Charm rescattering in B decays: possible CP violation mechanism?

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Future challenged in hadronic B decay

14 - 18 January 2019 - Mainz

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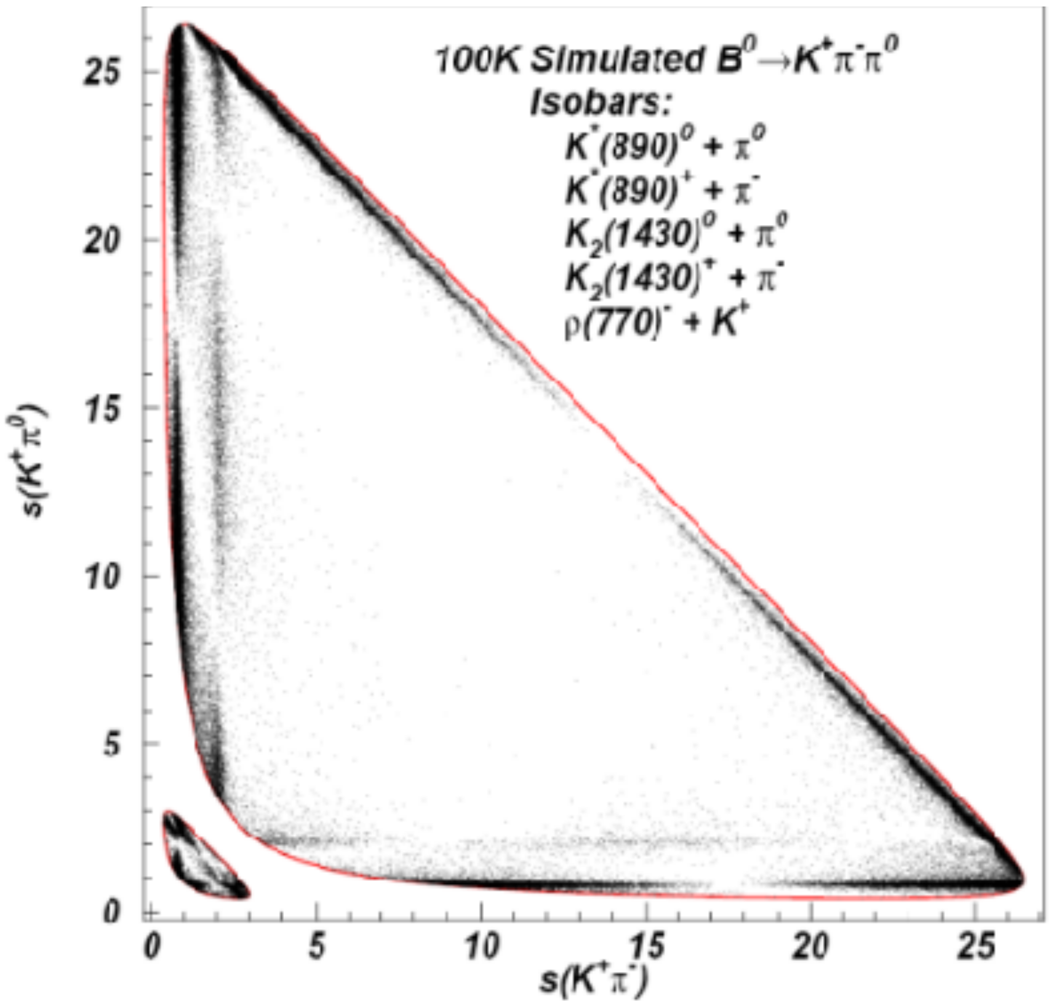
Context

- D and B three-body HADRONIC decays are dominated by resonances
  - spectroscopy
  - information of MM interactions ⟶ no $K\bar{K}$ data available
  - study of CP-Violation ⟶ can lead to new physics
- new high data sample from LHCb ⟶ more to come from LHCb and Belle II

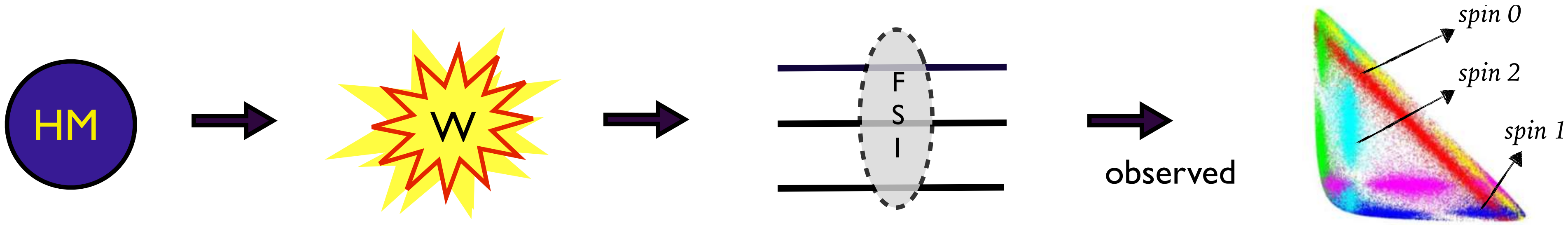
  ⟶ requires better models



- B and D 3-body decay…..
  - $\neq$ scales!!! ⟶ similar FSI
  - B phase-space ⟶ + FSI possibilities

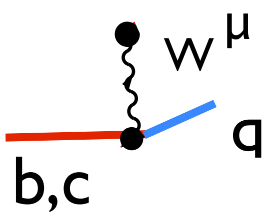
heavy meson decay

- dynamics



> to extract information from data we need an amplitude MODEL

- weak primary vertex (W)



quark → hadron

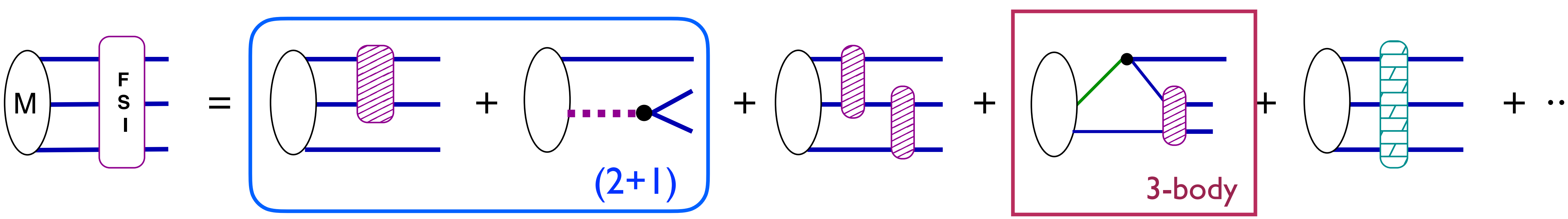
- QCD factorization approach — Tobias talk

  Benoit, Keri, Javier, Bruno, Boito, etc

  → not precise for 3-body

  not allow all kinds of FSI and 3-body NR

- Final State Interactions (FSI)



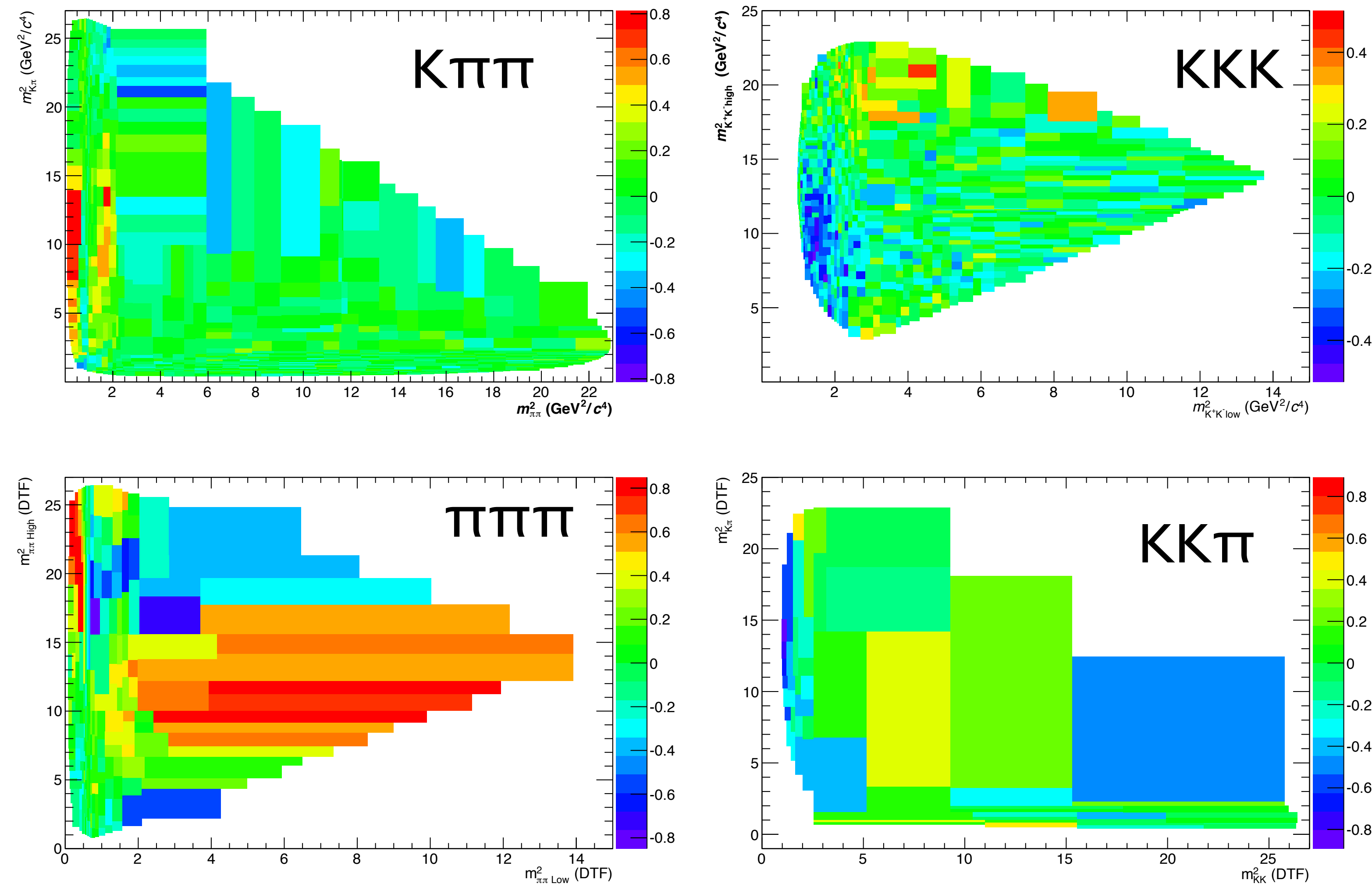
- 2-body is crucial
- full unitarity: Faddeev, Khury-Trieman, triangles

  PCM, Robilotta, T. Frederico, B. Kubis, B. Moussallam, Nakamura , etc

CPV on data

- massive localized Acp

$B^{\pm} \to hhh$



LHCb PRD90 (2014) 112004

- Charge Parity Violation :

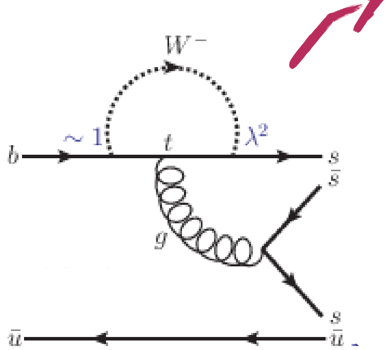
$$A_{M\to f} = A_1\, e^{i(\delta_1 - \phi_1)} + A_2\, e^{i(\delta_2 - \phi_2)}$$

$$|A_{M\to f}|^2 - |A_{\bar{M}\to \bar{f}}|^2 = -4A_1 A_2\, sin(\delta_1 - \delta_2)\, \sin(\phi_1 - \phi_2) \neq 0$$

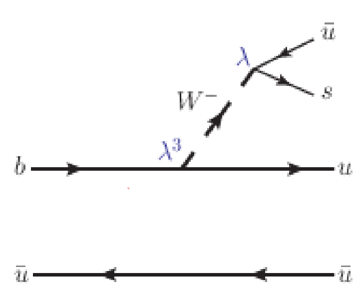
→ two $\neq$weak and strong phases

- BSS model  +  not enough!

Bander Silverman & Soni PRL 43 (1979) 242



strong phase



weak phase: CKM

- hadronic interactions

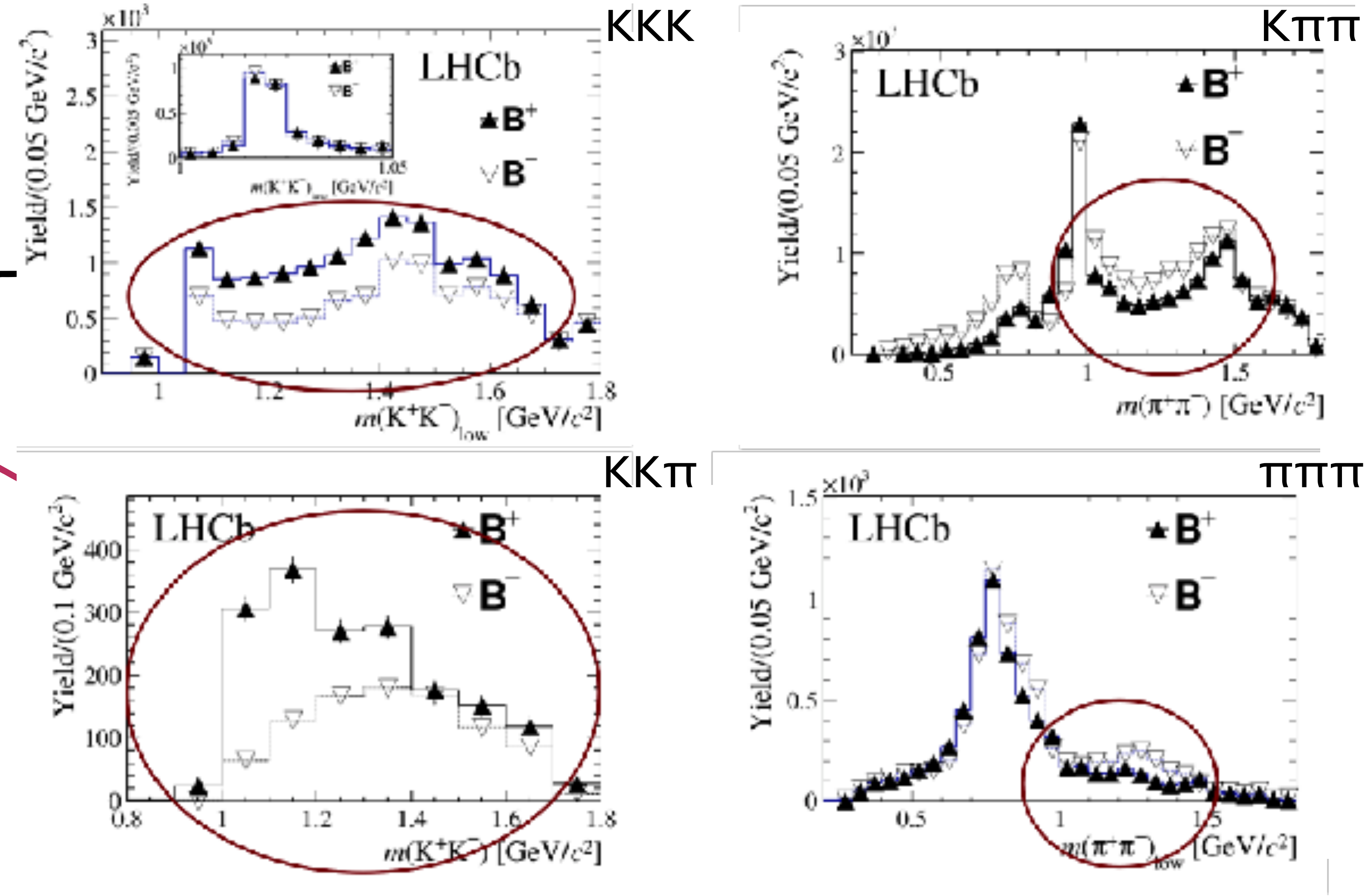
  → strong phase

CPV on data

- low-energy CPV [1 - 2] GeV

$$\boxed{\pi\pi \to KK}$$

Frederico, Bediaga & Lourenço
PRD89(2014)094013



LHCb PRD90 (2014) 112004

- FSI → strong phase
  Wolfenstein PRD43 (1991) 151

- CPT:

Lifetime $\tau = 1 / \Gamma_{total} = 1 / \overline{\Gamma}_{total}$

$$\Gamma_{total} = \Gamma_1 + \Gamma_2 + \Gamma_3 + \Gamma_4 + \Gamma_5 + \Gamma_6 + \ldots$$

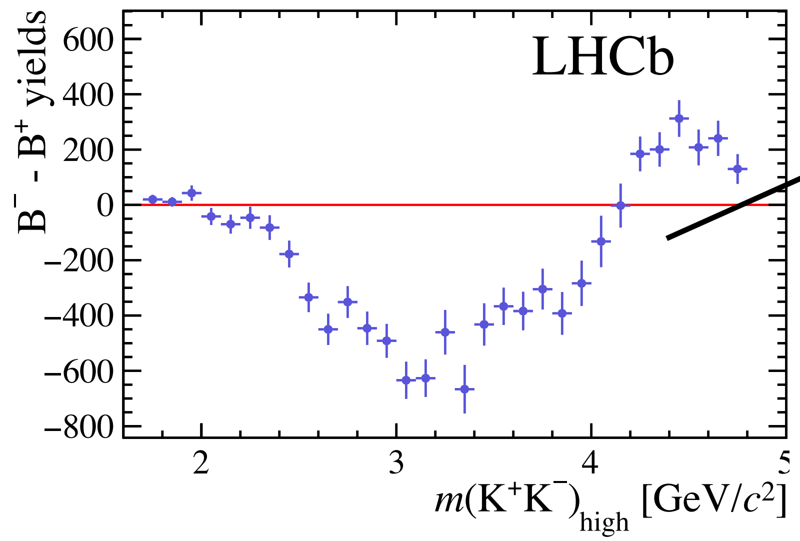
$$\overline{\Gamma}_{total} = \overline{\Gamma}_1 + \overline{\Gamma}_2 + \overline{\Gamma}_3 + \overline{\Gamma}_4 + \overline{\Gamma}_5 + \overline{\Gamma}_6 + \ldots$$

→ CPV in one channel should be compensated by another one with opposite sign

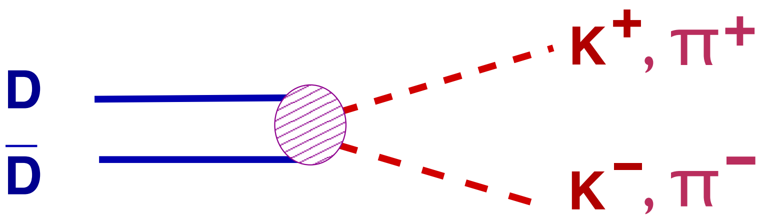
- high mass CPV?

CPV high energy

- CPV high mass?



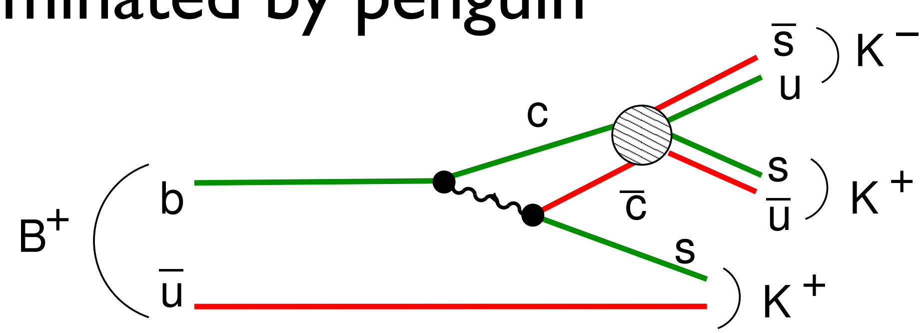
~ $D\bar{D}$ open channel →

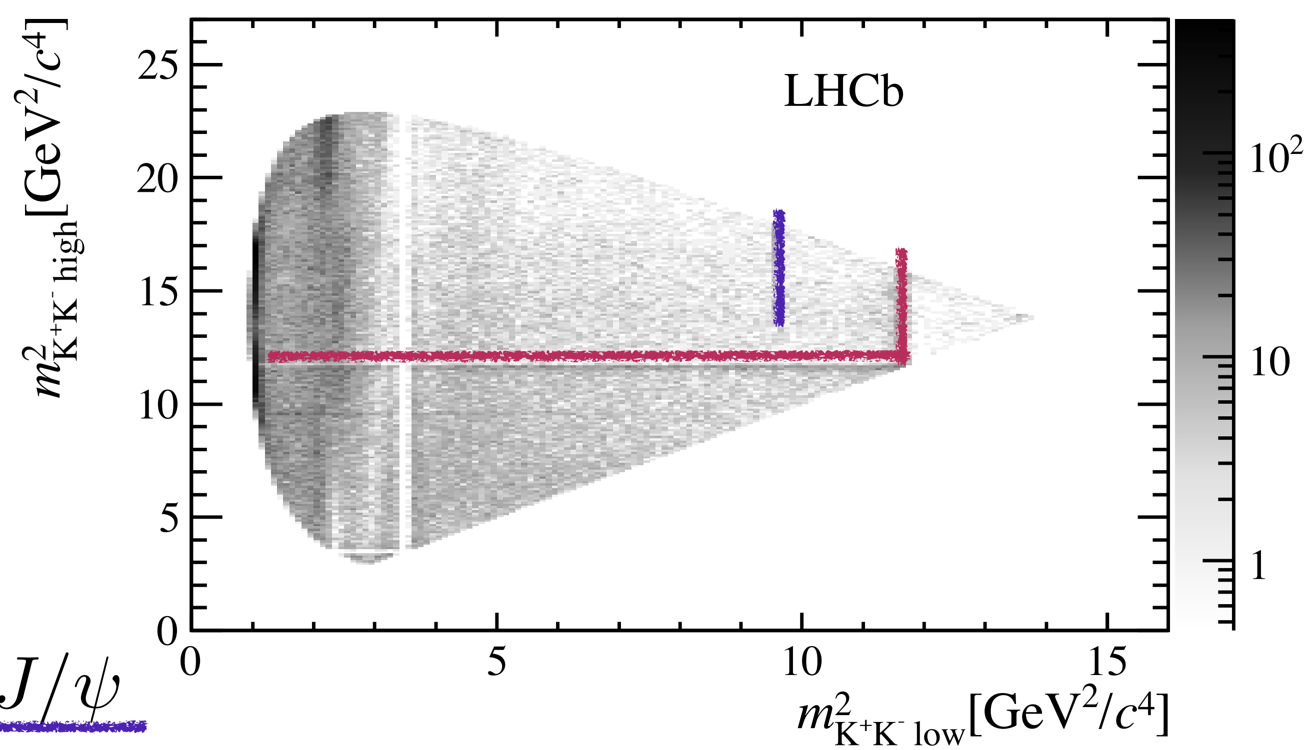


same observed in coupled-channels

→ charm intermediate processes as source of strong phase

- $B^+ \to K^- K^+ K^+$
  - $B^\pm \to hhh$ high statistic 109k LHCb
  - nonresonant → all phase-space
  - dominated by penguin



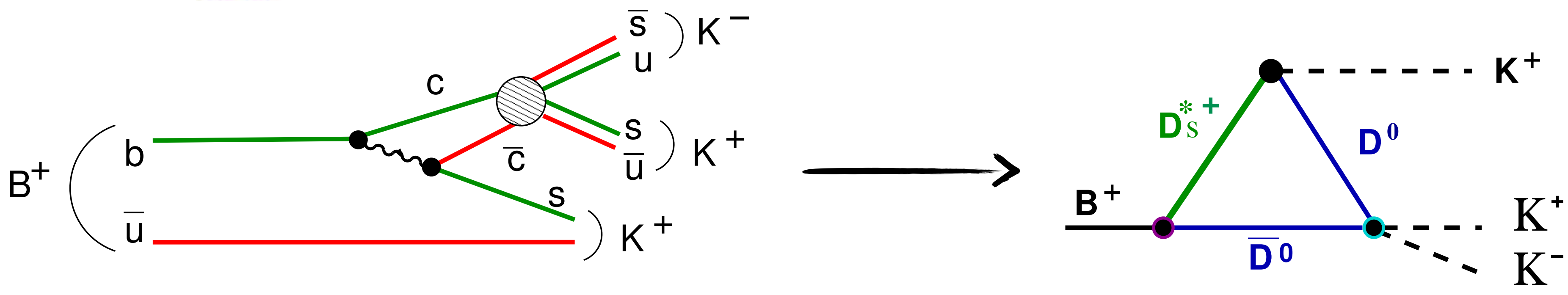


  - presence of charm resonances: χ_{c0} J/ψ

- charm FSI: $B \to 3h$, $B_c \to 3h$, $B \to K^* \mu\mu$, ...

charm  contribution to $B^{\pm} \to K^+ K^- K^+$

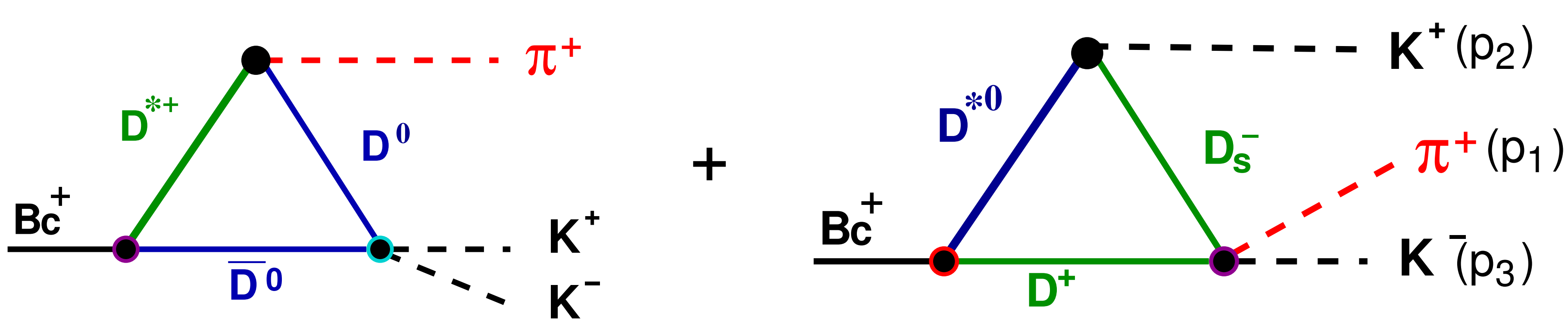
I. Bediaga, PCM, T Frederico
PLB 780 (2018) 357

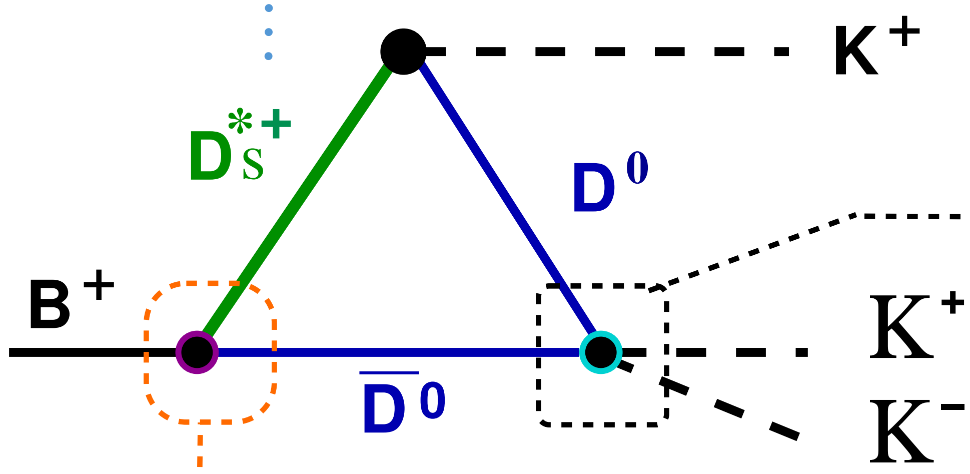


other application

charm rescattering to $B_c^+ \to K^- K^+ \pi^+$

I. Bediaga, PCM, T Frederico
PLB 785 (2018) 581





form factor for $W^+ \to D^0 K^+$

$D^0\bar{D}^0 \to K^+K^-$ scattering amplitude

phenomenological:
S- matrix unitarity + Regge theory

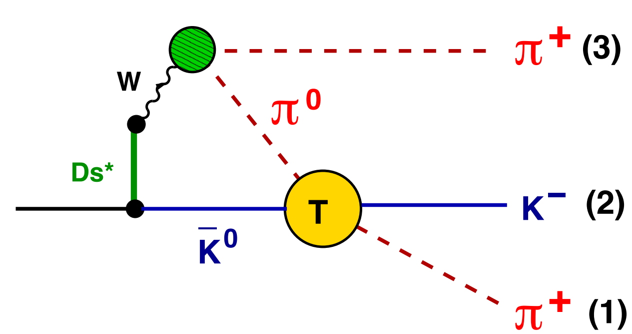
weak transition $B^+ \to W^+\bar{D}^0$ ➜ $C_0 \times$ form factor to regulate

- $Br\,[B \to DD_s^*]$ ~1% → **1000 x** $Br\,[B \to KKK]$
- hadronic loop ➜ three-body FSI - introduce new complex structures

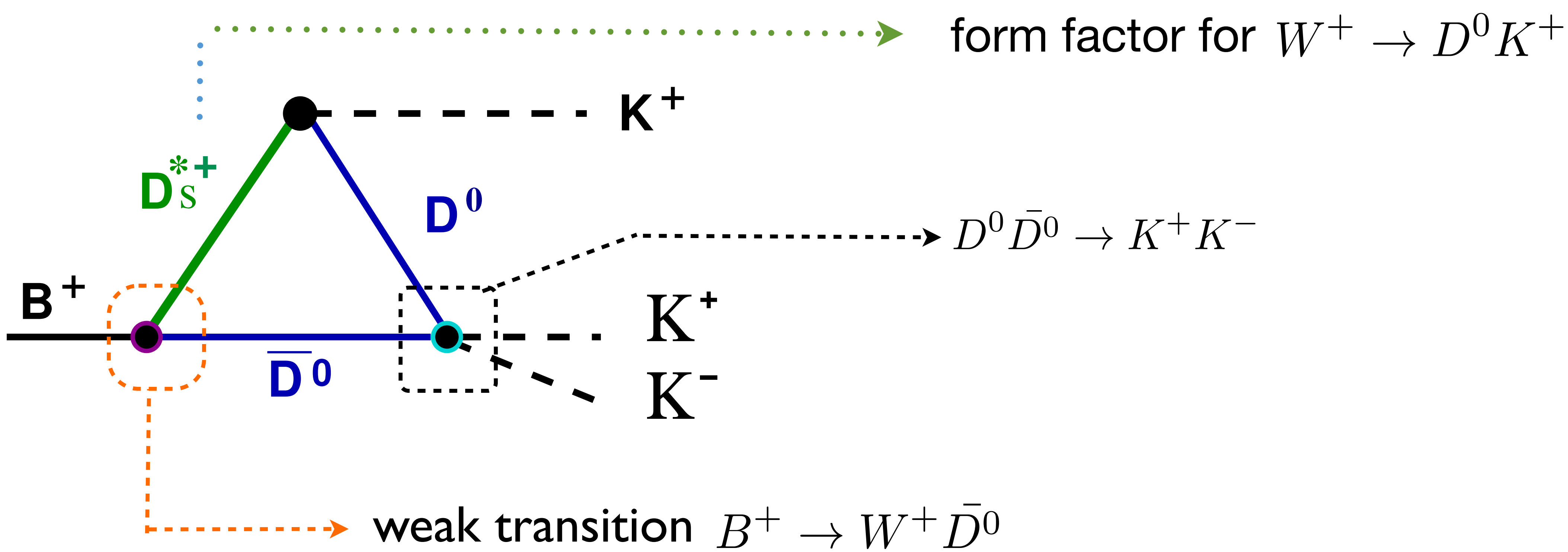
- $B^+ \to \pi^+\pi^-\pi^+$

PCM & I Bediaga
arXiv:1512.09284

- $D^+ \to \pi^+ K^- \pi^+$



PCM & M Robilotta
PRD 92 094005 (2015) [arXiv:1504.06346]
PCM et al
PRD 84 094001 (2011) [arXiv:1105.5120]



- $$A = iC\ m_a^2 \int \frac{d^4\ell}{(2\pi)^4} \frac{T_{\bar{D}^0 D^0 \to KK}(s_{23})\,[-2\,p_3' \cdot (p_2' - p_1)]}{\Delta_{D^{+*}}\,\Delta_{D^0}\,\Delta_{\bar{D}^0}\,\Delta_a}\,, \quad \to \quad \Delta_{D^{+*}} = s - m^2_{D^{*+}}$$

$$A = iC\ m_a^2\ T_{\bar{D}^0 D^0 \to KK}(s_{23}) \int \frac{d^4\ell}{(2\pi)^4} \frac{\Delta_{D^0} + 2\,\Delta_{\bar{D}^0} - 2\,s_{23} + 3\,M_K^2 + M_B^2 - l^2}{\Delta_{D^0}\,\Delta_{\bar{D}^0}\,\Delta_{D*}\,[l^2 - m_{B^*}]}$$

$$Loop \to \frac{1}{m_{B*}^2 - \Theta_{D*}} I_{B*\,D*\,D_0\,\bar{D}_0}(M_B^2 + 2M_{\bar{D}_0}^2 + M_K^2 + m_{B*}^2 - 2s) - I_{B*\,D*\,D_0} + I_{B*\,D*\,\bar{D}_0} + I_{B*\,D*\,\bar{D}_0}\left(1.0 + \frac{M_B^2 - M_{D_0}^2}{m_{B*}^2}\right)$$

$\to$ simplify to diff integrals solved by Feynman

PCM: PRD 92 094005 (2015) [arXiv:1504.06346]

$D^0\bar{D}^0 \to K^+K^-$ scattering amplitude

- not well understand on literature

- important as FSI in B two-body decays

Donoghue *et al.*, *PRL* 77(1996)2178;
Suzuki,Wolfenstein, PRD 60 (1999)074019;
Falk et al. PRD 57,4290(1998);
Blok, Gronau, Rosner, PRL 78, 3999 (1997).

- phenomenological amplitude

Antunes, Bediaga, Frederico, PCM
ICHEP2016 - proceedings

  - unitarity of the S-matrix $S = \begin{pmatrix} \eta\, e^{2i\alpha} & \sqrt{1-\eta^2}\, e^{i(\alpha+\beta)} \\ -\sqrt{1-\eta^2}\, e^{i(\alpha+\beta)} & \eta\, e^{2i\beta} \end{pmatrix}$

  - inspired in the damping factor of the S matrix i.e. $\pi\pi \to KK$

$$\eta = \mathcal{N}\sqrt{s/s_{th} - 1}/(s/s_{th})^{2.5}$$

KK: $e^{2i\alpha} = 1 - \dfrac{2ik_1}{\frac{c}{1-k_1/k_0} + ik_1}$, DD: $e^{2i\beta} = 1 - \dfrac{2ik}{\frac{1}{a} + ik}$

$k = \sqrt{\frac{s-s_{th}}{4}}$, $k_1 = \sqrt{\frac{s-s_{th1}}{4}}$ and $k_0 = \sqrt{\frac{s_0-s_{th}}{4}}$

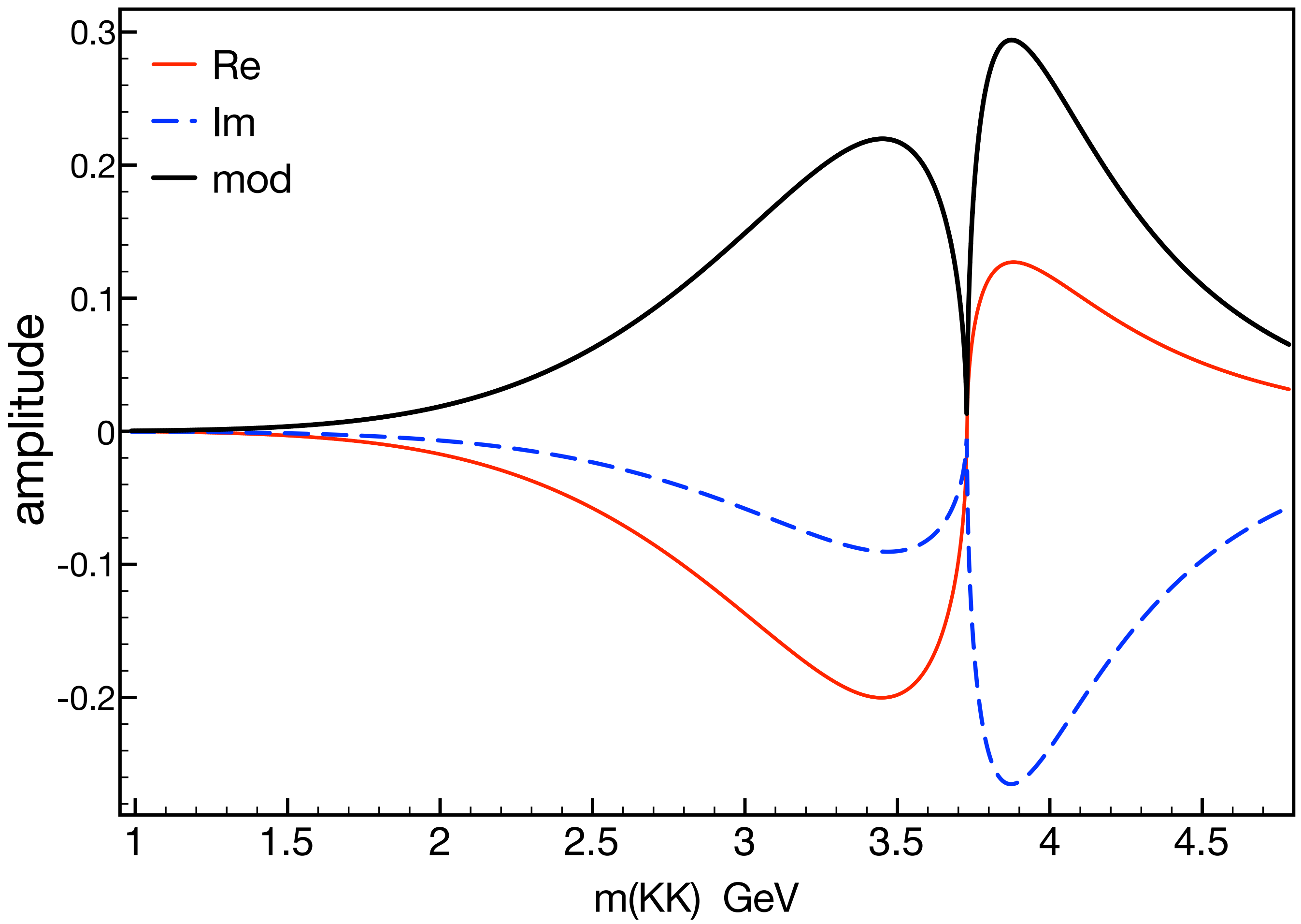
$$S_{\beta,\alpha} = \delta_{\beta,\alpha} + it_{\beta,\alpha}$$

$$\boxed{t_{\beta,\alpha} = \sqrt{1-\eta^2}e^{i(\alpha+\beta)}}$$

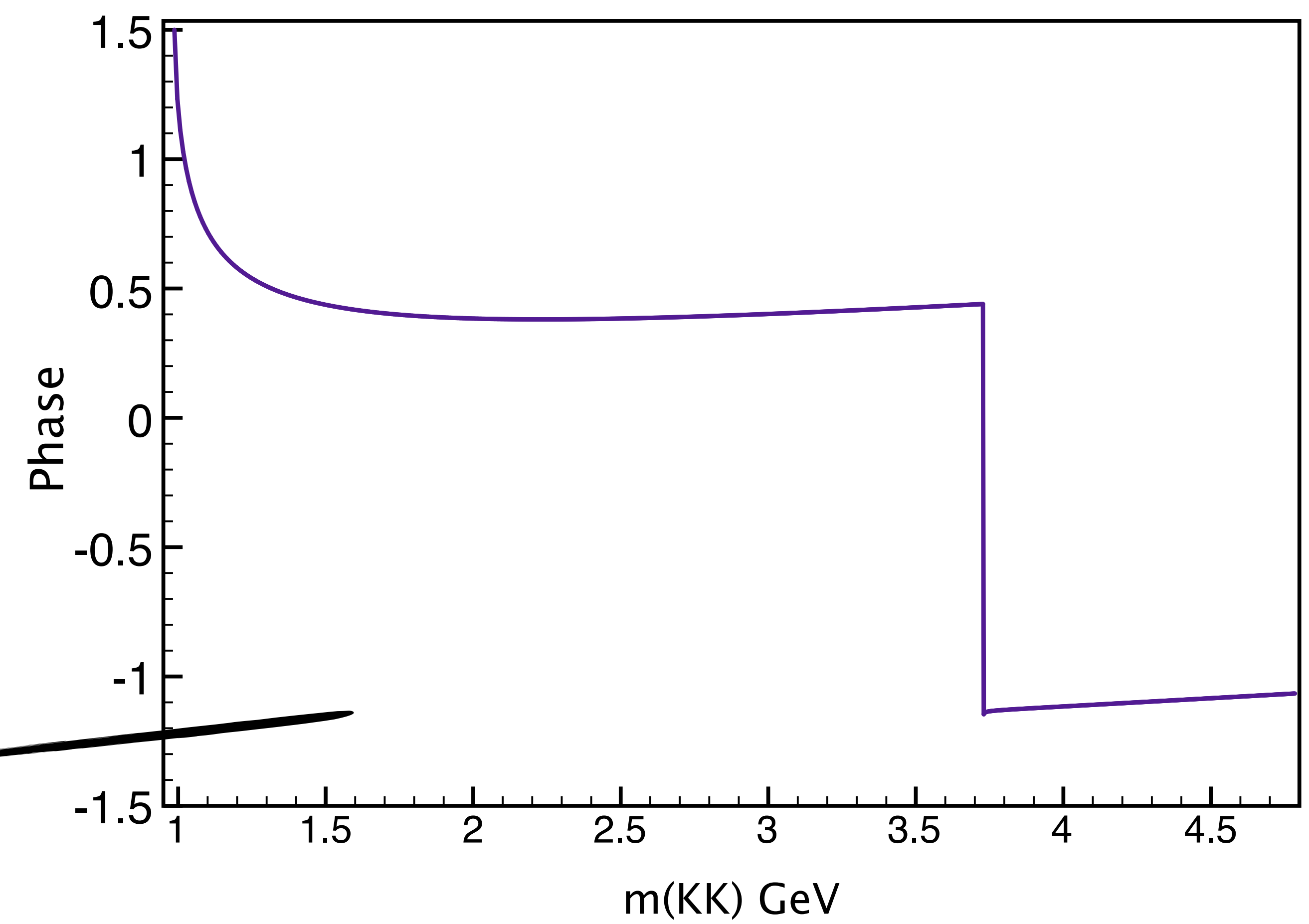
$D^0\bar{D}^0 \to K^+K^-$ scattering amplitude

- $$T_{\bar{D}^0 D^0 \to KK}(s) = \frac{s^\alpha}{s^\alpha_{th\,D\bar{D}}} \frac{2\kappa_2}{\sqrt{s_{th\,D\bar{D}}}} \left(\frac{s_{th\,D\bar{D}}}{s+s_{QCD}}\right)^{\xi+\alpha} \left[\left(\frac{c+bk_1^2-ik_1}{c+bk_1^2+ik_1}\right)\left(\frac{\frac{1}{a}+\kappa_2}{\frac{1}{a}-\kappa_2}\right)\right]^{\frac{1}{2}},\quad s < s_{th\,D\bar{D}}$$
$$= -i\,\frac{2\,k_2}{\sqrt{s_{th\,D\bar{D}}}} \left(\frac{s_{th\,D\bar{D}}}{s+s_{QCD}}\right)^{\xi} \left(\frac{m_0}{s-m_0}\right)^{\beta} \left[\left(\frac{c+bk_1^2-ik_1}{c+bk_1^2+ik_1}\right)\left(\frac{\frac{1}{a}-ik_2}{\frac{1}{a}+ik_2}\right)\right]^{\frac{1}{2}},\, s \geq s_{th\,D\bar{D}}$$

parameters fix by data!



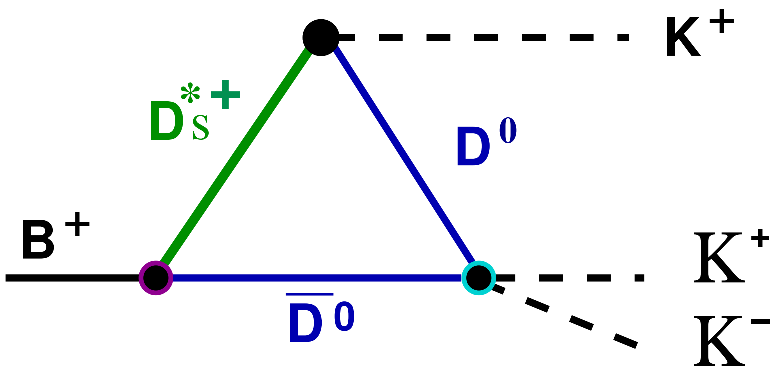
zero at threshold

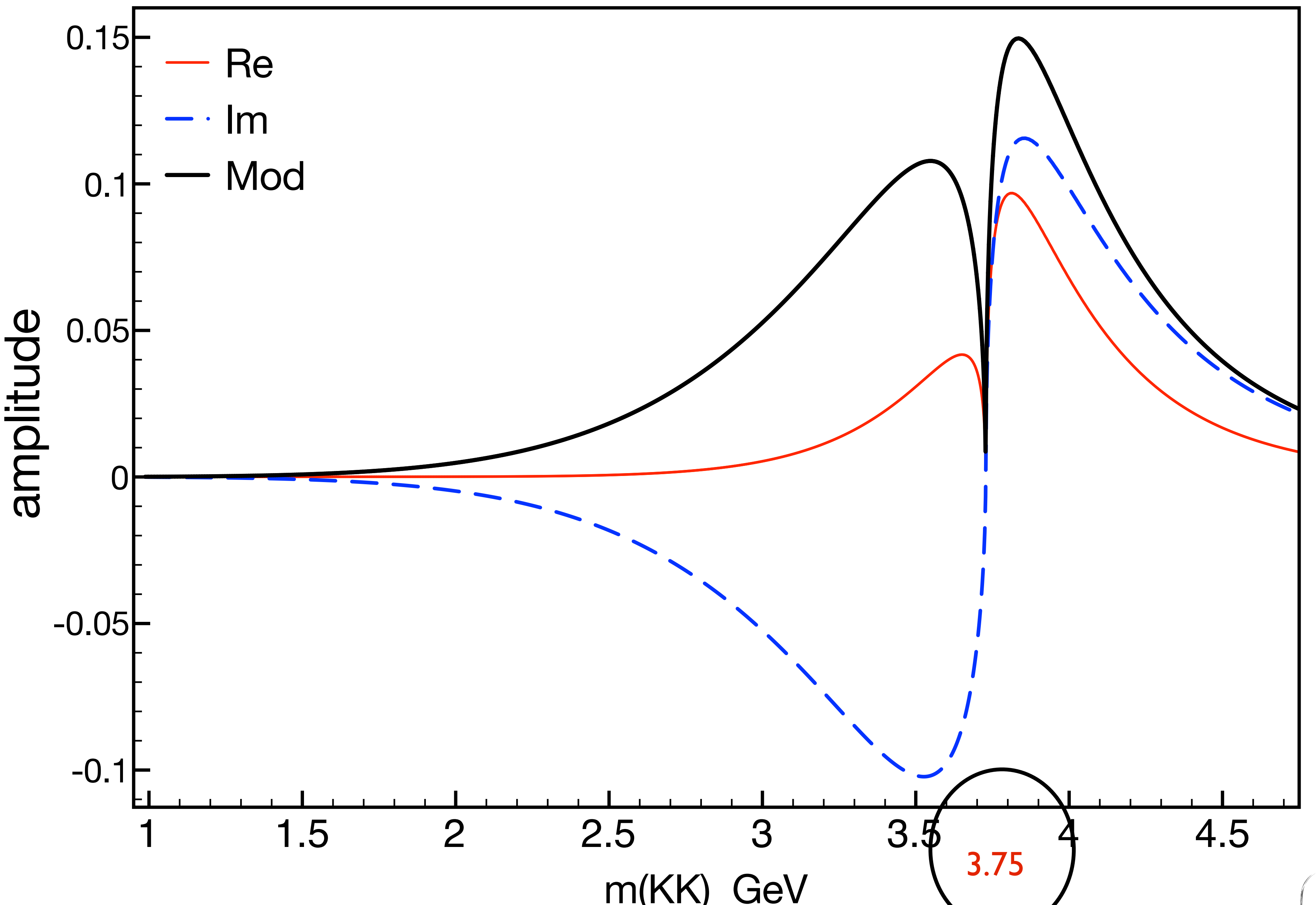


discontinuity at threshold

hadronic loop

- $$A = iC\ m_a^2 \int \frac{d^4\ell}{(2\pi)^4}\ \frac{T_{\bar{D}^0 D^0 \to KK}(s_{23})\,[-2\,p_3' \cdot (p_2' - p_1)]}{\Delta_{D^{+*}}\,\Delta_{D^0}\,\Delta_{\bar{D}^0}\,\Delta_a}\ ,$$

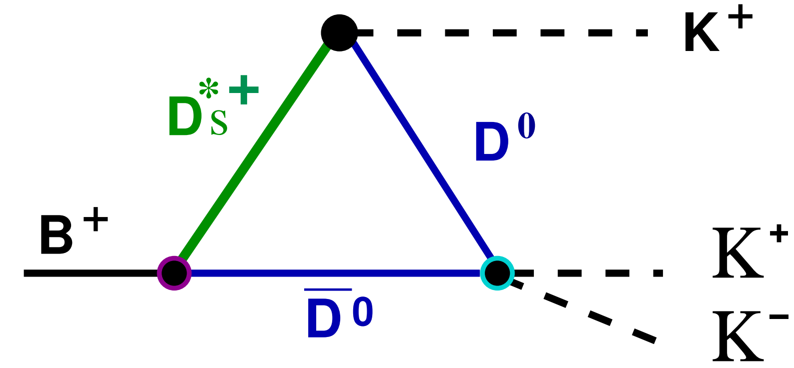


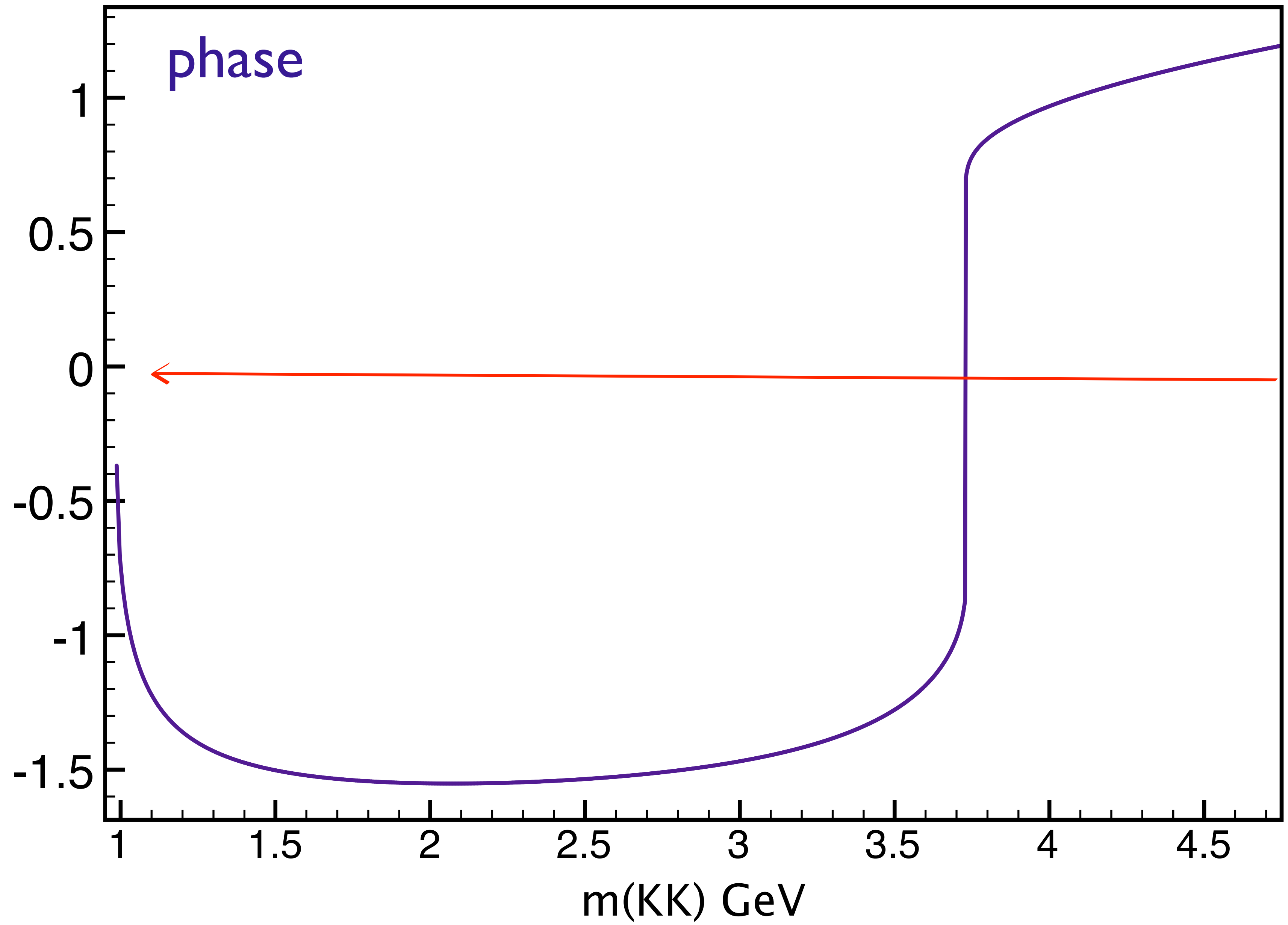


→ zero in between two bumps

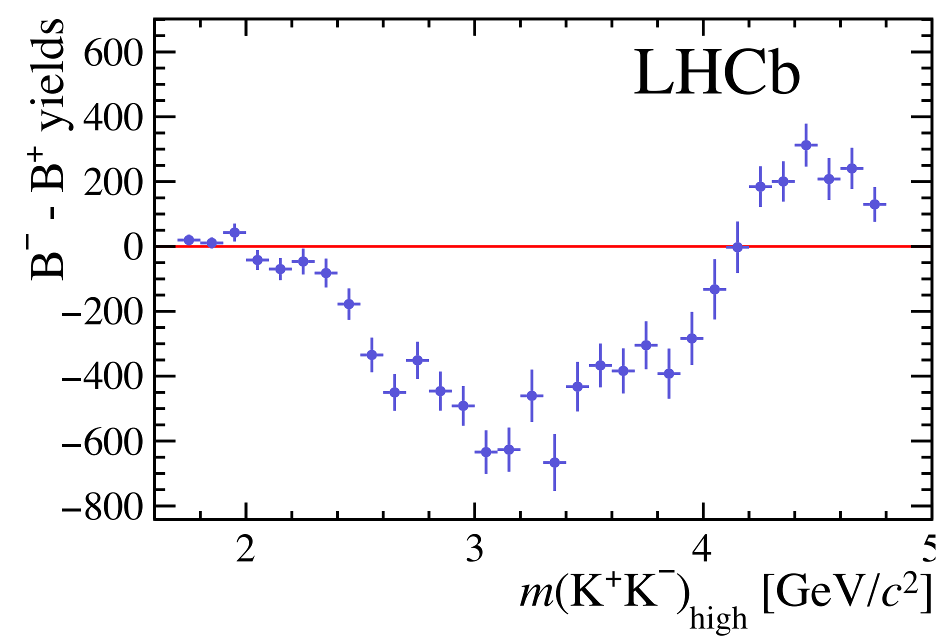
rescattering $D^0\bar{D}^0 \to K^+K^-$ play a major role

- $$A = iC\ m_a^2 \int \frac{d^4\ell}{(2\pi)^4}\ \frac{T_{\bar{D}^0 D^0 \to KK}(s_{23})\,[-2\,p_3' \cdot (p_2' - p_1)]}{\Delta_{D^{+*}}\,\Delta_{D^0}\,\Delta_{\bar{D}^0}\,\Delta_a}\ ,$$

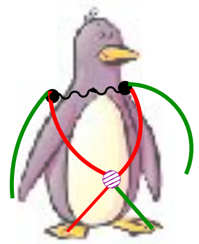




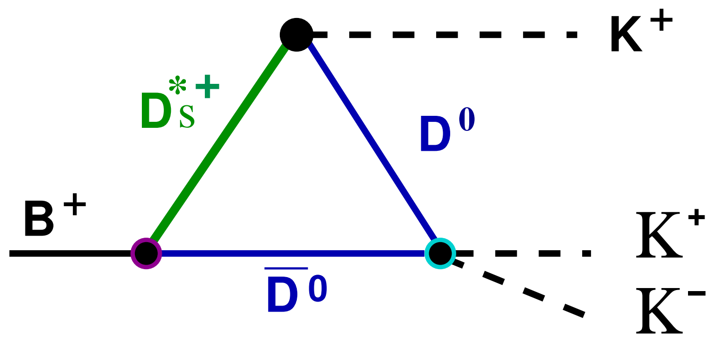
→ change signal in the same region as Acp data



→ can explain change CPV signal in DP!!!



- Triangle hadronic loop with FSI



- amplitude: two narrow peaks in between a zero (threshold)
  → superposition of triangles

- phase: change sign in a region close where data shows a CP asymmetry change in sign!

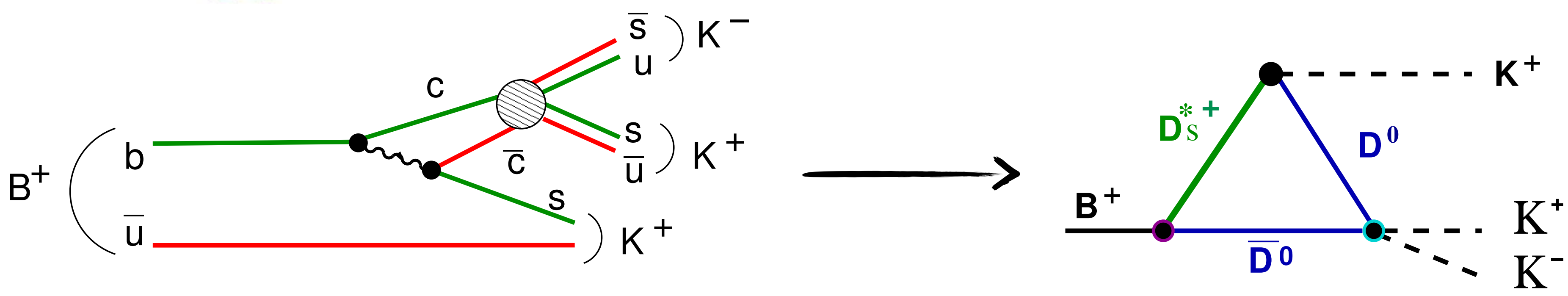
→ FSI mechanism to produce CP asymmetry at high mass

- interference between: ≠ triangles & NR sources & resonances
  → can shift the position of the CP asymmetry sign change

→ should be tested in data ANA!

charm  contribution to $B^{\pm} \to K^+ K^- K^+$

I. Bediaga, PCM, T Frederico
PLB 780 (2018) 357



interesting application

charm rescattering to $B_c^+ \to K^- K^+ \pi^+$

I. Bediaga, PCM, T Frederico
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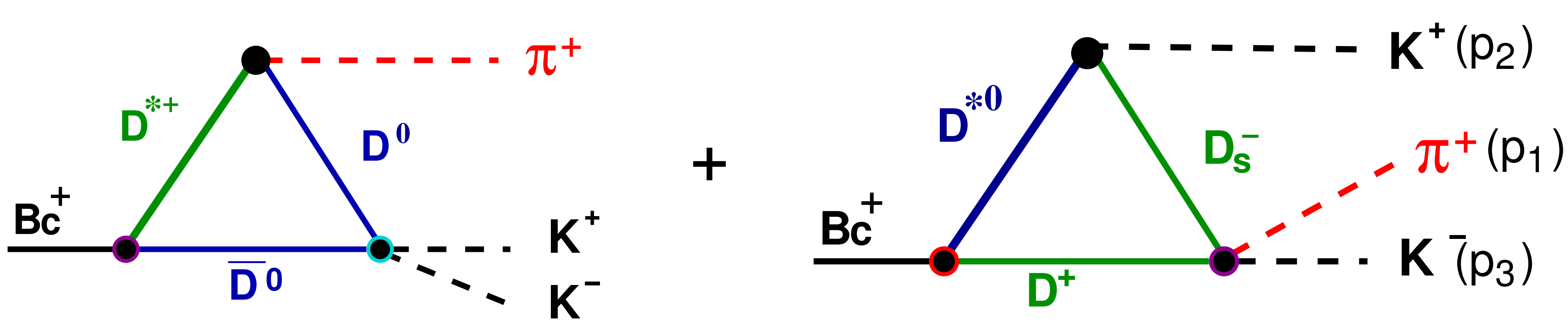
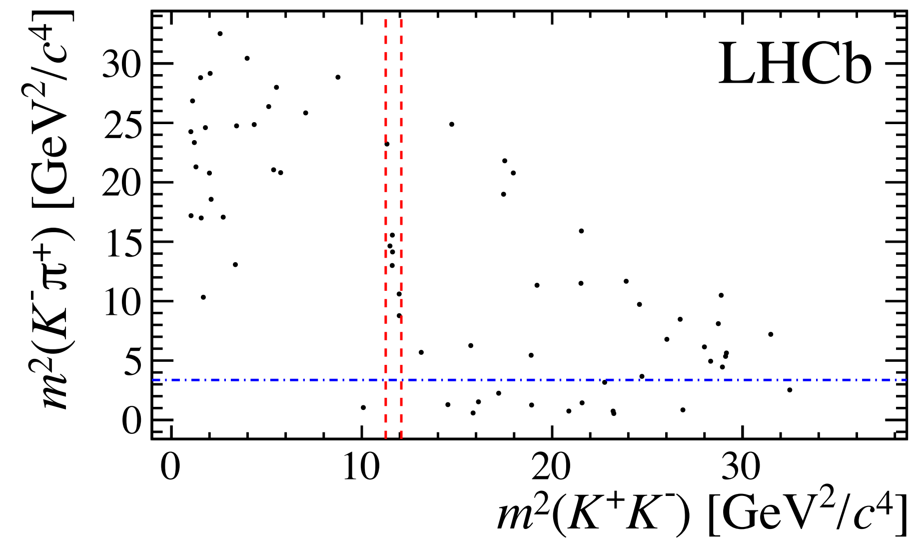


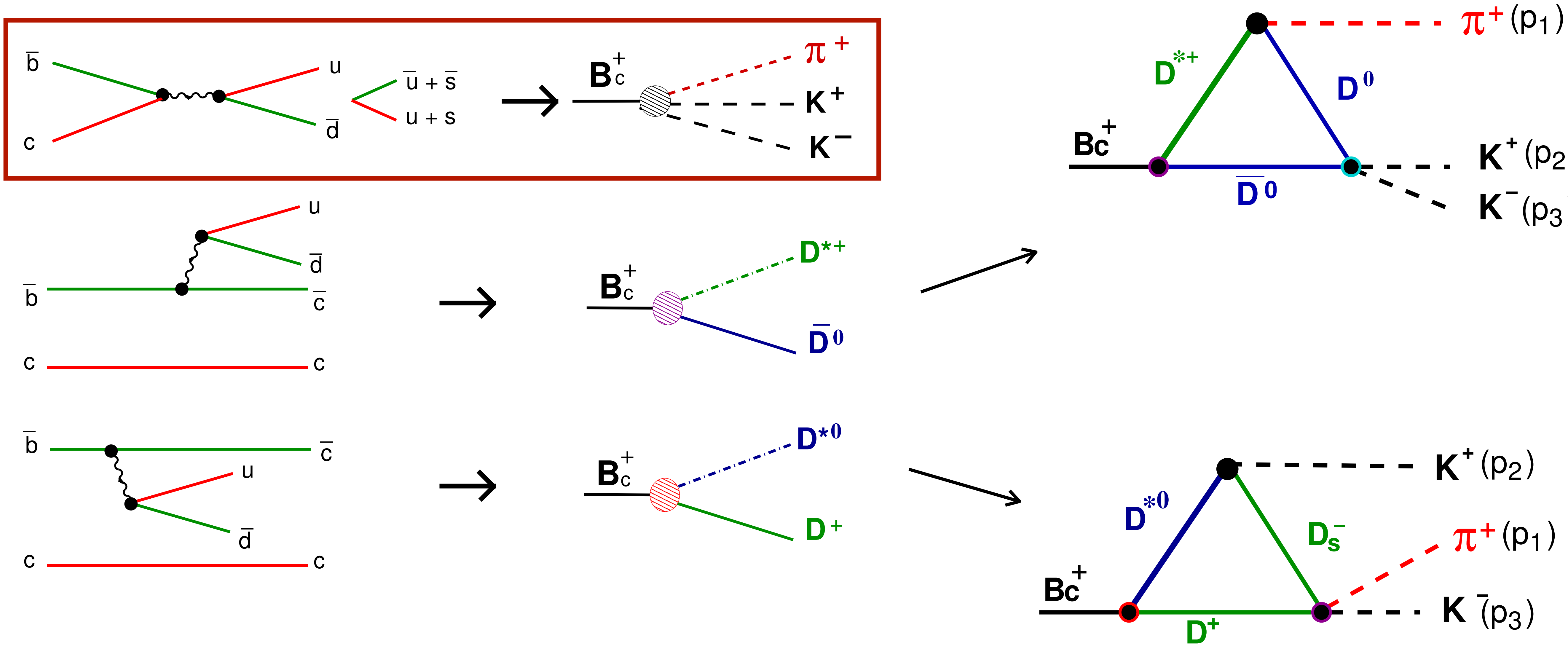
Charm rescattering

- $B_c^+ \to K^- K^+ \pi^+$

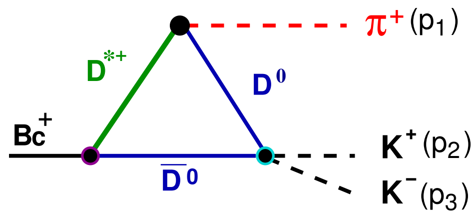
Phys.Rev. D94 (2016) no.9, 091102



- very suppressed direct production (annihilation)
- charm rescattering can be the dominant mechanism



- toy Monte Carlo generator



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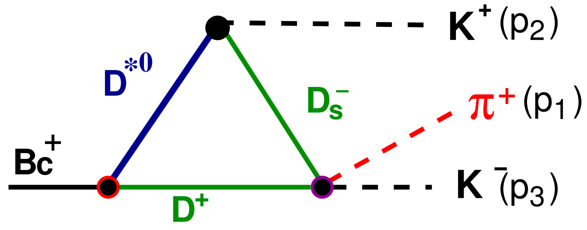
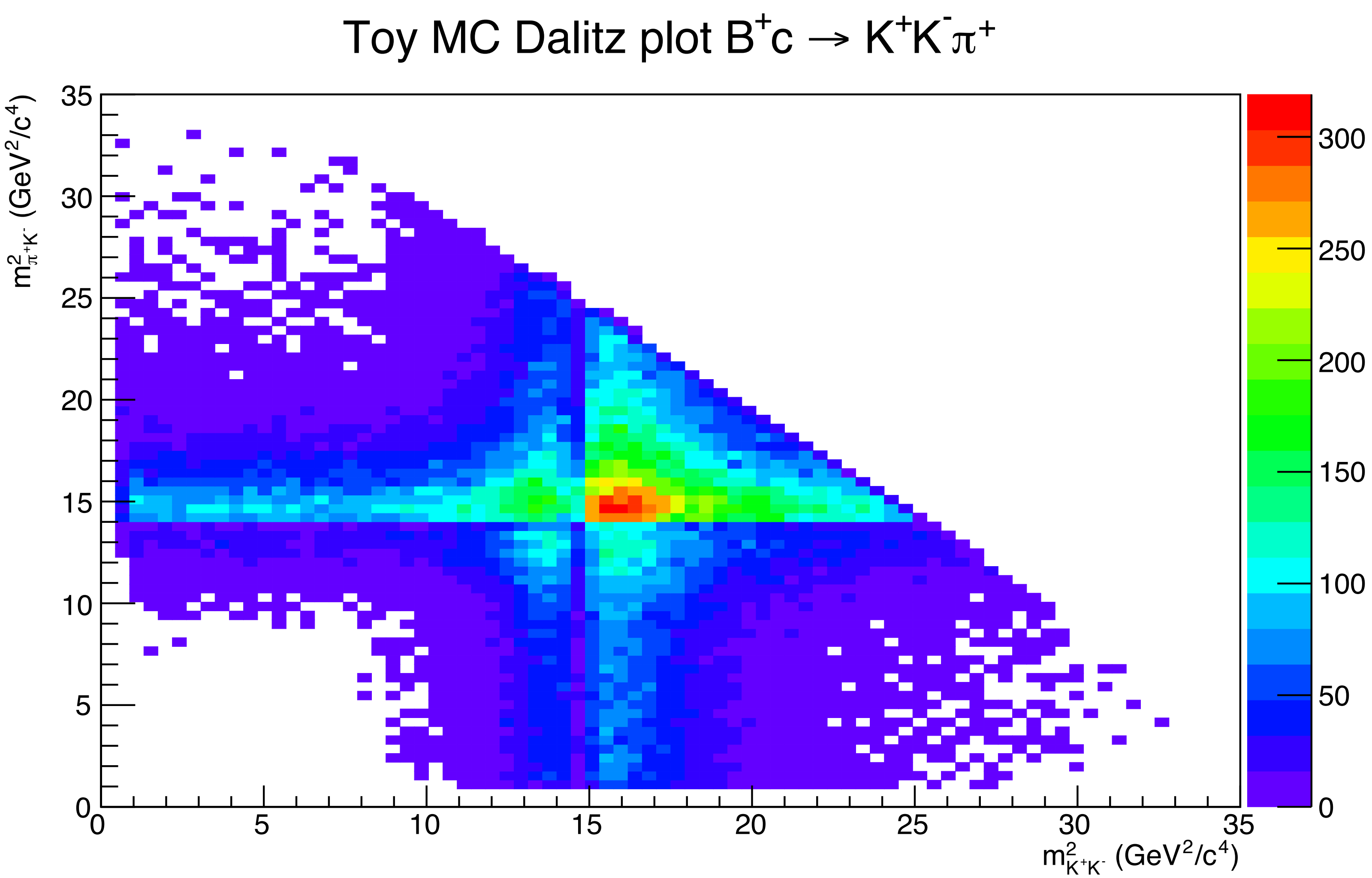
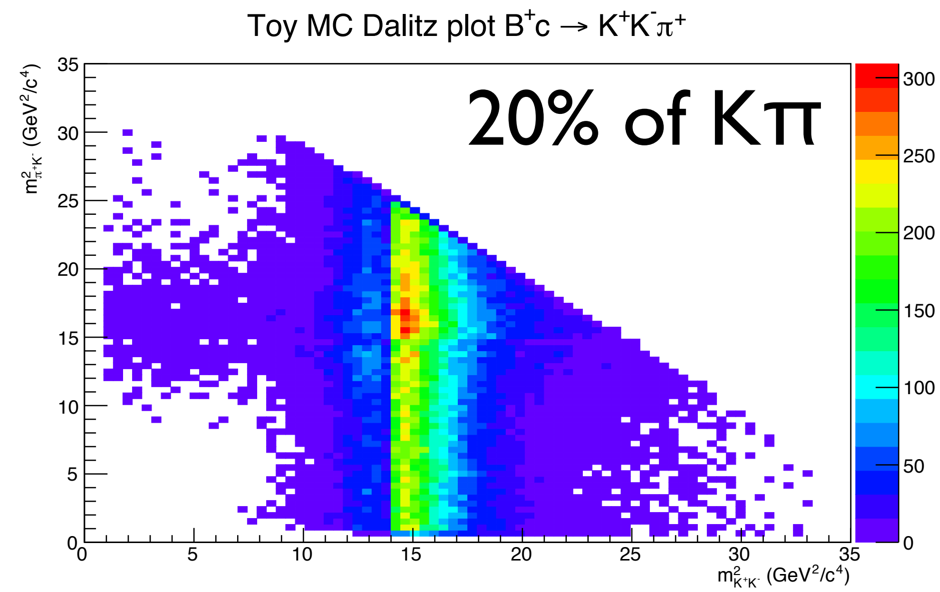


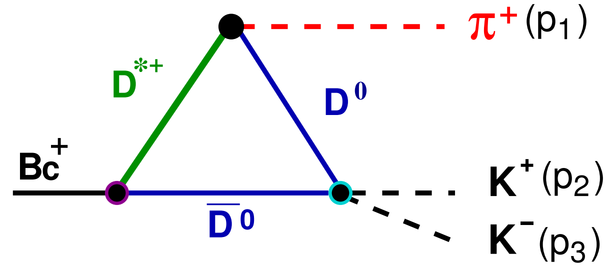


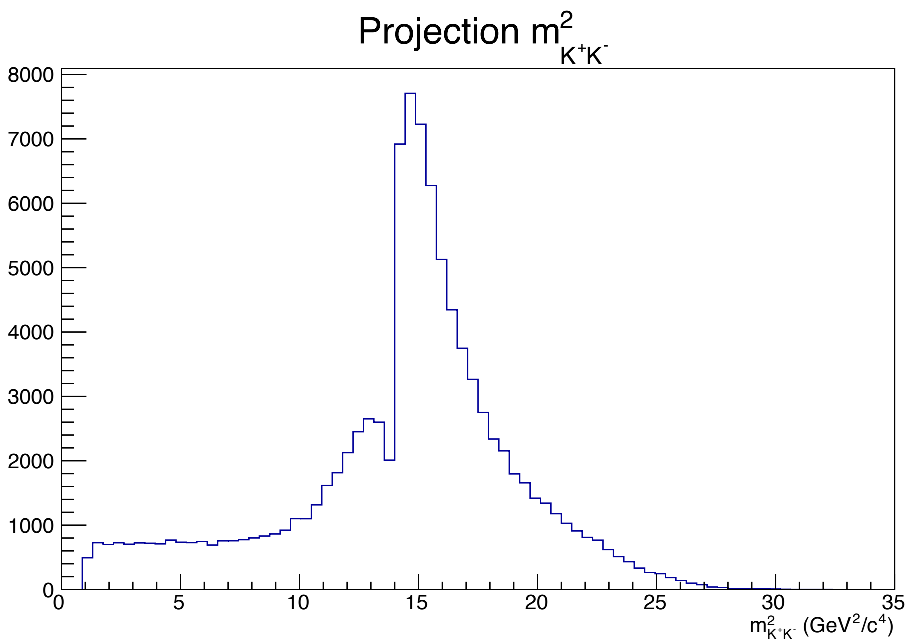


change side bands but not the minimum position (thresholds)

→ leave a signature in the middle of the Dalitz plot

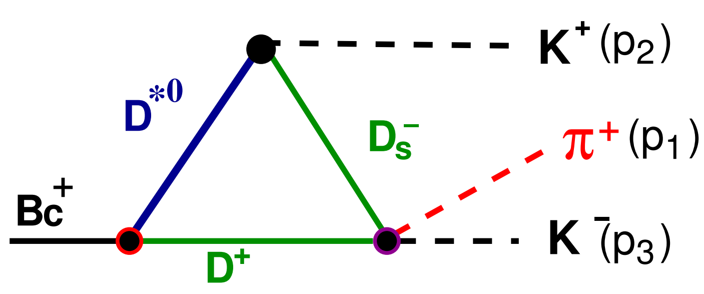
- Amplitudes projections

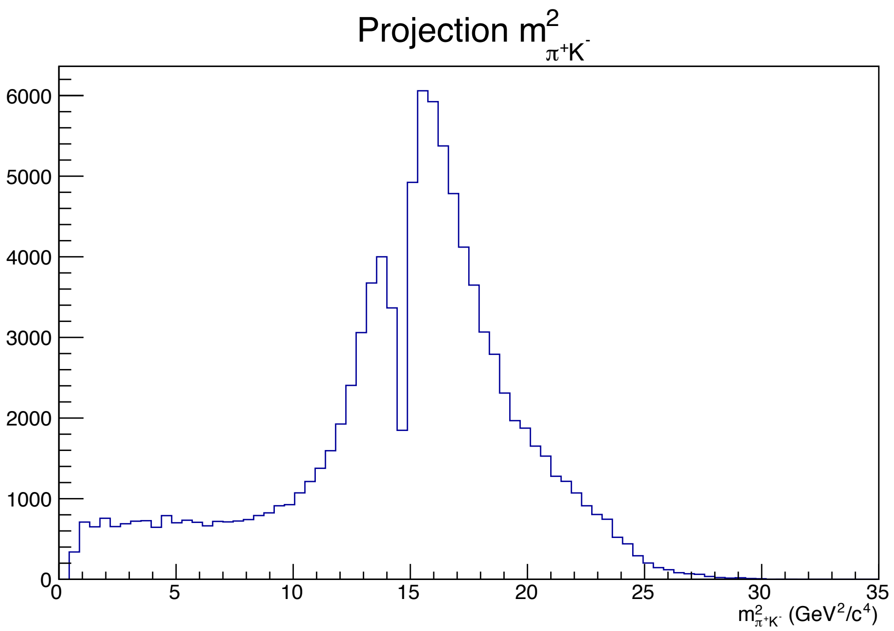




→ minima in different positions ($\neq$ thresholds)

→ $\neq$ mass parameters inside triangle and rescattering amplitudes are relevant





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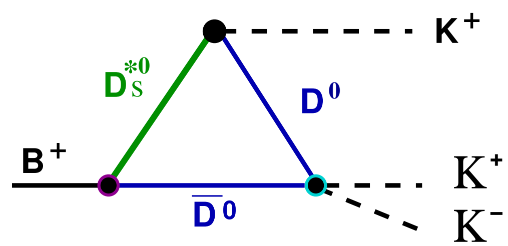
final remarks

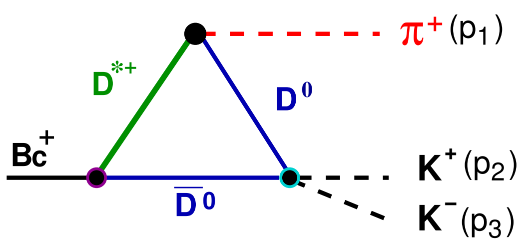
Triangle hadronic loop with charm FSI play an important role!

- $B^{\pm} \to K^{+}K^{-}K^{+}$



→ mechanism to produce CP asymmetry at high mass

- $B_c^{+} \to K^{-}K^{+}\pi^{+}$



→ main mechanism to produce this final state

- If direct production (annihilation) → expect resonances in KK and Kπ channels
  → not observed

- real data: interference between ≠ triangles & NR sources & resonances
  → canNOT change the signature of a minima between the bumps and phases!
  → LHCb run 2 to confirm

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FSI are important and play a major role in hadronic 3-body decays!

→ superposition of resonant and non-resonant at low and high energy

To do list

- different weak vertices topologies for same FS → how to add them?
    - need to merge the short and long distance descriptions!

- extend to other $B^+ \to h^+h^-h^+$

Thank you very much!

Backup slides

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FSI in three-body decay :

references

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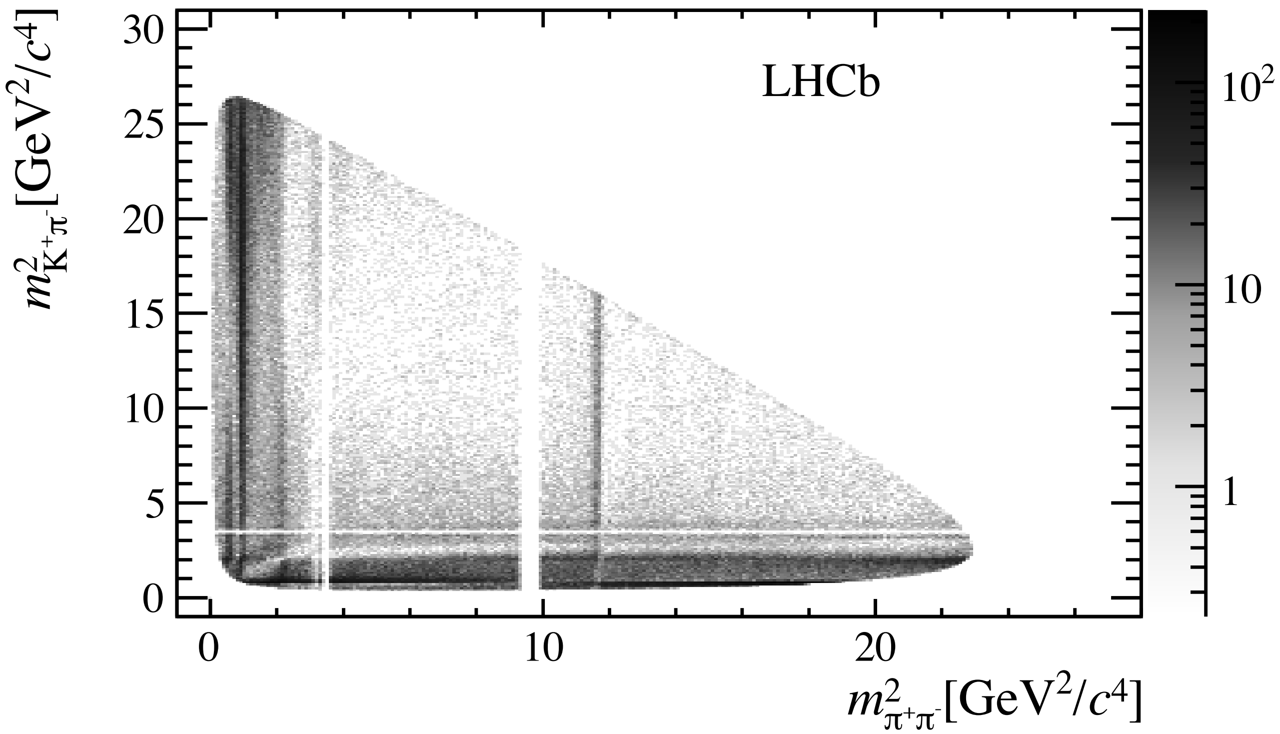
Blok, Gronau, Rosner, *Phys. Rev Letters* 78, 3999 (1997).

many more ...

if needed

Kpp



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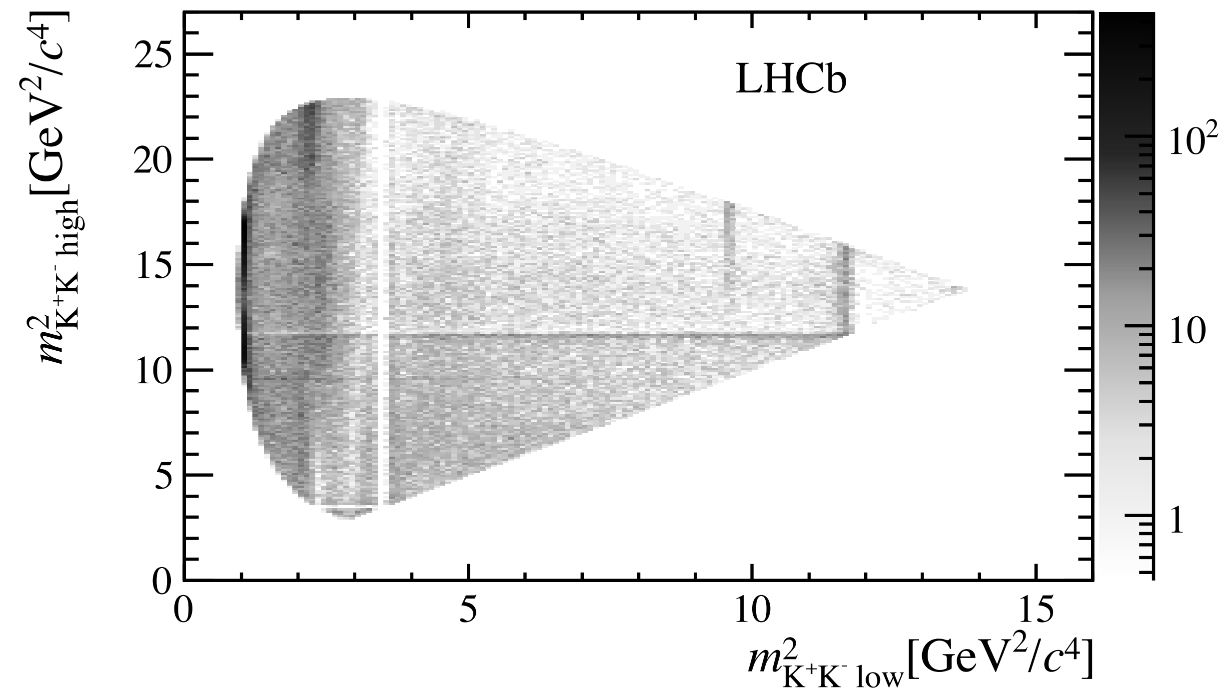

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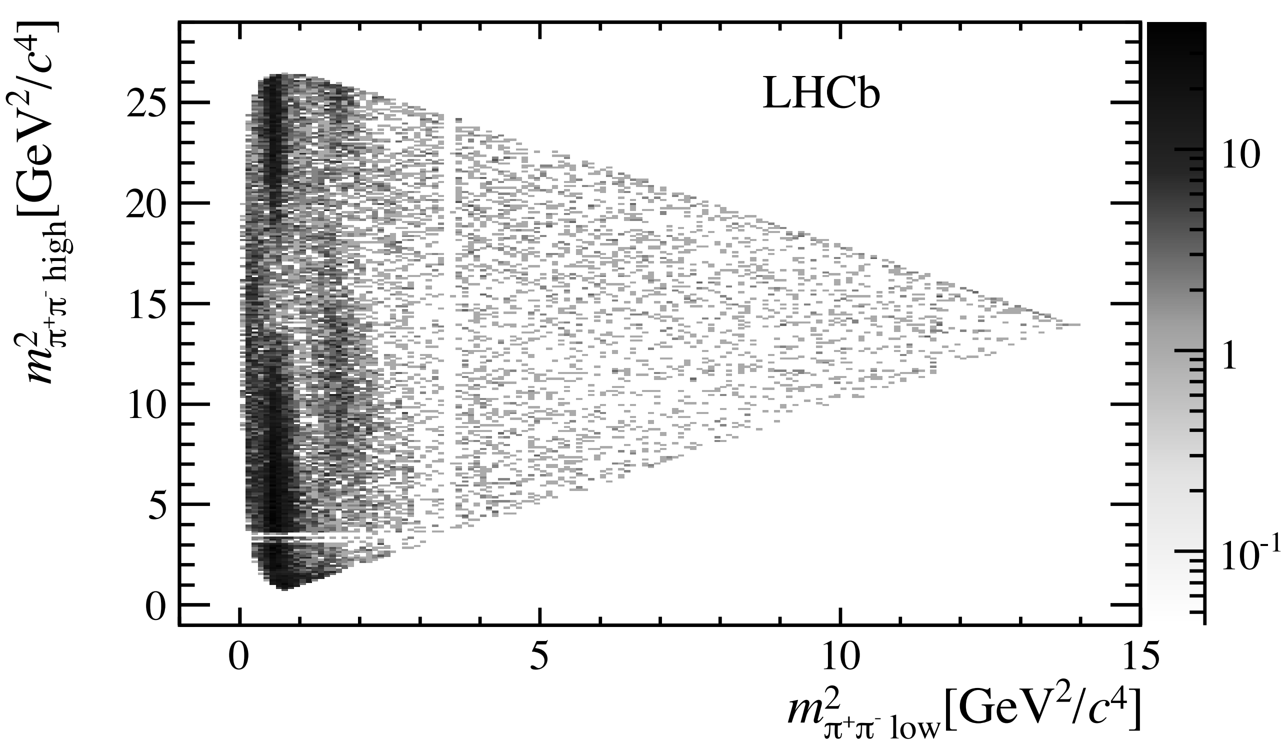

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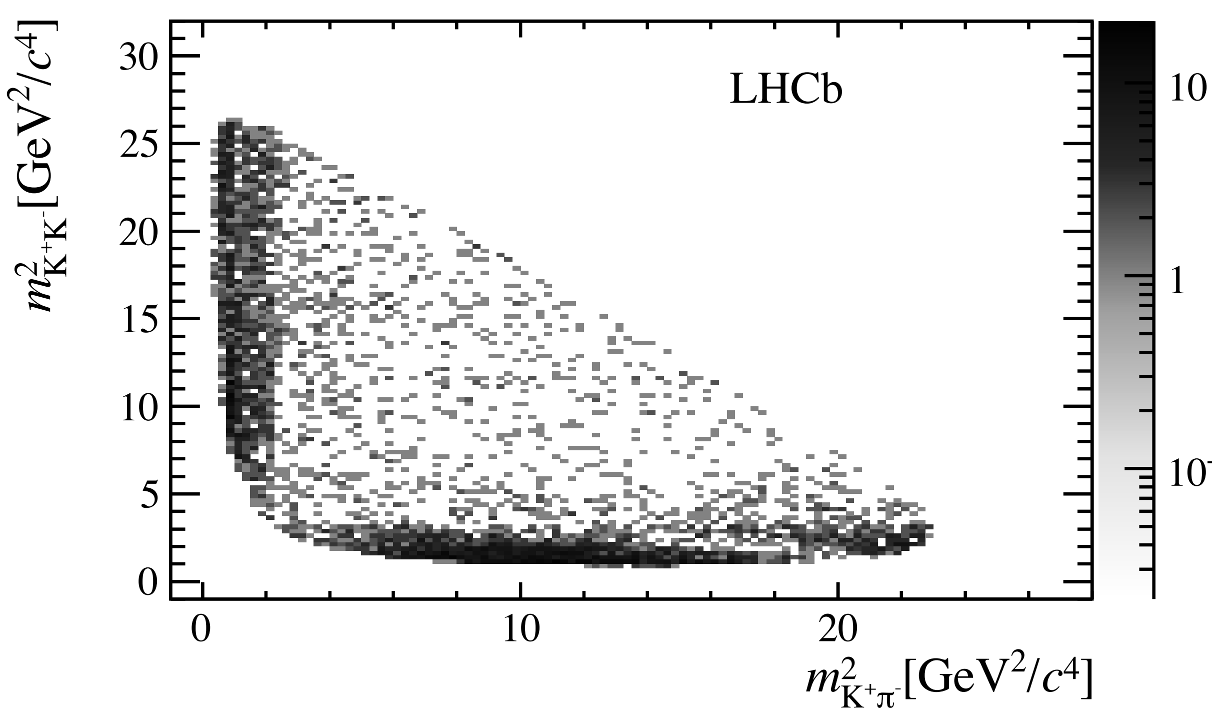

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