
$C_{9,\mu}^{NP}$	[-1.06 , 1.01]	-2.4
	[-1.19 , -0.67]	43
$\{C_{9,\mu}^{NP}, C_{10,\mu}^{NP}\}$	{[-0.83 , 1.06], [-0.07 , 0.43]}	-3.4
	{[-1.22 , -0.70], [-0.37 , 0.00]}	41
$\{C_{9,\mu}^{NP}, C_{9,\mu}^{\prime,NP}\}$	$\{[-1.06, 1.40], [-2.20, 1.31],$	-4.1
	$\{[-1.33, -0.79], [0.08, 0.88],$	45
$\{C_{9,\mu}^{NP}, C_{10,\mu}^{\prime,NP}\}$	$\{[-1.07, 1.20], [-0.28, 0.20],$	-5.1
	$\{[-1.34, -0.77], [-0.39, 0.02],$	41
$\{C_{9,\mu}^{NP}, C_{10,\mu}^{NP}, C_{9,\mu}^{\prime,NP}, C_{10,\mu}^{\prime,NP}\}$	$\{[-0.90, 1.49], [-0.15, 0.62], [-2.27, 1.18], [-0.33, 0.47]\}$	-8.1
	$\{[-1.38, -0.82], [-0.39, 0.02], [-0.49, 0.79], [-0.46, 0.17]\}$	57



MC, M. Fedele, E. Franco, A. Paul, L. Silvestrini, M. Valli, arXiv:2212.10516



Per finire…

bdecaysLL.frm

```
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S Vud,Vus,Vub,Vcd,Vcs,Vcb,Vtd,Vts,Vtb;
S Vdu,Vsu,Vbu,Vdc,Vsc,Vbc,Vdt,Vst,Vbt;
S C1,C2,C3,C4,C5,C6,C9,C10;
S O1,O2,O3,O4,O5,O6,O9,O10,O1C,O2C;
S O1P,O2P,O1CP,O2CP,O3P,O4P,O5P,O6P,O9P,O10P,Obd,Obs;
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F D0S,D0bS,DPS,DMS,DsPS,DsMS;
F Bd,Bs,BP;
F PP,P0,PM,KP,KM,K0,K0b,ET1,ET8,ETc;
F RP,R0,RM,KPS,KMS,K0S,K0bS,PH,OM,JPSI;
F CP,DP,CPA,DPA,CPE,DPE,DAE,CAE,DCA,DDA;
F CE,DE,CA,DA,DELL,DELR,DESP;
CF Blob;
L H=Vbu*Vud*(C1*O1 + C2*O2)
   +Vbc*Vcd*(C1*O1C + C2*O2C)
   -Vbt*Vtd*(C3*O3 + C4*O4 + C5*O5 + C6*O6 + C9*O9 + C10*O10 )
   +Vbu*Vus*(C1*O1P + C2*O2P)
   +Vbc*Vcs*(C1*O1CP + C2*O2CP)
   -Vbt*Vts*(C3*O3P + C4*O4P + C5*O5P + C6*O6P + C9*O9P + C10*O10P )
   +Vbu*Vcd*(C1*P1 + C2*P2)
   +Vbc*Vud*(C1*P1C + C2*P2C)
   +Vbu*Vcs*(C1*P1P + C2*P2P)
   +Vbc*Vus*(C1*P1CP + C2*P2CP)
   -Vbt*Vtd*Obd-Vbt*Vts*Obs;
* Decadimenti del B in due pseudoscalari
* In questa versione c`e' un editing finale che permette una rapido
* uso dell'output secondo la parametrizzazione del nostro papero.
#-
```

Per finire…

Thank you all
and
thank you Enrico

bdecaysLL.frm

```
S LL,LR,SP;
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S O1,O2,O3,O4,O5,O6,O9,O10,O1C,O2C;
S O1P,O2P,O1CP,O2CP,O3P,O4P,O5P,O6P,O9P,O10P,Obd,Obs;
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F PP,P0,PM,KP,KM,K0,K0b,ET1,ET8,ETc;
F RP,R0,RM,KPS,KMS,K0S,K0bS,PH,OM,JPSI;
F CP,DP,CPA,DPA,CPE,DPE,DAE,CAE,DCA,DDA;
F CE,DE,CA,DA,DELL,DELR,DESP;
CF Blob;
L H=Vbu*Vud*(C1*O1 + C2*O2)
   +Vbc*Vcd*(C1*O1C + C2*O2C)
   -Vbt*Vtd*(C3*O3 + C4*O4 + C5*O5 + C6*O6 + C9*O9 + C10*O10 )
   +Vbu*Vus*(C1*O1P + C2*O2P)
   +Vbc*Vcs*(C1*O1CP + C2*O2CP)
   -Vbt*Vts*(C3*O3P + C4*O4P + C5*O5P + C6*O6P + C9*O9P + C10*O10P )
   +Vbu*Vcd*(C1*P1 + C2*P2)
   +Vbc*Vud*(C1*P1C + C2*P2C)
   +Vbu*Vcs*(C1*P1P + C2*P2P)
   +Vbc*Vus*(C1*P1CP + C2*P2CP)
   -Vbt*Vtd*Obd-Vbt*Vts*Obs;
* Decadimenti del B in due pseudoscalari
* In questa versione c`e' un editing finale che permette una rapido
* uso dell'output secondo la parametrizzazione del nostro papero.
#-
```

Few remarks on the results

- ✗ charming penguins are the power-suppressed corrections needed to reproduce the $B \to K\pi$ BRs: no more, no less.
- ✗ CP asymmetries are predicted with large errors. However vanishing values of A($B \to K^-\pi^+$) and A($B \to K^-\pi^0$) are not easily accomodated
- ✗ factorization+charming penguin predict a value of BR($B_d \to \pi^+\pi^-$) too large. However:
  - charming penguins are not Cabibbo-enhanced in $B \to \pi\pi$ modes
  - many other missing power-suppressed terms (e.g. GIM penguins)
- ✗ BR($B_d \to \pi^+\pi^-$) wants large power corrections. Otherwise it constrains the values of the input parameters (e.g. small form factors, large γ, ...)
- ✗ large Λ/m_b terms in $B \to \pi\pi$ modes may enhance BR($B_d \to \pi^0\pi^0$) up to few $\times 10^{-6}$

2010 → today

Step 1: no new non-perturbative calculation. However an hierarchy among contributions in the helicity basis has been found

Jäger, Camalich, arXiv:1212.2263

$$h_+ \sim \mathcal{O}\left(\frac{\Lambda}{m_b}\right) h_-$$

Step 2: recent attempts to gain more control over the q^2 dependence improving the dispersion relation approach

1. new phenomenological model using resonance data over the full dimuon spectrum
   Blake, Egede, Owen, Pomery, Petridis, arXiv:1709.03921,
   see next talk
2. replace the dispersion relation with a z-expansion of h_λ, constraining the coefficients using analiticity and
   Bobeth, Chrzaszcz, van Dyk, Virto, arXiv:1707.07305
   1. resonant $B \to \Psi^{(n)} K^*$ data (masses and amplitudes)
   2. LCSR + QCDF theoretical results at small/negative q^2

c-loop from analyticity

Bobeth, Chrzaszcz, van Dyk, Virto, arXiv:1707.07305

Features:

- get rid of DD branch cut modeling by mapping it at the boundary of the expansion region
- exploits the $\psi^{(\prime)}$ resonance data to constrain the expansion

Open issues:

- strong phases related to the DD_s cut in p^2 are taken from LCSR and QCDF calculations. Are they reliable?

k	0	1	2
$\mathrm{Re}[\alpha_k^{(\perp)}]$	-0.06 ± 0.21	-6.77 ± 0.27	18.96 ± 0.59
$\mathrm{Re}[\alpha_k^{(\parallel)}]$	-0.35 ± 0.62	-3.13 ± 0.41	12.20 ± 1.34
$\mathrm{Re}[\alpha_k^{(0)}]$	0.05 ± 1.52	17.26 ± 1.64	–
$\mathrm{Im}[\alpha_k^{(\perp)}]$	-0.21 ± 2.25	1.17 ± 3.58	-0.08 ± 2.24
$\mathrm{Im}[\alpha_k^{(\parallel)}]$	-0.04 ± 3.67	-2.14 ± 2.46	6.03 ± 2.50
$\mathrm{Im}[\alpha_k^{(0)}]$	-0.05 ± 4.99	4.29 ± 3.14	–

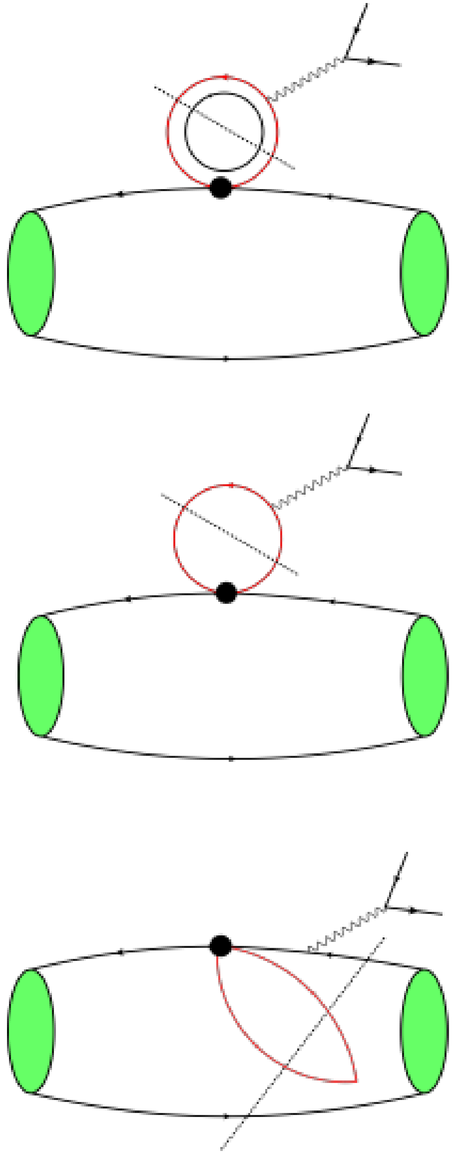
- z expansion: no sign of convergence for the typical values |z|~ 0.2-0.4

NB: z expansion of FF at much smaller values

$D\bar{D}$

$\psi^{(n)}$

DD_s



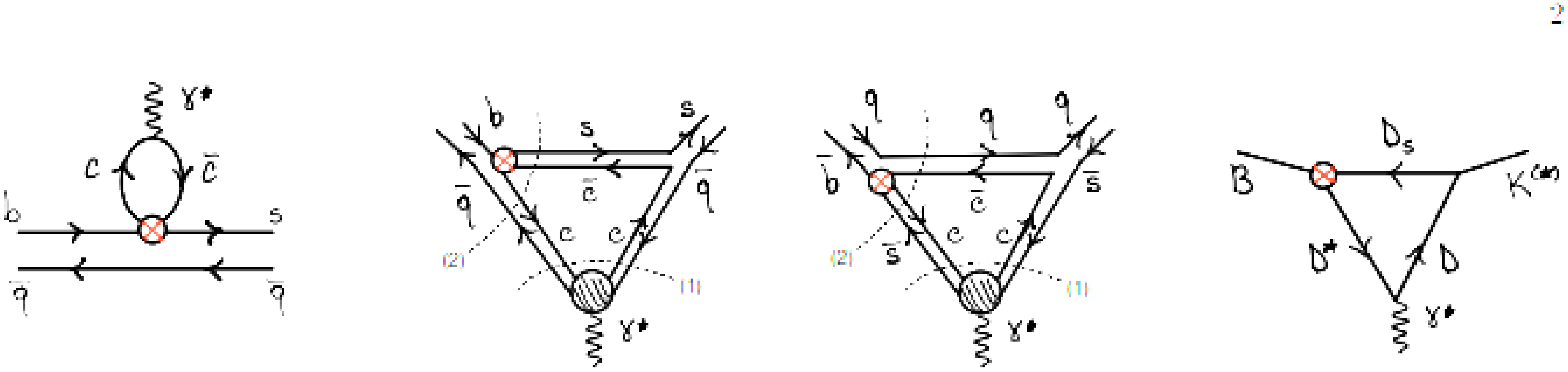
Charm loop: dangerous or  harmless?

A clear-cut non-perturbative calculation is not available yet

Combinations of QCDF, LCSR, analiticity and unitarity point to a moderate effect with a flat q^2 dependence in the region of interest. Yet their ability to fully describe c-loop rescattering is questionable

Future data could be able to pin down hadronic contributions with no short-distance counterparts (all but ΔC_7 and ΔC_9)

LFUV signals are not affected, but their interpretation may be


2
γ*
c
c̄
b
s
q̄
(2)
(1)
q
b̄
s̄
B
D_s
K^(*)
D*
D