Charm rescattering in B decays: a new CP violation mechanism?

Patricia C. Magalhães[#]

I. Bediaga[+] and T. Frederico[*]

Technical University of Munich - TUM

+ CBPF - RJ - Brazil

* ITA - SP - Brazil

Implications of LHCb measurements and future prospects

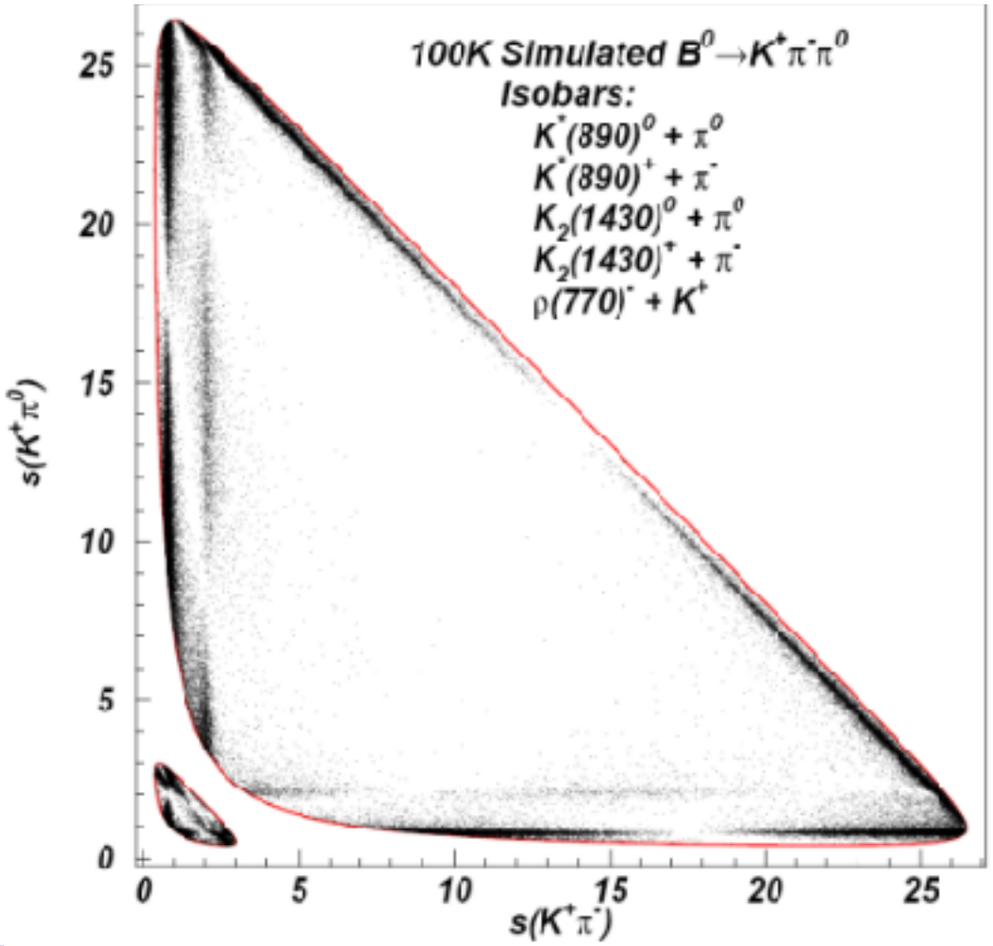
17 - 19 October 2018 - CERN

patricia.magalhaes@tum.de

Context

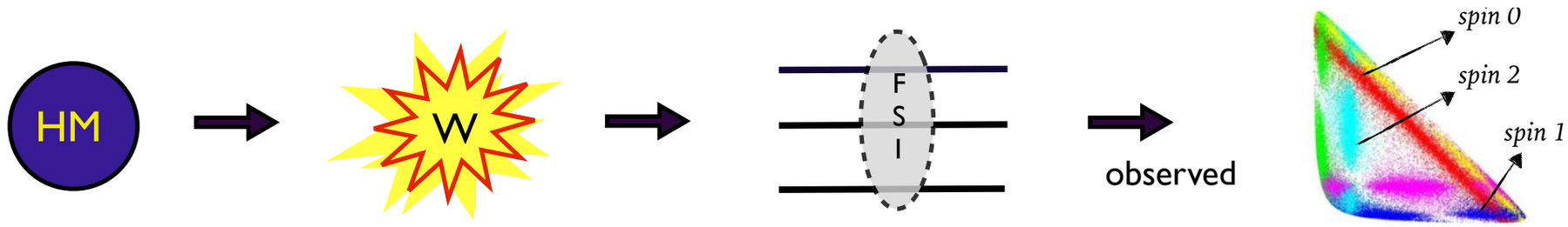
- D and B three-body HADRONIC decays are dominated by resonances
  - spectroscopy
  - information of MM interactions → no $K\bar{K}$ data available
  - study of CP-Violation → can lead to new physics
- new high data sample from LHCb → more to come from LHCb and Belle II
  → requires better models

- B and D 3-body decay…..
  - ≠ scales!!! → similar FSI
  - B phase-space → + FSI possibilities



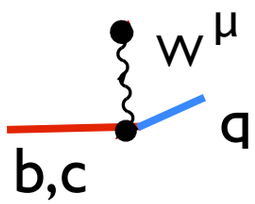
heavy meson decay

- dynamics



to extract information from data we need an amplitude MODEL

- weak primary vertex (W)



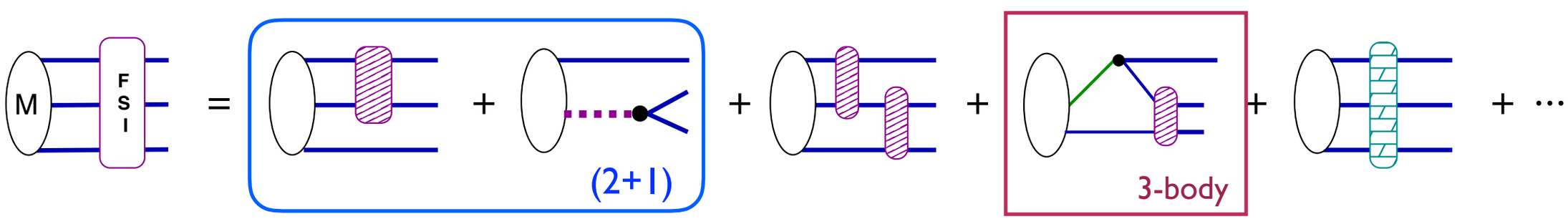
quark → hadron

- QCD factorization approach

  → not precise for 3-body

  not allow all kinds of FSI and 3-body NR

- Final State Interactions (FSI)

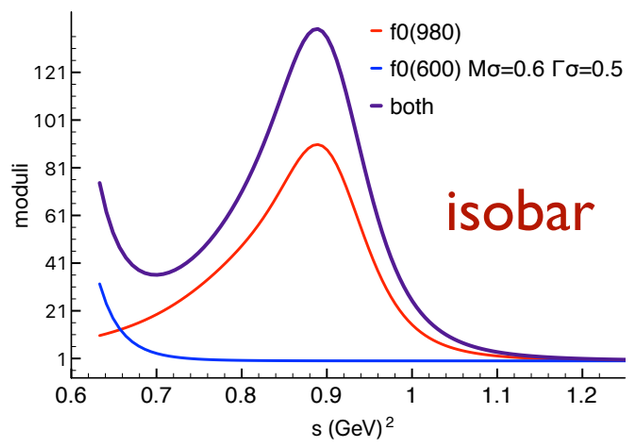


- 2-body is crucial
- full unitarity: Faddeev, Khury-Trieman, triangles

Amplitude analysis models

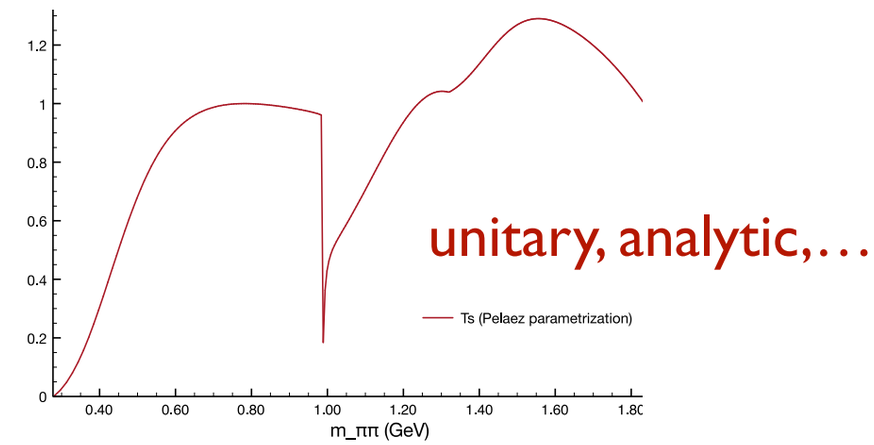
- isobar model:
  - violates two-body unitarity (2 res in the same channel);
  - do NOT include rescattering and coupled-channels;
  - non resonant as constant
  - free parameters are not connected with theory !

- ππ S-wave



→ fit could change this interference

more than 2 scalars ←



- new LHCb amplitude analysis models
  - $B^+ \to \pi^+\pi^-\pi^+$, $B^+ \to \pi^+K^-K^+$ → ππ S-wave parametrisation, rescattering, … (2+1)
    Maria's talk
  - $\bar{B}^0 \to K_s\pi^-\pi^+$ → Kπ S-wave FF from DR (2+1) PRL 120 (2018)26, 261801
  - $D^+ \to K^+K^+K^-$ → theoretical model based on Chiral Lagrangian (2+1+3) soon!

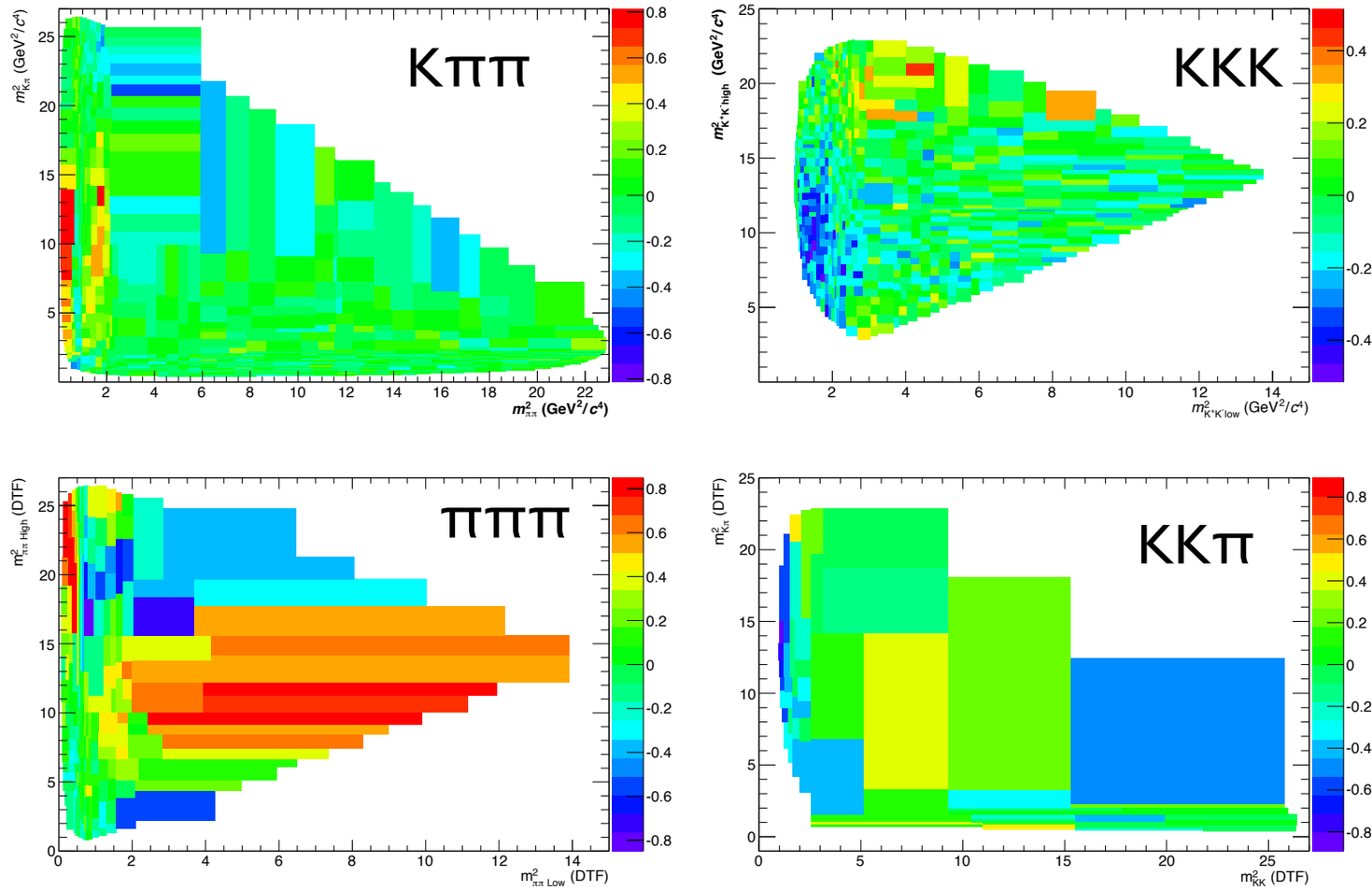
    PRD 98 056021 (2018) Aoude, Magalhaes, dos Reis & Robilotta

    → prediction for KK scattering amplitude

CPV on data

- massive localized Acp

$$B^{\pm} \to hhh$$



LHCb PRD90 (2014) 112004

- Charge Parity Violation :

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

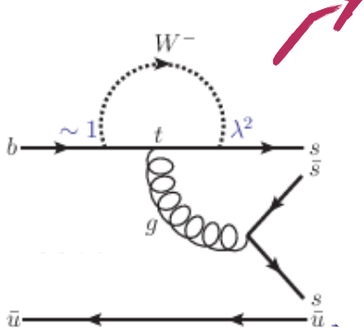
$$|A_{M\to f}|^2 - |A_{\bar{M}\to \bar{f}}|^2 = -4A_1A_2\, sin(\delta_1-\delta_2)\, \sin(\phi_1-\phi_2) \neq 0$$

→ two ≠weak and strong phases

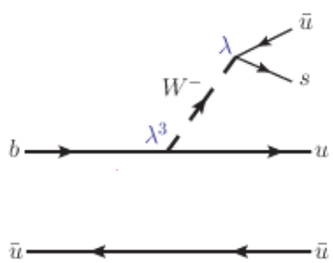
- BSS model  +  not enough!

Bander Silverman & Soni PRL 43 (1979) 242

strong phase



weak phase: CKM



- hadronic interactions

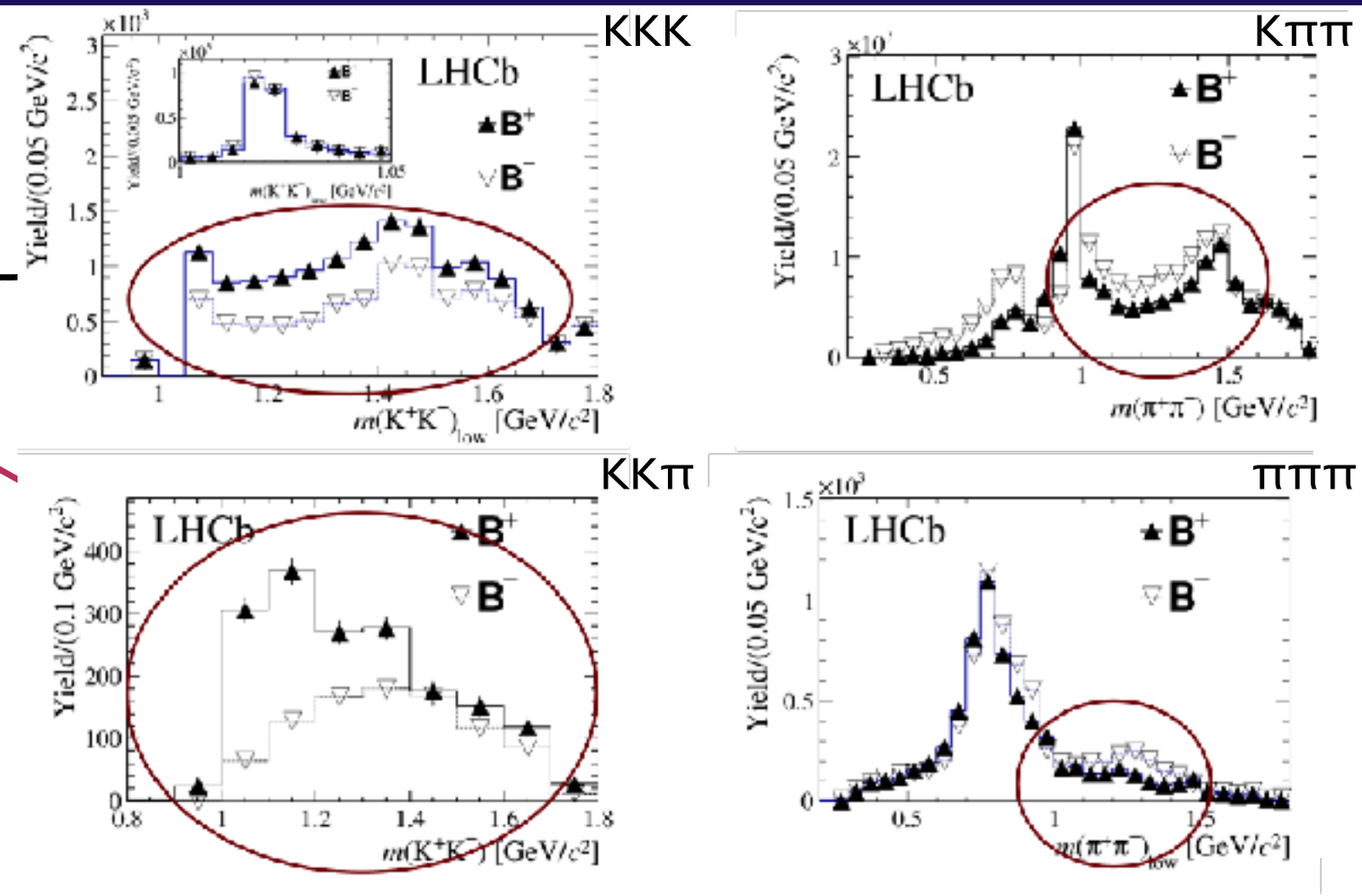
→ strong phase

CPV on data

- low-energy CPV [1 - 2] GeV

$$\pi\pi \to KK$$

Frederico, Bediaga & Lourenço
PRD89(2014)094013



LHCb PRD90 (2014) 112004

- FSI → strong phase

Wolfenstein PRD43 (1991) 151

- CPT:

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

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

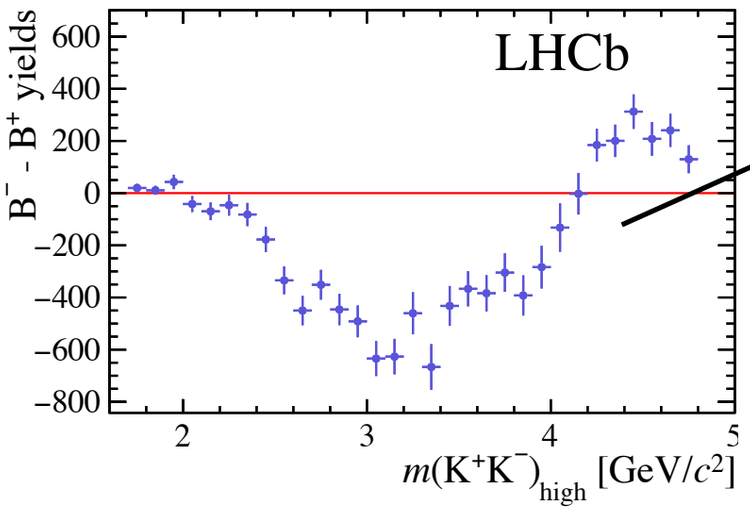
$$\bar{\Gamma}_{total} = \bar{\Gamma}_1 + \bar{\Gamma}_2 + \bar{\Gamma}_3 + \bar{\Gamma}_4 + \bar{\Gamma}_5 + \bar{\Gamma}_6 + \ldots$$

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

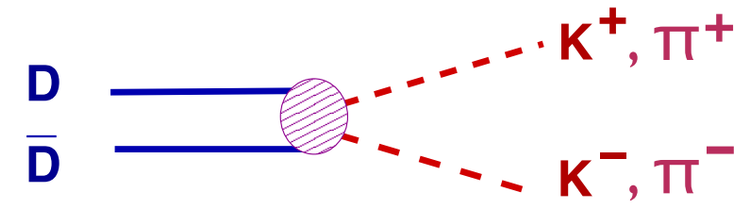
- high mass CPV?

CPV high energy

- CPV high mass?



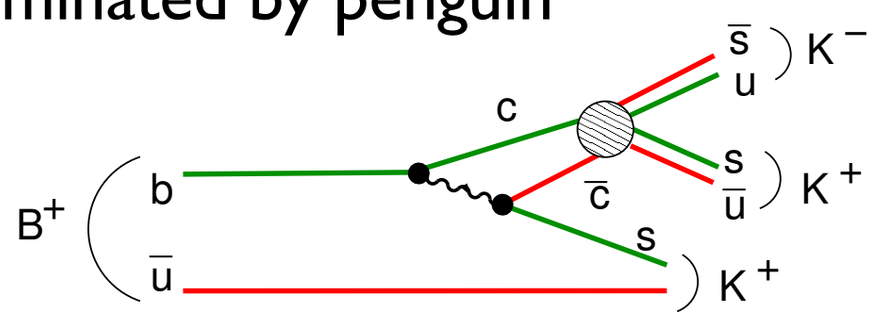
~ $D\bar{D}$ open channel →

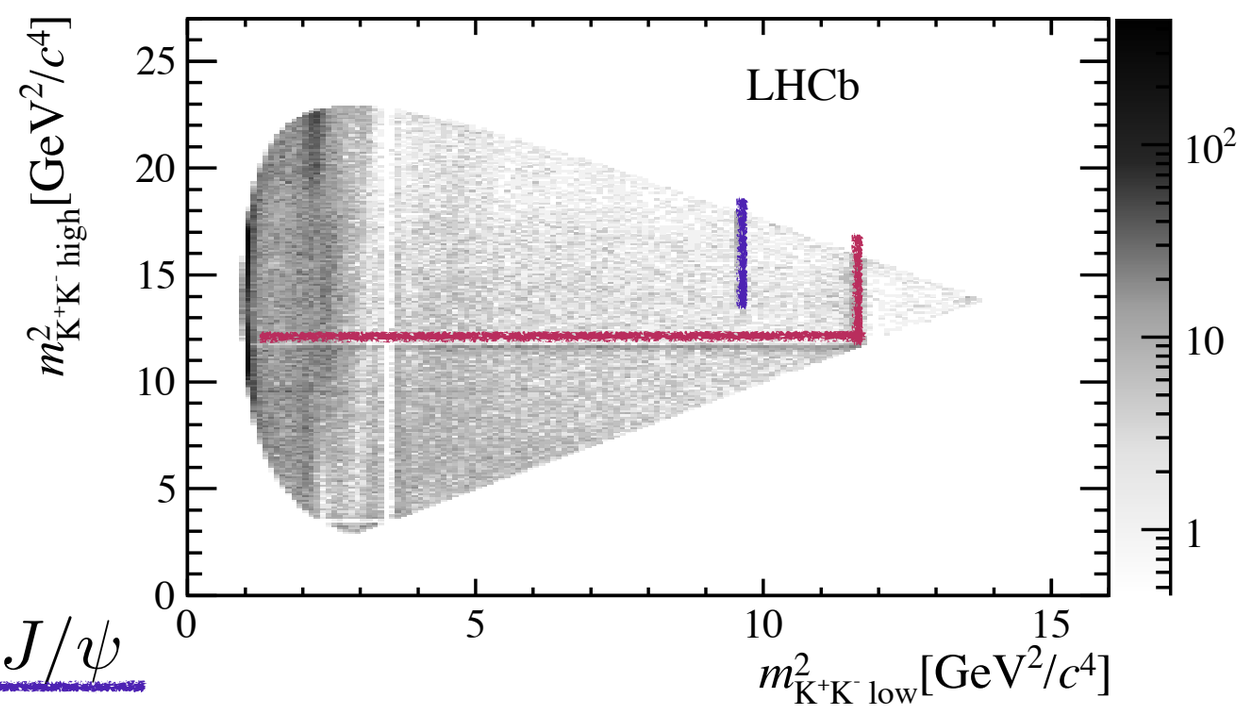


same opposite Acp observed in coupled-channels

→ charm intermediate processes as source of strong phase

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





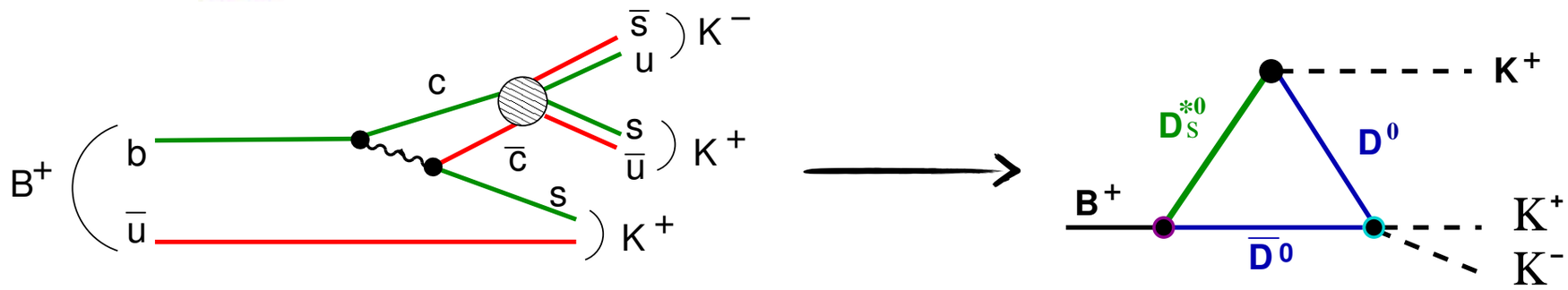
- presence of charm resonances: χ_{c0} J/ψ

Charm rescattering

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

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

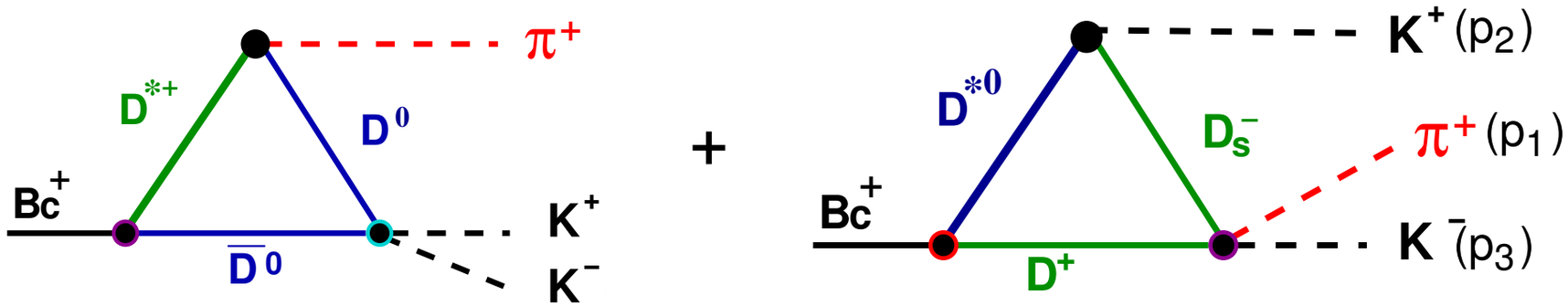
PLB 780 (2018) 357



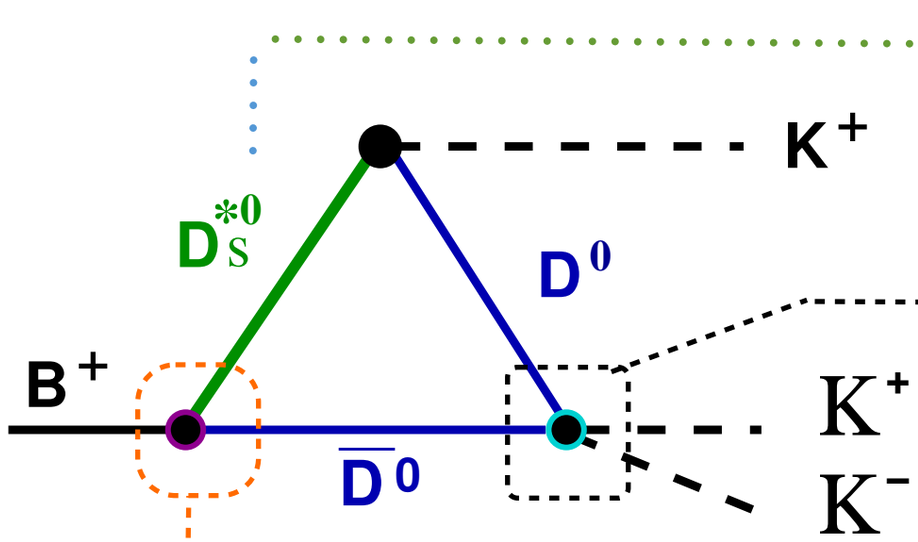
other application

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

PLB 785 (2018) 581



hadronic loop



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

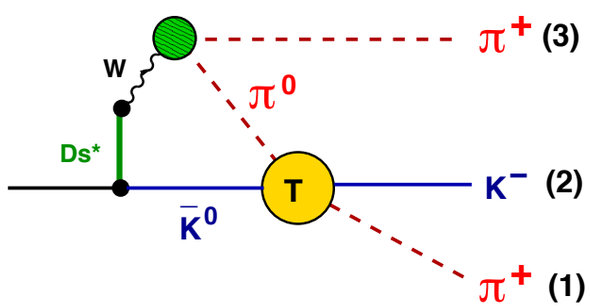
- $Br\,[B \to D D_s^*]$ **~1%** → **1000 x** $Br\,[B \to KKK]$

- 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]

$D^0\bar{D}^0 \to K^+K^-$ 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 $k_0 = \sqrt{\frac{s_0-s_{th}}{4}}$

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

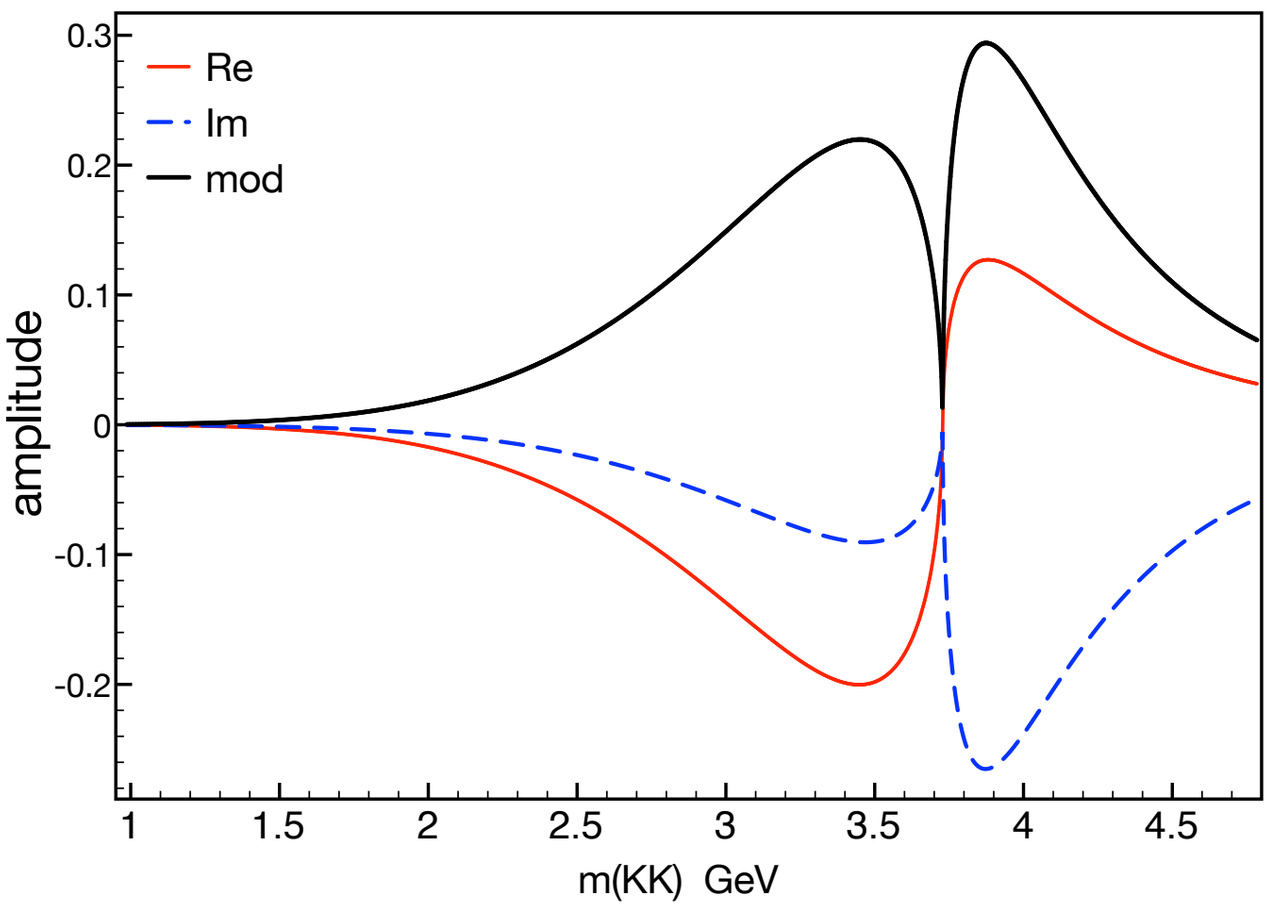
$$t_{\beta,\alpha} = \sqrt{1-\eta^2}e^{i(\alpha+\beta)}$$

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

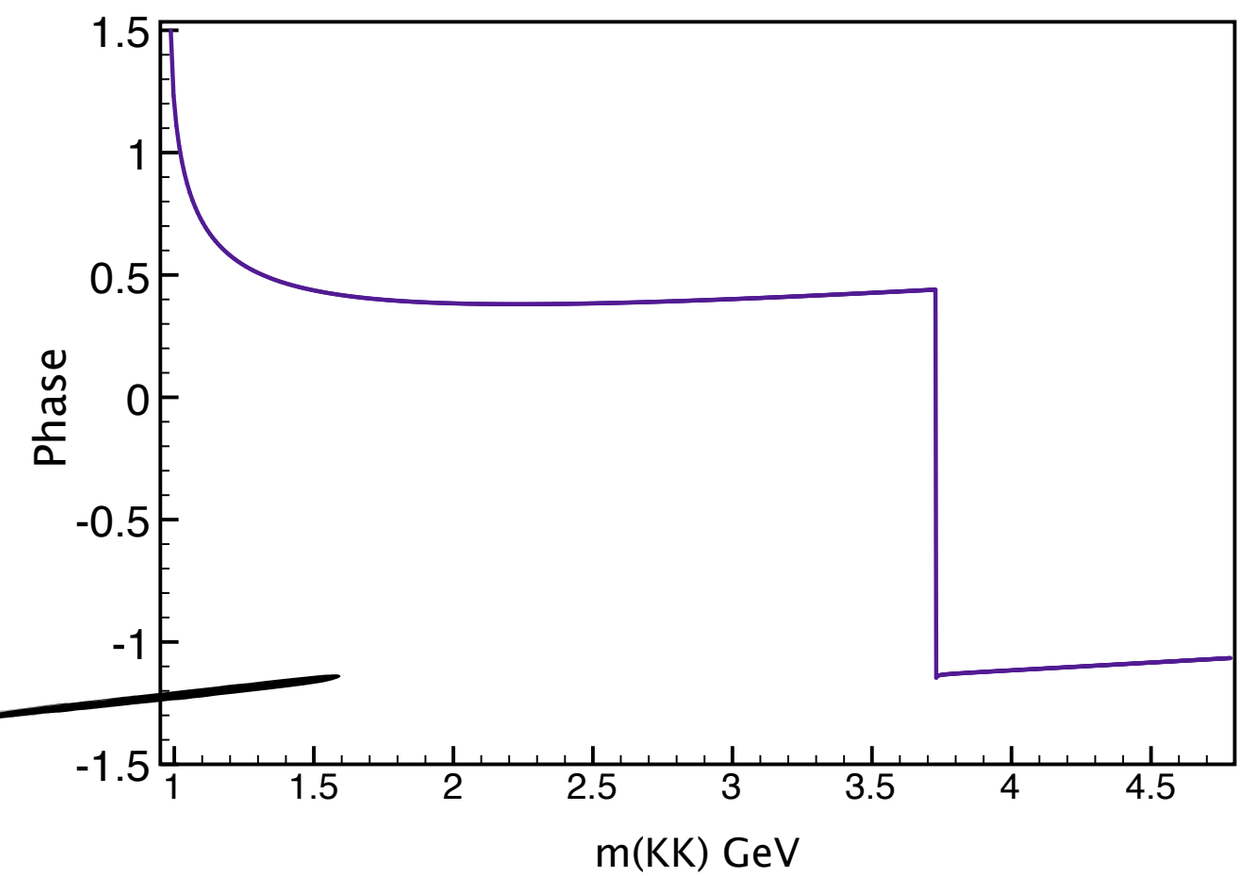
$$T_{\bar{D}^0 D^0 \to KK}(s) = \frac{s^\alpha}{s^\alpha_{th\,D\bar{D}}} \frac{2\kappa_2}{\sqrt{s_{th\,D\bar{D}}}} \left(\frac{s_{th\,D\bar{D}}}{s+s_{QCD}}\right)^{\xi+\alpha} \left[\left(\frac{c+bk_1^2-ik_1}{c+bk_1^2+ik_1}\right)\left(\frac{\frac{1}{a}+\kappa_2}{\frac{1}{a}-\kappa_2}\right)\right]^{\frac{1}{2}},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

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

→ parameters fix by data!



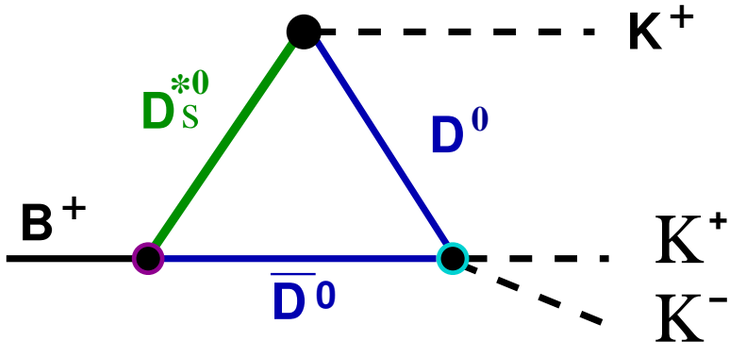
→ zero at threshold

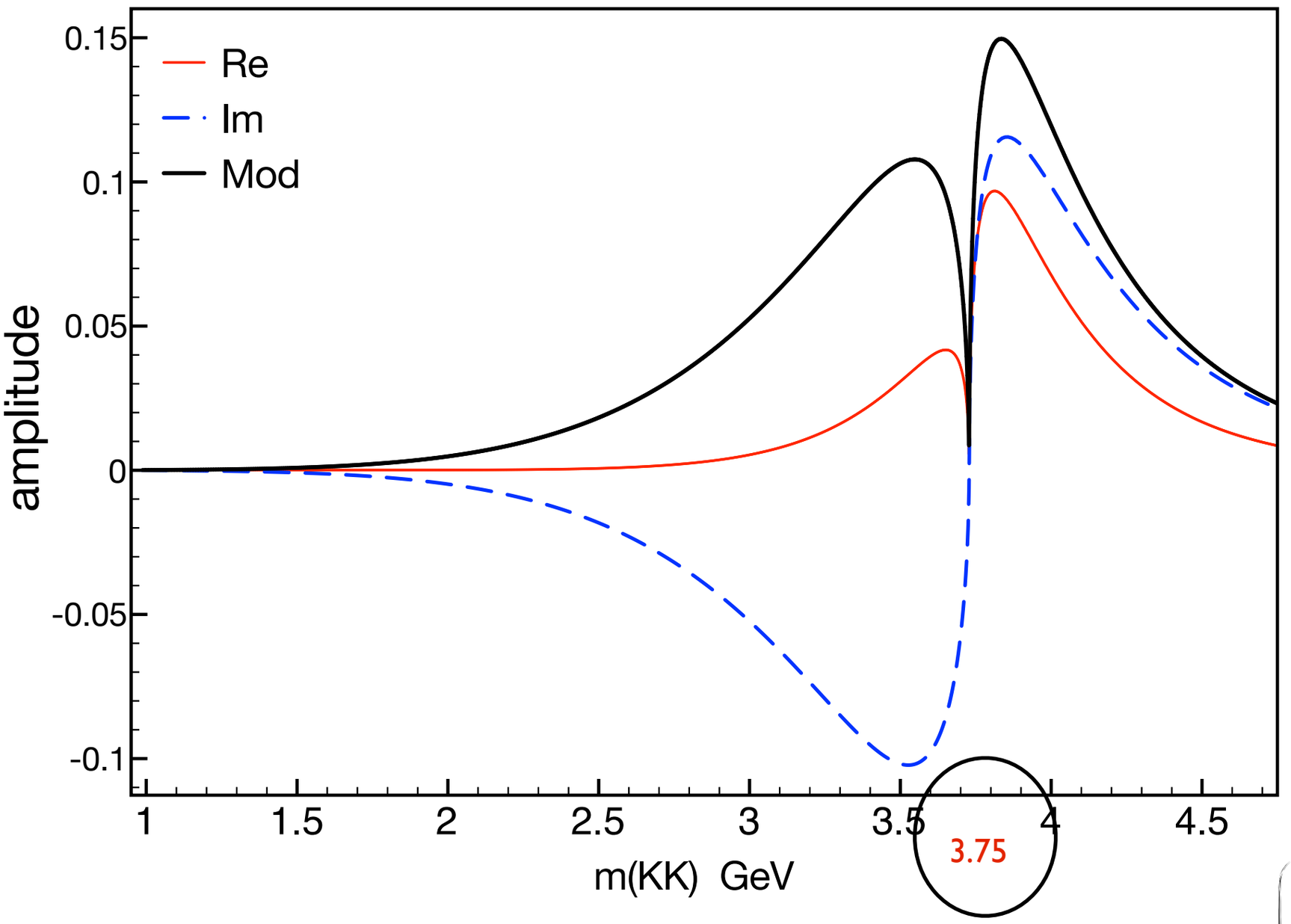


discontinuity at threshold ←

hadronic loop

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



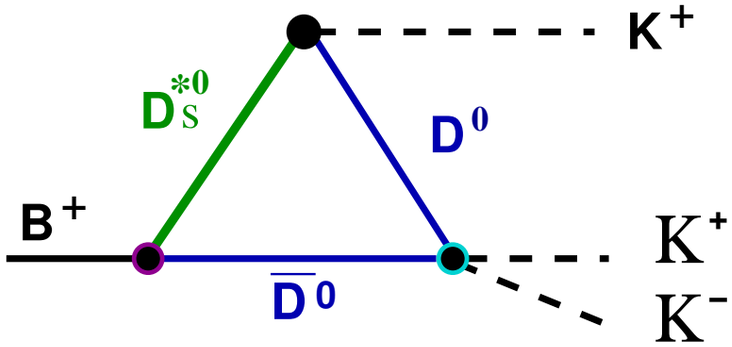


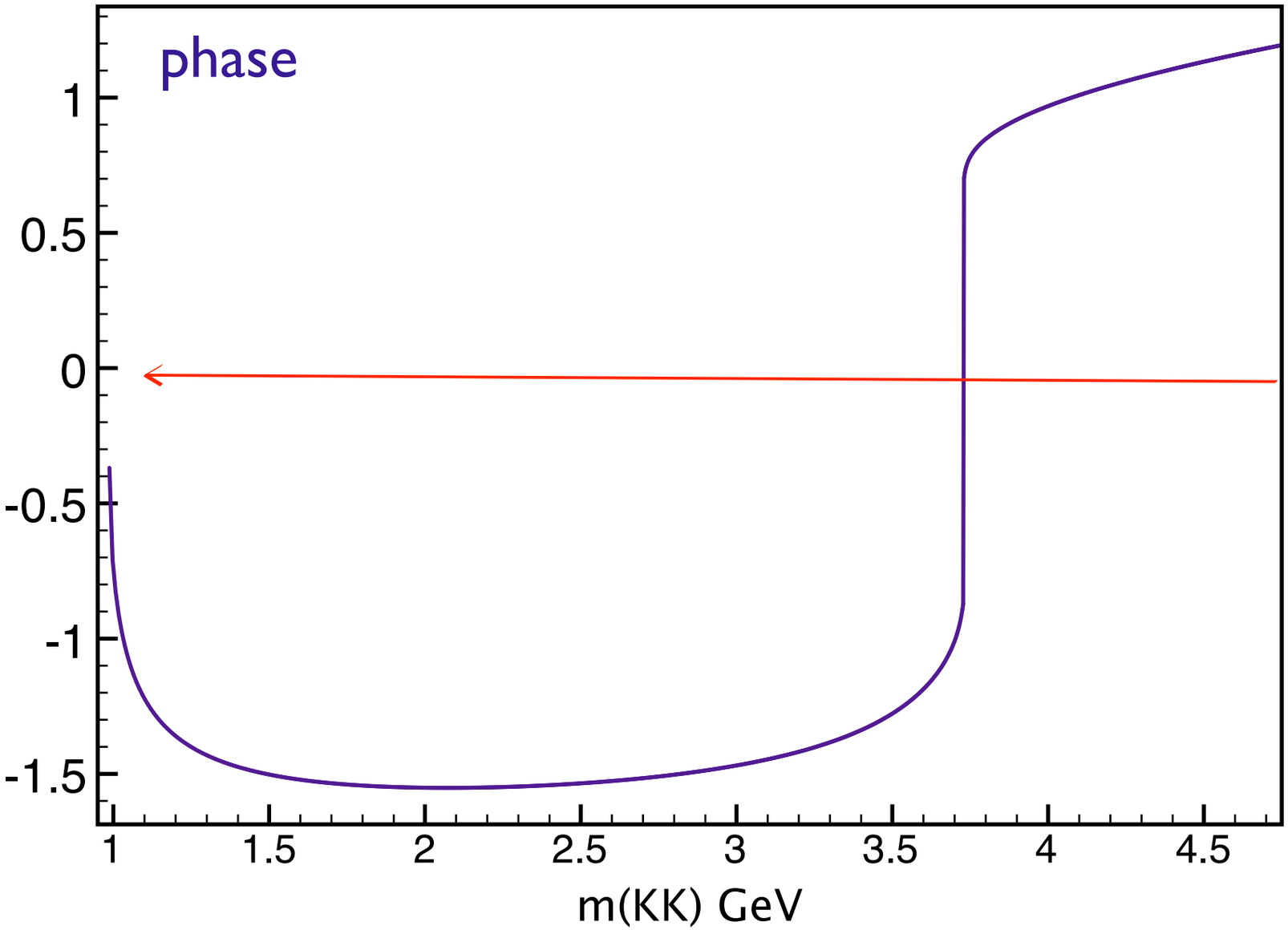
→ zero in between two bumps

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

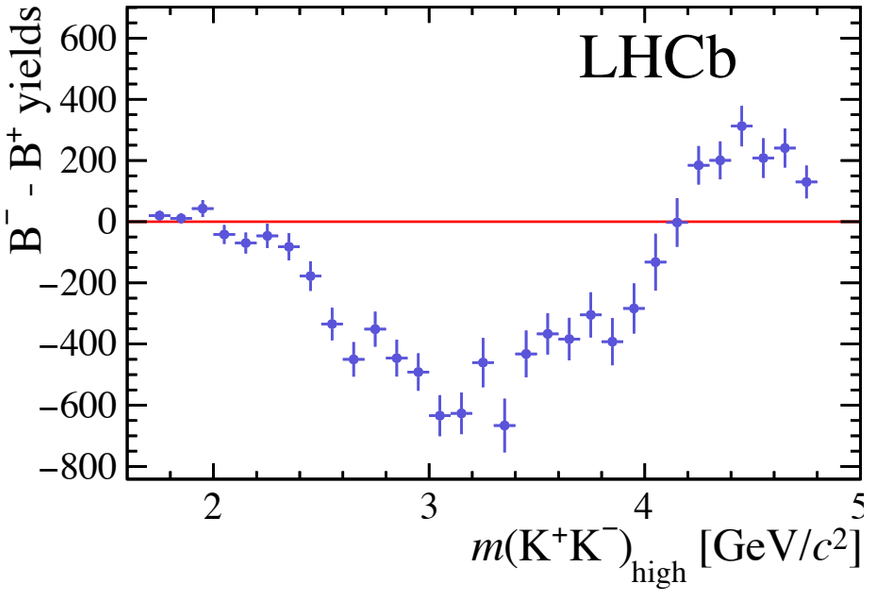
hadronic loop

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





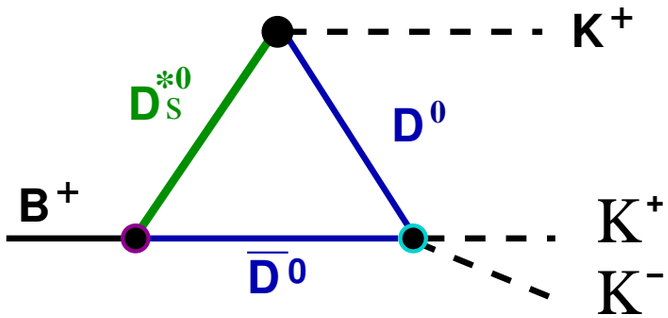
→ change signal in the same region as Acp data

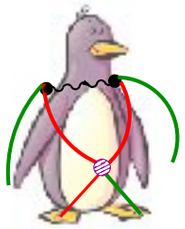


→ can explain change CPV signal in DP!!!

remarks on $B^+ \to K^- K^+ K^+$ charm rescattering

- 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

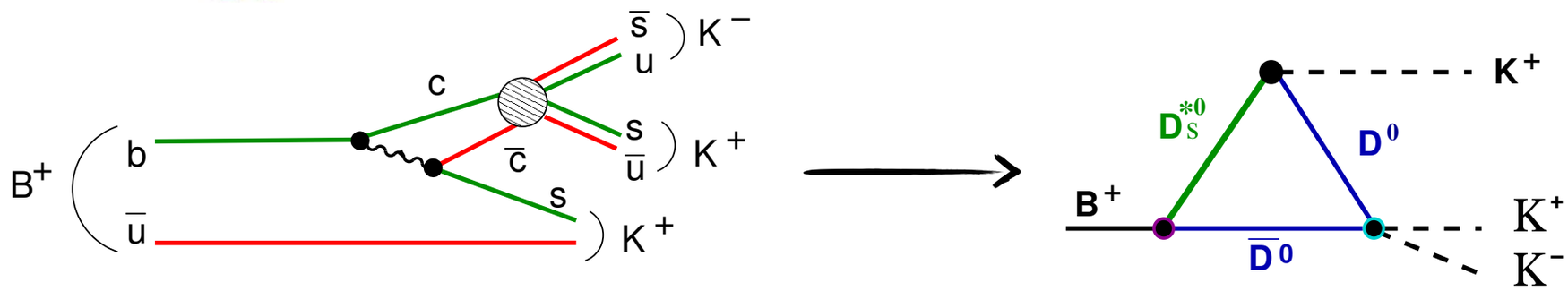
  → can shift the position of the CP asymmetry sign change

→ should be tested in data ANA!

Charm rescattering on $B_c^+ \to K^- K^+ \pi^+$

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

PLB 780 (2018) 357

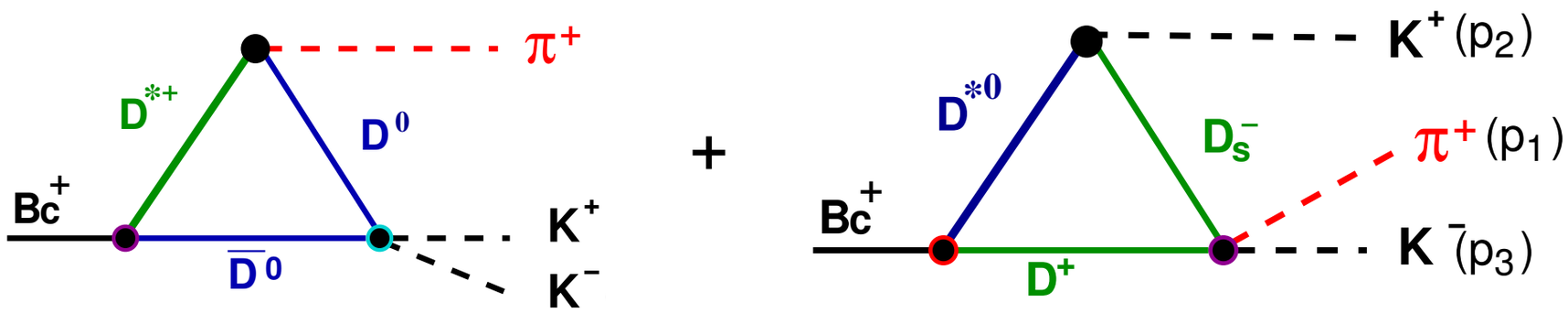


Cabibbo favoured V_{bc}

interesting application

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

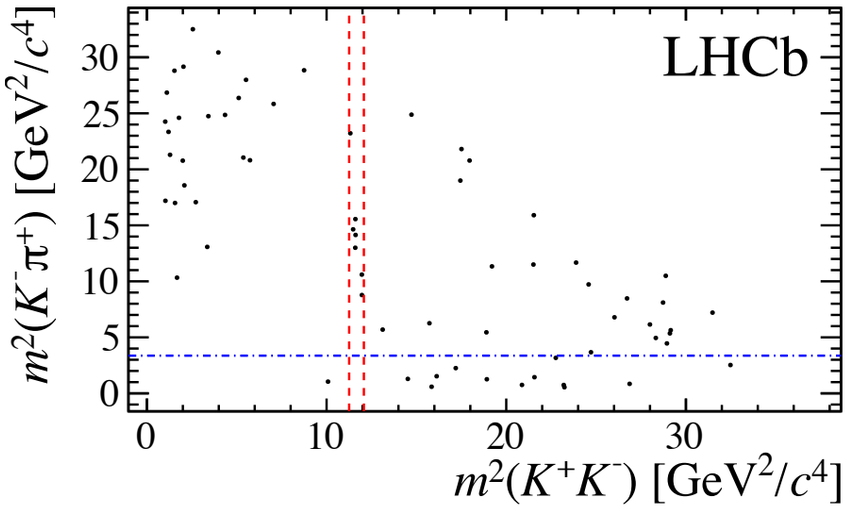
PLB 785 (2018) 581



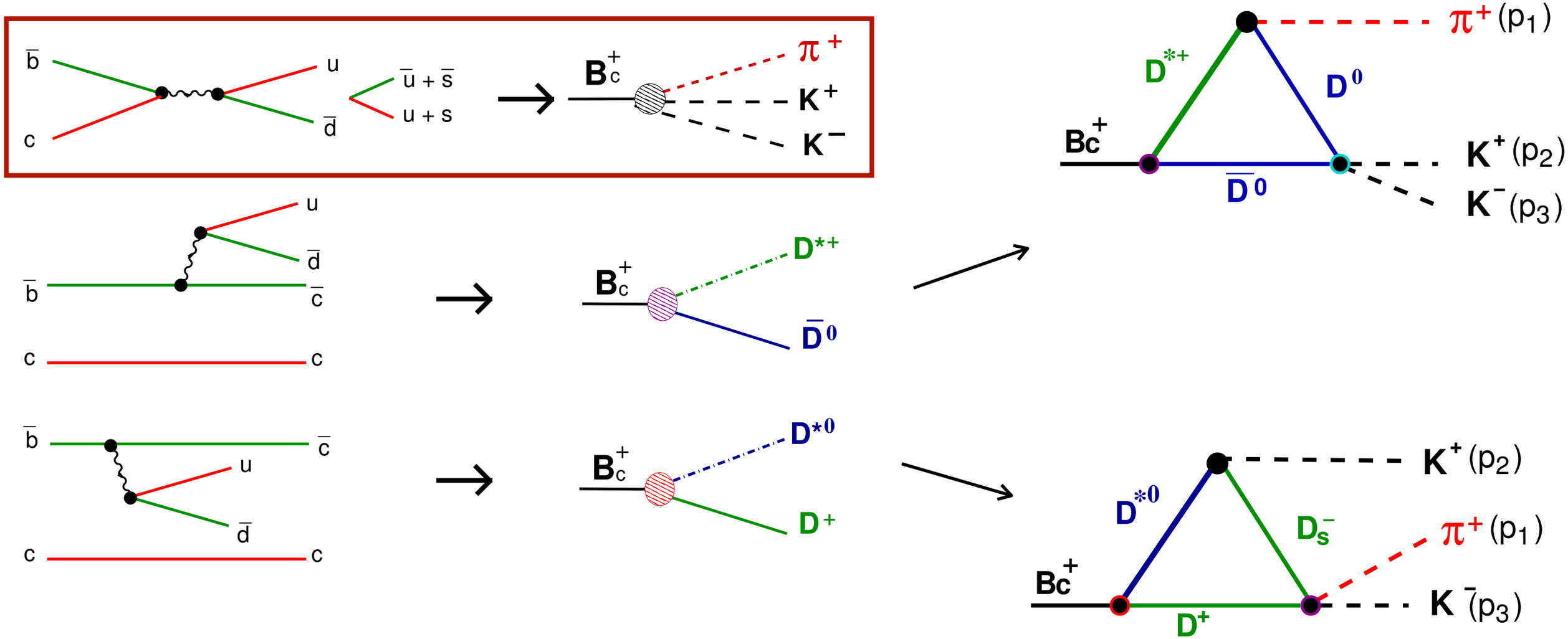
Charm rescattering

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

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

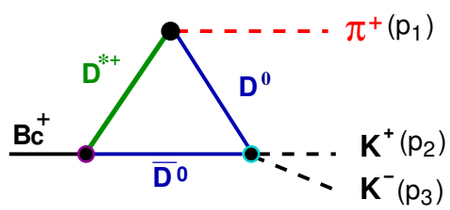


- very suppressed direct production (annihilation)
- charm rescattering can be the dominant mechanism

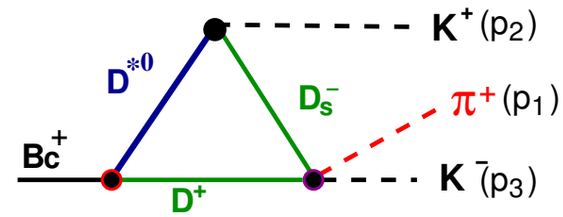


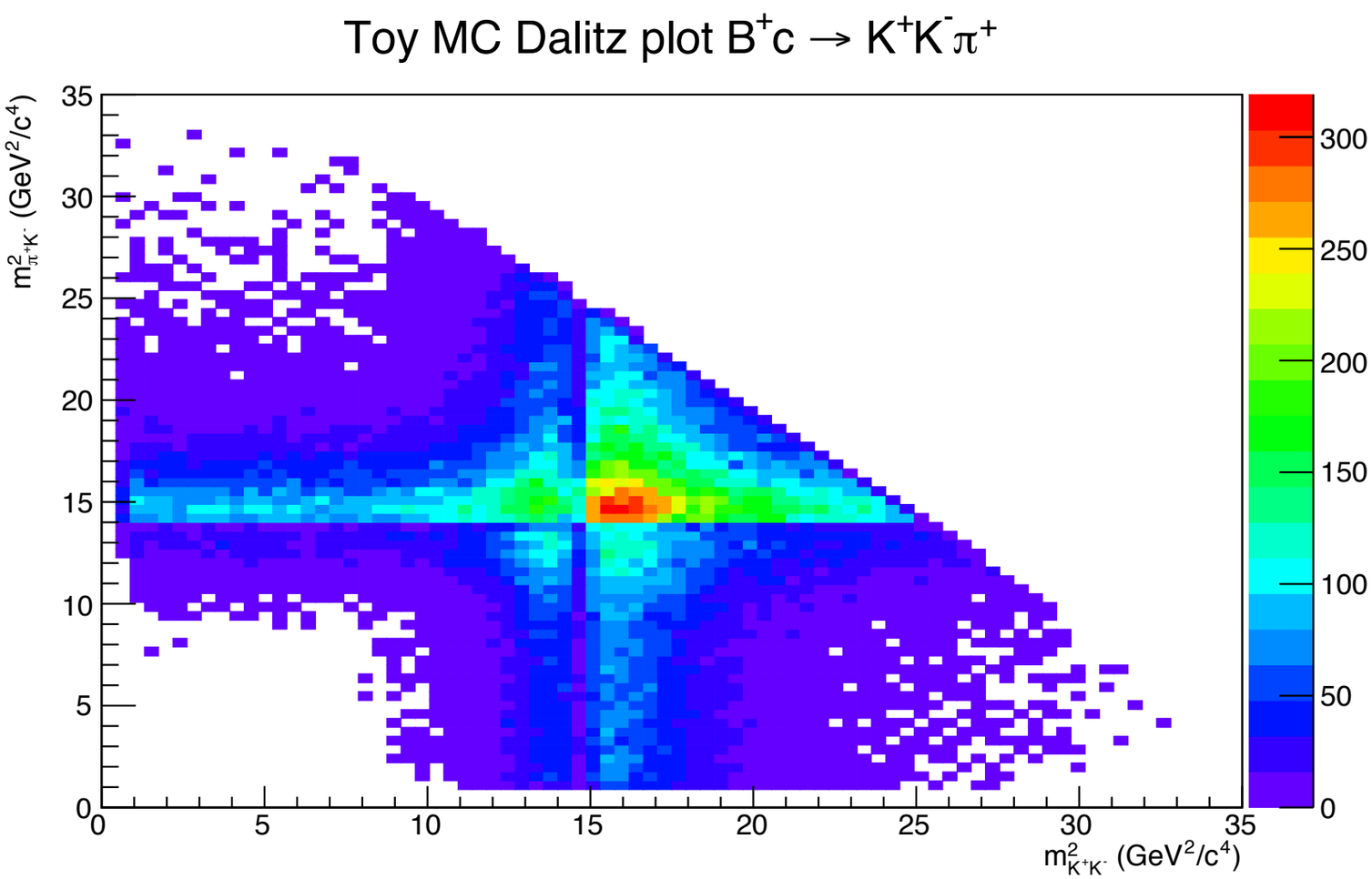
Charm rescattering $B_c^+ \to K^- K^+ \pi^+$

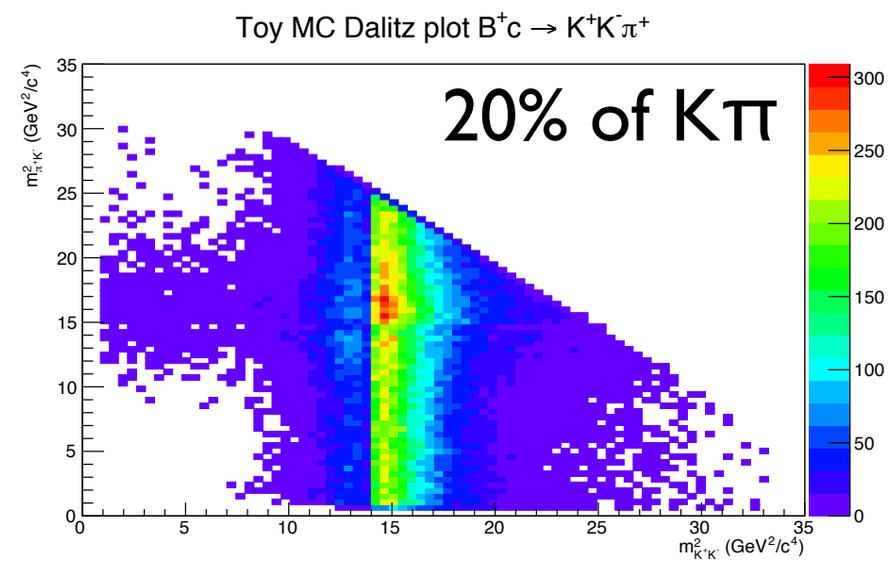
- toy Monte Carlo generator



&







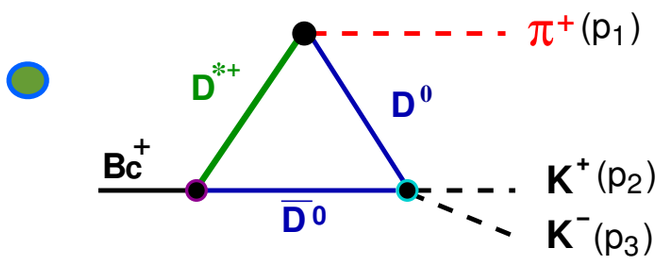
↓

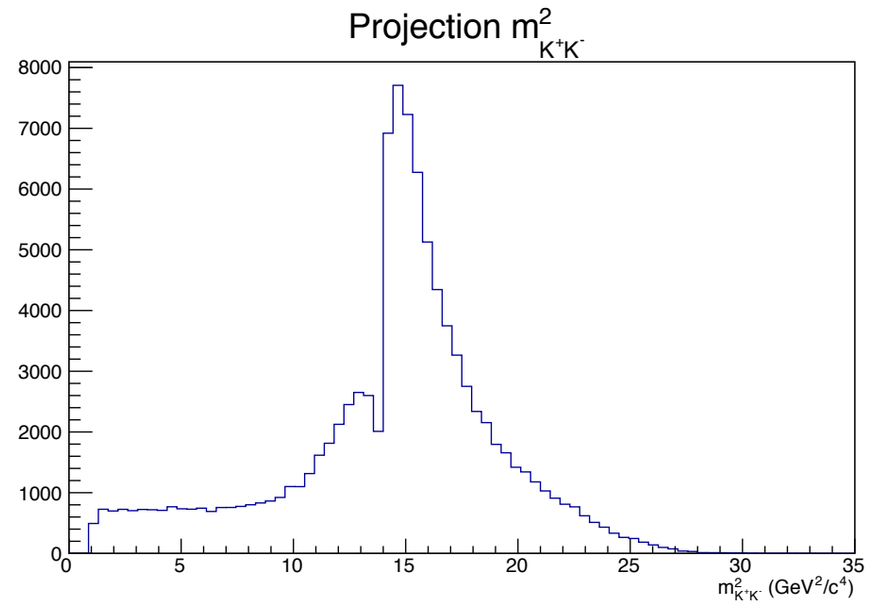
change side bands but not the minimum position (thresholds)

→ leave a signature in the middle of the Dalitz plot

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

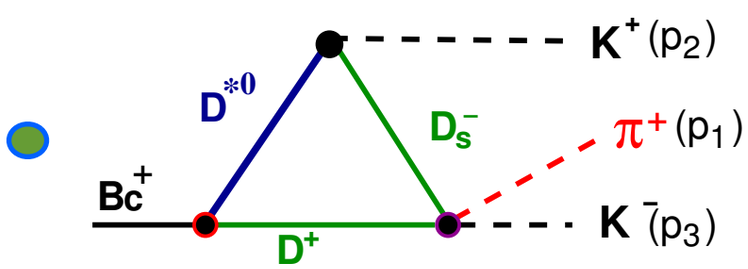
- Amplitudes projections

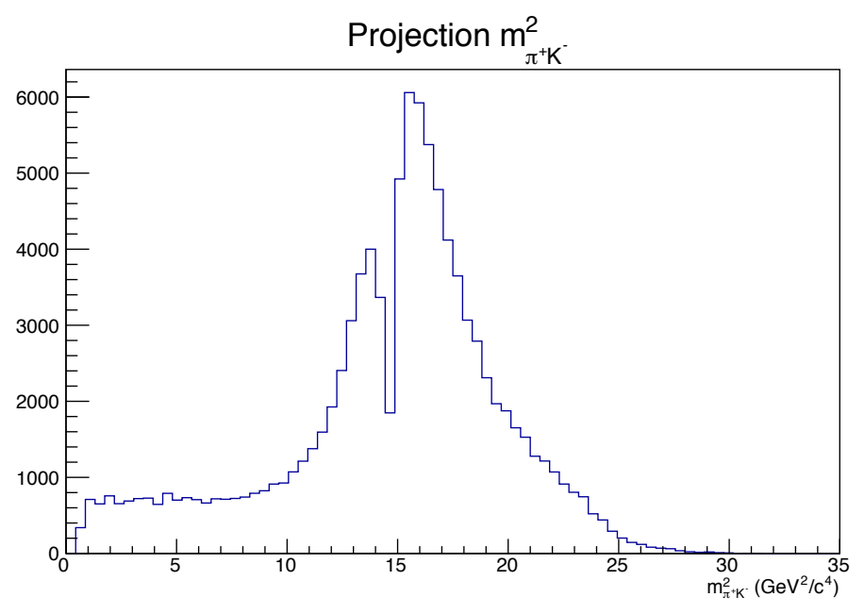




→ minima in different positions (≠ thresholds)

→ ≠ mass parameters inside triangle and rescattering amplitudes are relevant

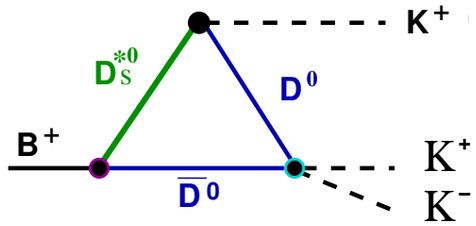




final remarks

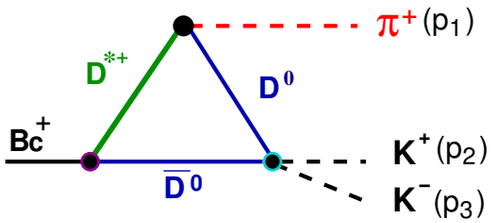
Triangle hadronic loop with charm FSI play an important role!

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



→ 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

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

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

- different weak vertices topologies for same FS → how to add them?
  - need to merge the short and long distance descriptions!
- to improve ANA and learn from data we need: work in progress

→ good analytic and unitary 2-body coupled-channels up to high energy;

→ B-decays must include diff allowed dynamics at high-energy

→ charm rescattering!!

Thank you very much!

Backup slides

FSI in three-body decay :

references

I. Bediaga, I., T. Frederico, T. and O. Louren Phys. Rev. D89, 094013(2014),[arXiv:1307.8164]

J. H. Alvarenga Nogueira, I. Bediaga, A. B. R. Cavalcante, T. Frederico and O. Louren¸ Phys. Rev. D92, 054010 (2015) [ArXiv:1506.08332].

PC Magalhães and I Bediaga arXiv:1512.09284;

P. C Magalhães and R.Robilotta, Phys. Rev. D92 094005 (2015) [arXiv:1504.06346] ; P.C.Magalhães et. al. Phys. Rev. D84 094001 (2011) [arXiv:1105.5120]; P.C. Magalhães and Michael C. Birse, PoS QNP2012, 144 (2012).

I. Caprini, Phys. Lett. B 638 468 (2006).

Bochao Liu, M. Buescher, Feng-Kun Guo, C. Hanhart, and Ulf-G. Meissner, Eur. Phys. J. C 63 93 (2009).

F Niecknig and B Kubis - JHEP 10 142 (2015) ArXiv:1509.03188

H. Kamano, S.X. Nakamura, T.-S.H. Lee and T. Sato, Phys. Rev. D 84, 114019 (2011).

S. X. Nakamura, arXiv:1504.02557 (2015).

J. -P. Dedonder, A. Furman, R. Kaminski, L. Lesniak, L. and B. Loiseau, Acta Phys. Polon. B42, 2013 (2011), [Arxiv: 1011.0960]

J.-P. Dedonder, R. Kaminski, L. Lesniak, and B. Loiseau, , Phys. Rev.D89, 094018 (2014).

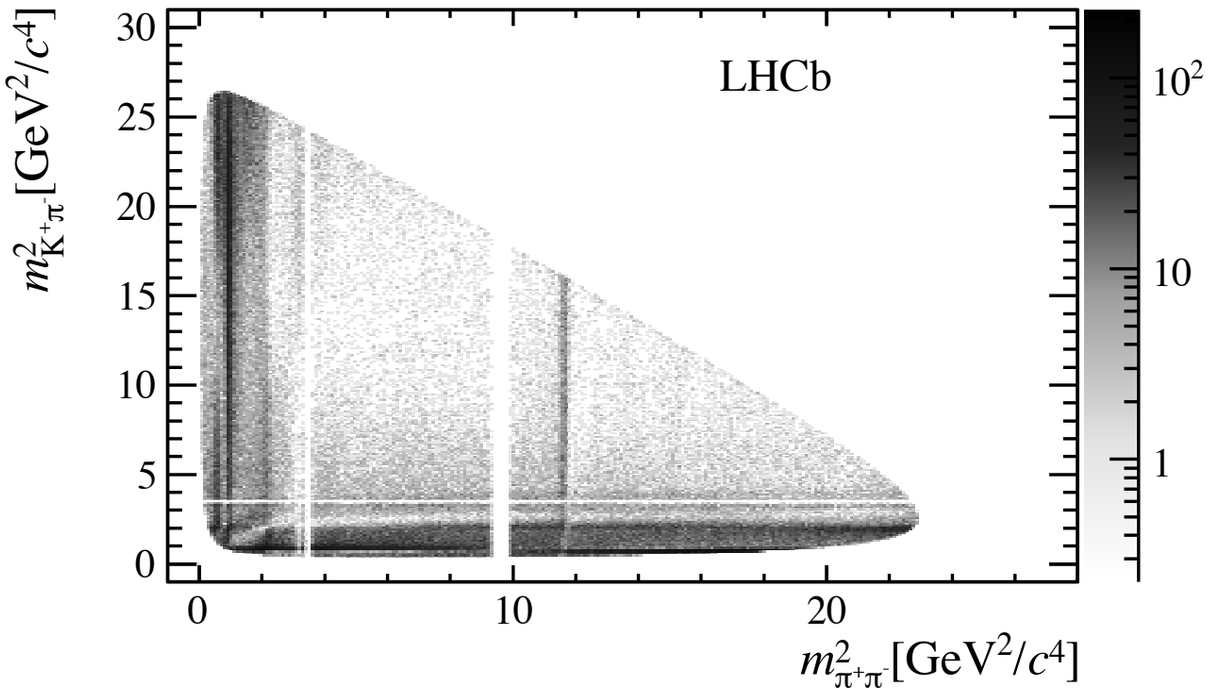
Donoghue *et al.*, *Phys. Rev Letters* 77(1996) 2178;

Suzuki,Wolfenstein, Phys. Rev. D 60 (1999)074019;
Falk et al. Phys. Rev. D 57,4290(1998);
Blok, Gronau, Rosner, *Phys. Rev Letters* 78, 3999 (1997).

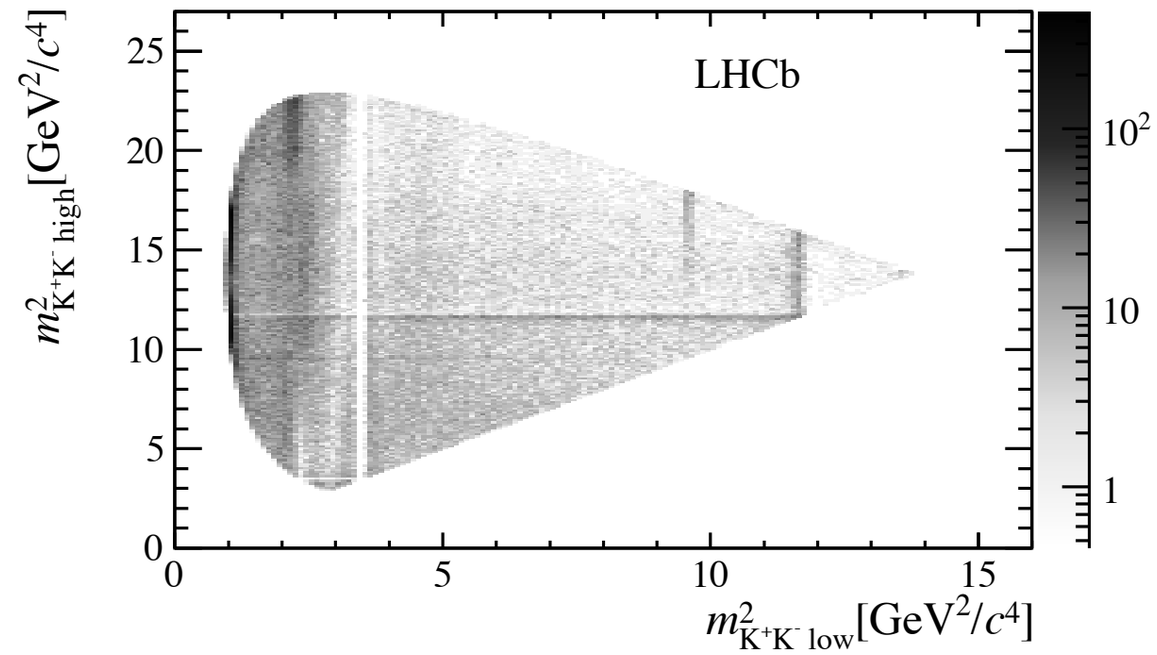
many more ...

if needed

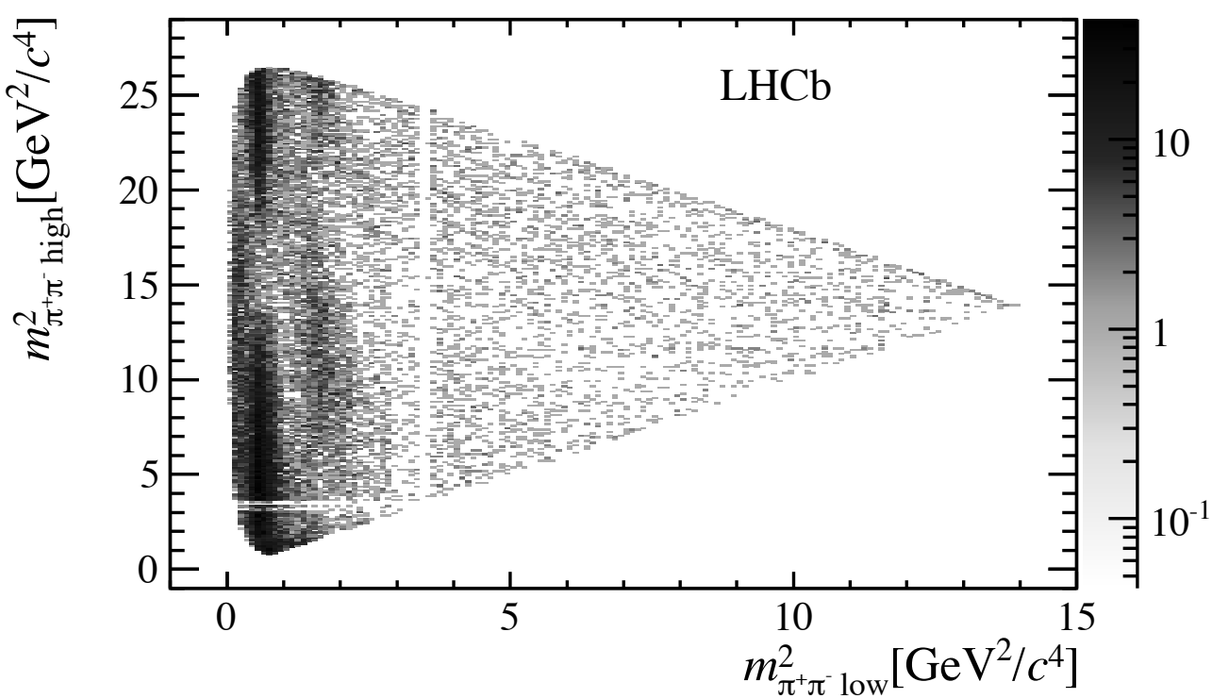
Kpp



KKK



PPP



KKp