Challenges and future of three-body heavy meson decays

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seminar @ Imperial College
London, 30 October 2019

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discussion topics

Please stop me at any moment!

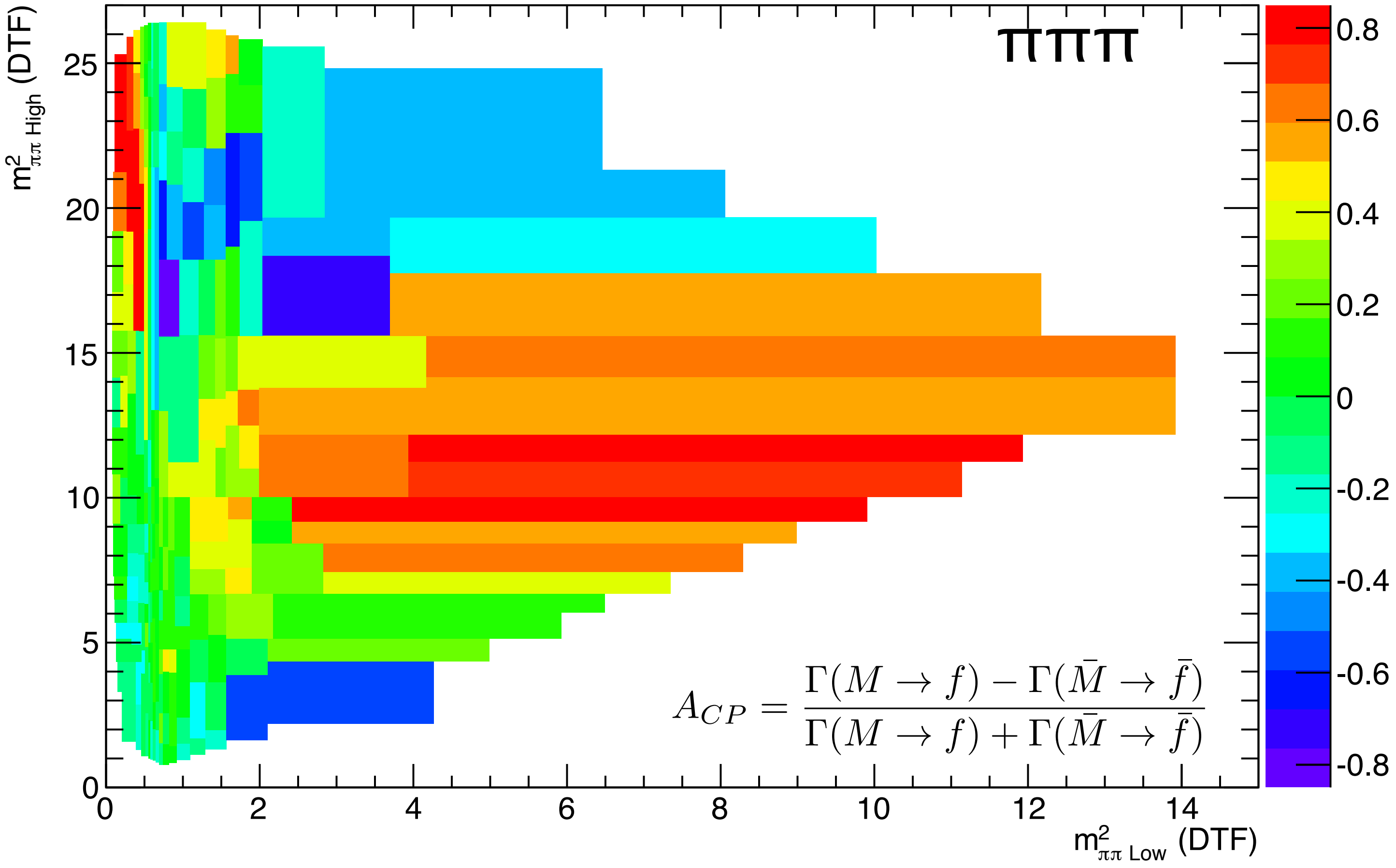
- Why we study 3-body hadronic decay?
- What are the tools?
  - Dalitz plot
  - 2-body x 3-body
  - dynamics
- $D^+ \to K^-K^+K^-$ decay
  - can extract KK scattering amplitude
- CP violation in B decays
  - charm rescattering in $B^+ \to K^-K^+K^-$
- final remarks

Motivation

- Standard Model works quite well but... some gaps!

  → baryogenesis !

- CP-Violation
  - $B^{\pm} \to h^{\pm}h^{-}h^{+}$ LHCb massive localized Acp



LHCb PRD90 (2014) 112004

→ dynamic effect !!

- 1st observation in charm

  LHCb $D^0(\bar{D}^0) \to h^{-}h^{+}$ mixing

  → CPV on three-body?

→ can lead to new physics

Context

- D and B three-body HADRONIC decays are dominated by low E resonances
  - spectroscopy: new resonances, their properties…
  - information of MM interactions ⟶ no $K\bar{K}$ available

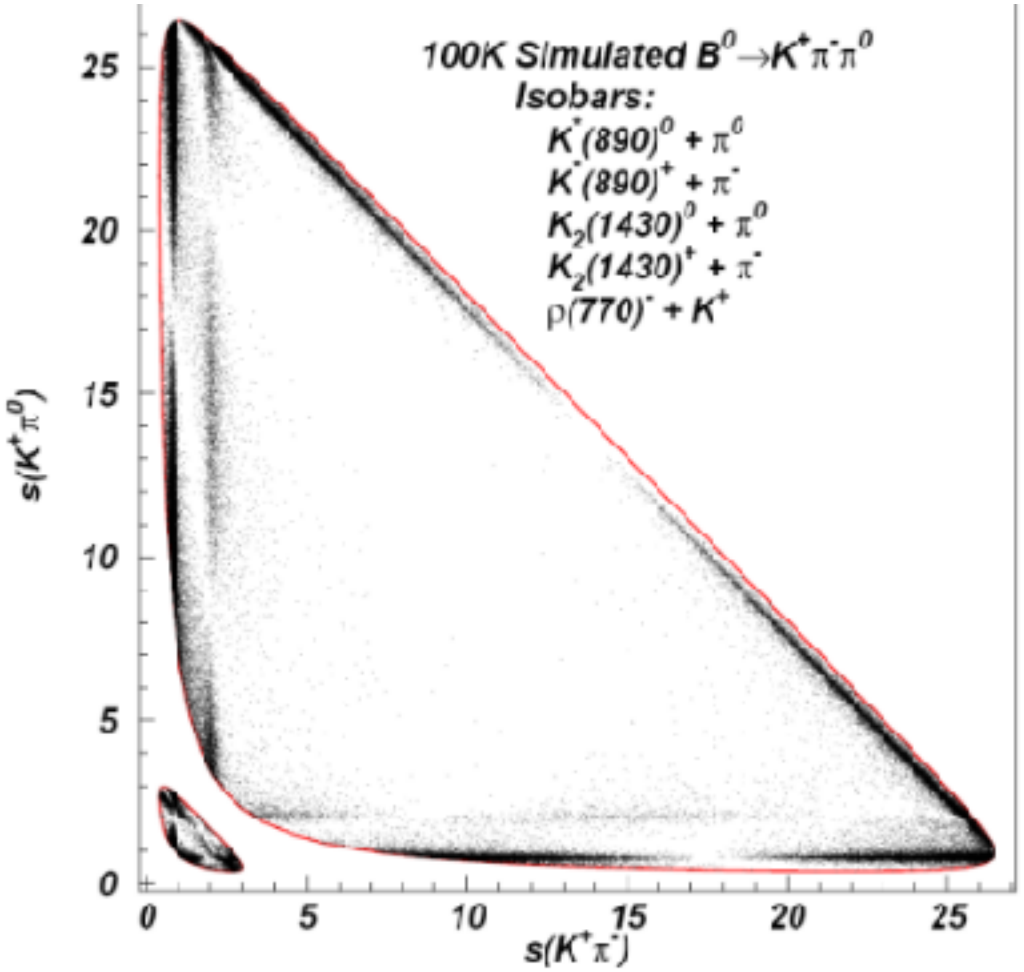
1st observation of σ [$f_0(600)$] and κ [$K_0^*(700)$] in D decays

- new high data sample from LHCb ⟶ more to come from LHCb and Belle II

↪ simple models (only focus on two-body resonances) are not enough to explain data anymore

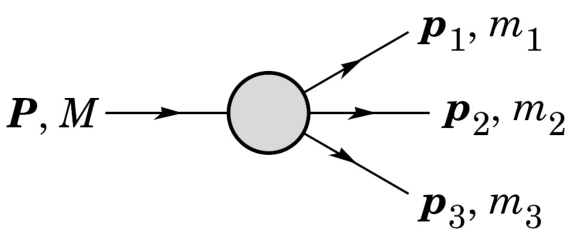
theoretical challenge !

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



Three-body kinematics : DALITZ plot

- In three-body decay phase-space is NOT one-dimension!
  - ↳ bi-dimension phase-space information



- DALITZ PLOT : proposed by Richard Dalitz (1925-2006) in 1953

Mandelstam variables for 3-body

$$s_{12} = (p_1 + p_2)^2 = m_{12}^2$$

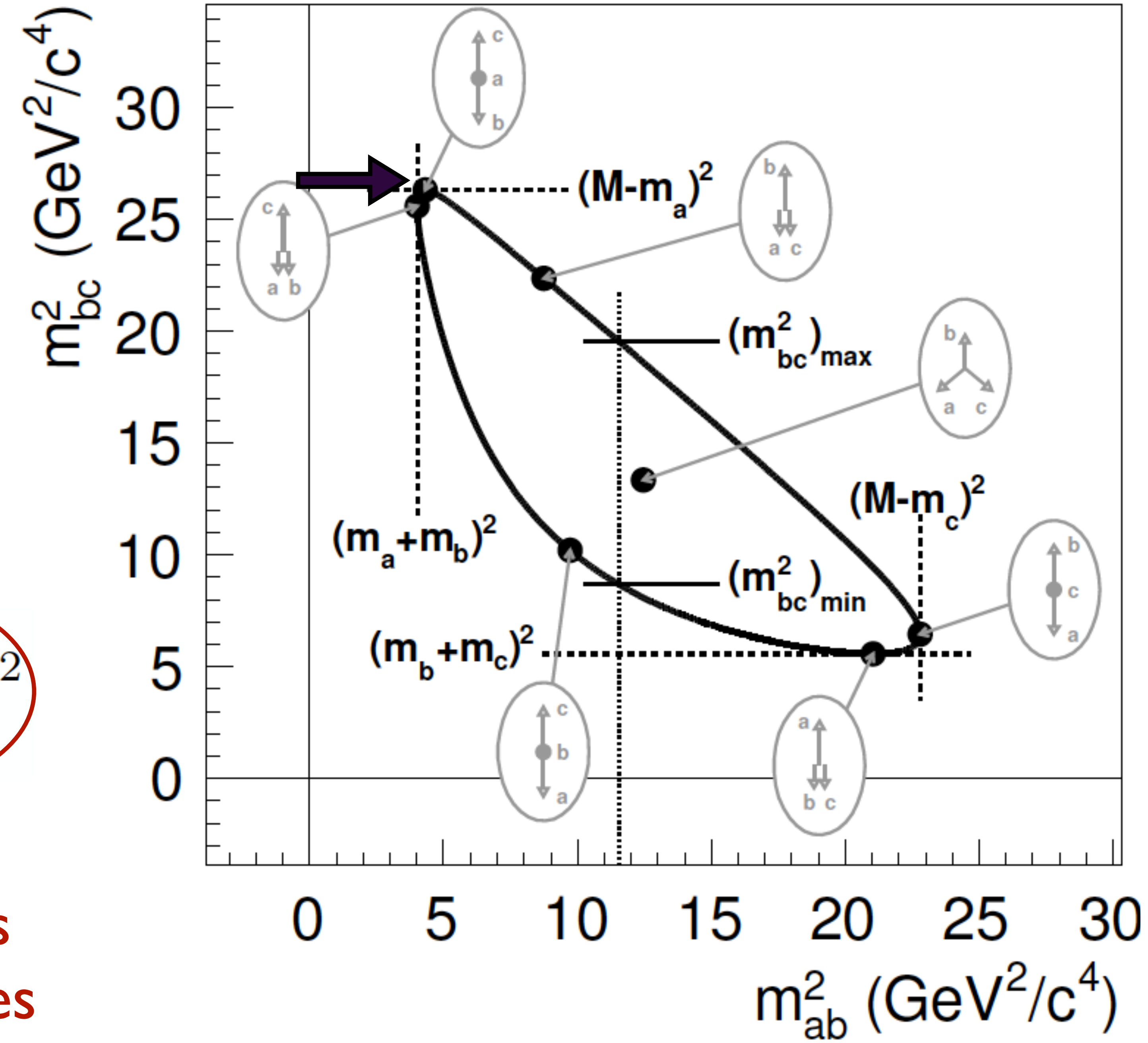
$$s_{13} = (p_1 + p_3)^2 = m_{13}^2$$

$$s_{23} = (p_2 + p_3)^2 = m_{23}^2$$

$$s_{12} + s_{13} + s_{12} = M^2 + m_1^2 + m_2^2 + m_3^2$$

$$\frac{d\Gamma}{ds_{12}ds_{23}} = \frac{1}{(2\pi)^3}\frac{1}{32M^3}|\mathcal{A}(s_{12}, s_{23})|^2$$

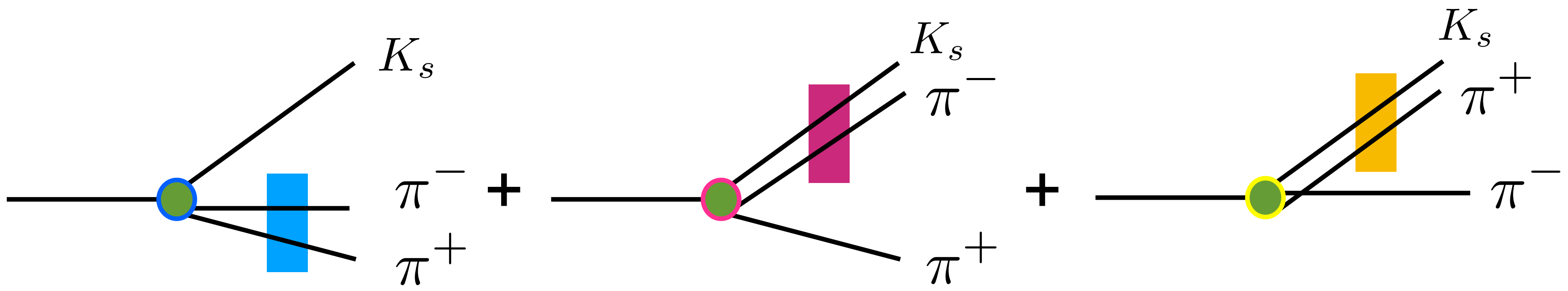
dynamics
resonances



Three-body kinematics : DALITZ plot

- common cartoon to described 3-body decay

$D^0 \to K_s\pi^-\pi^+$



- If true, one expect 2-body resonances → But in reality……. not all of them are clearly present

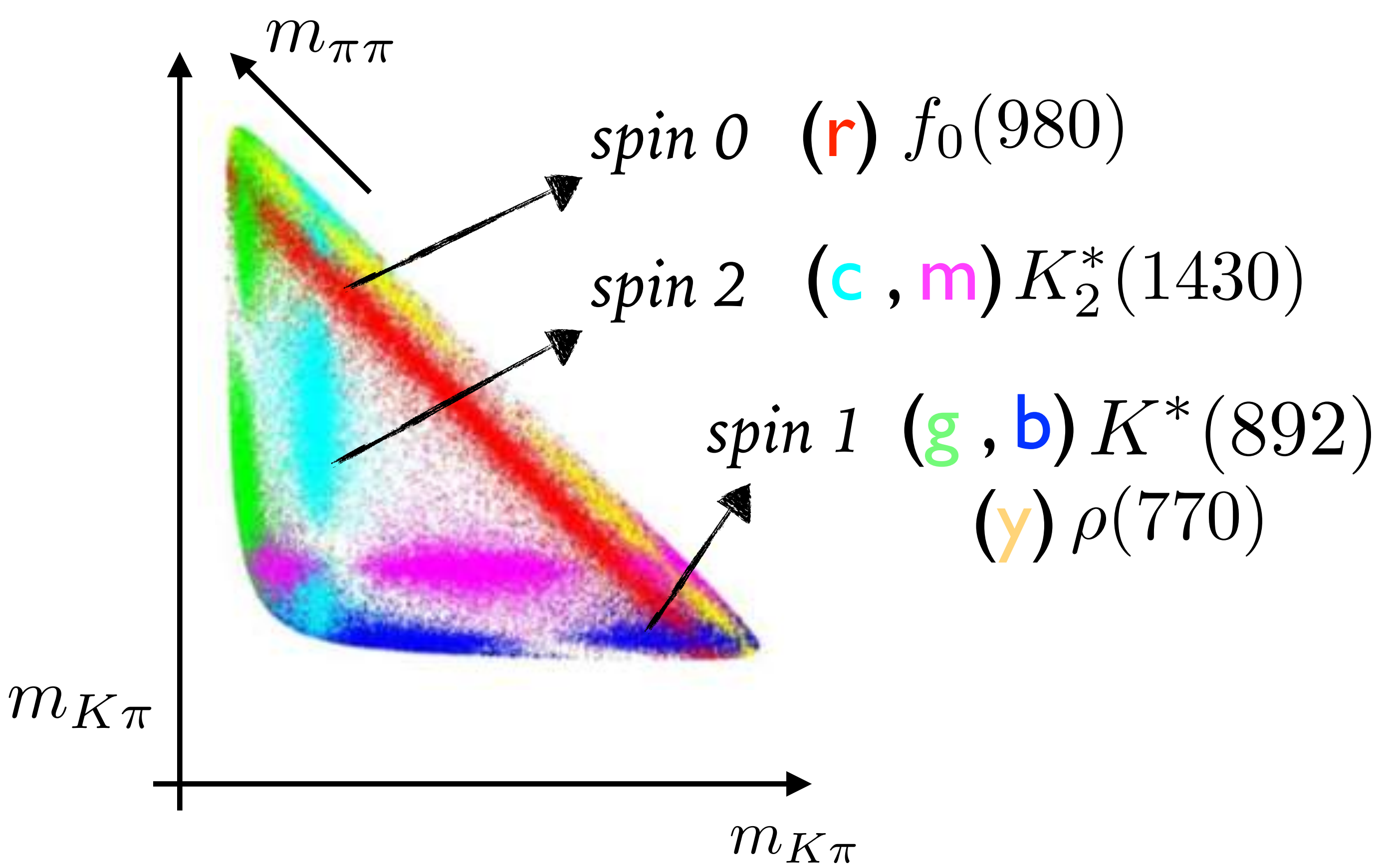
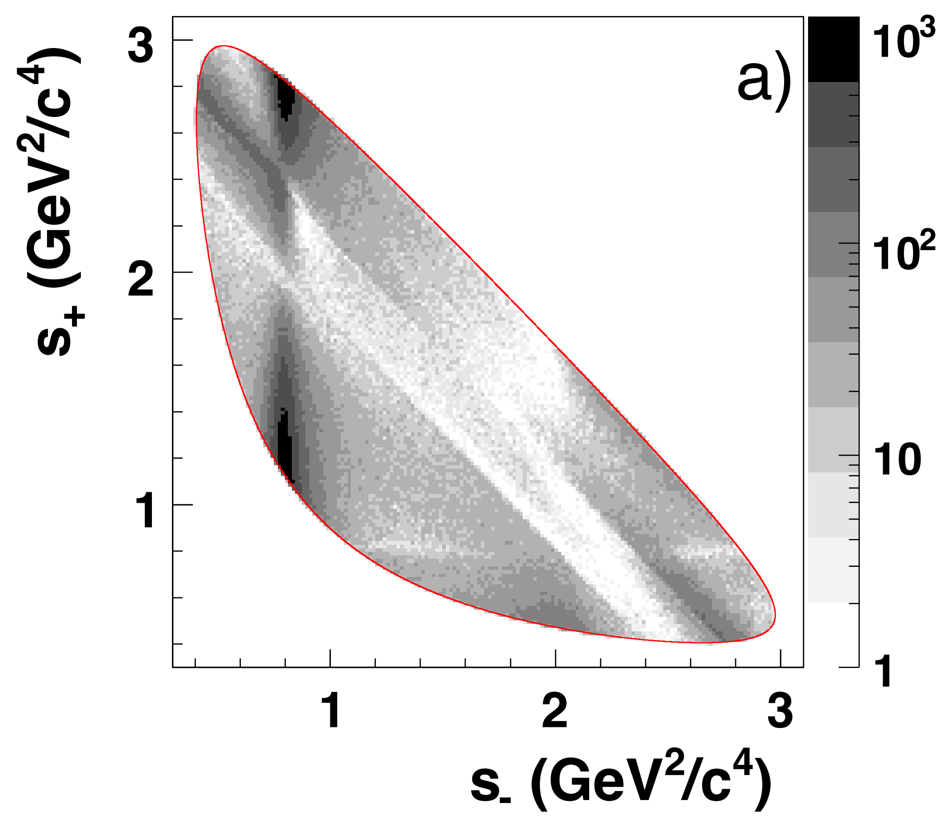


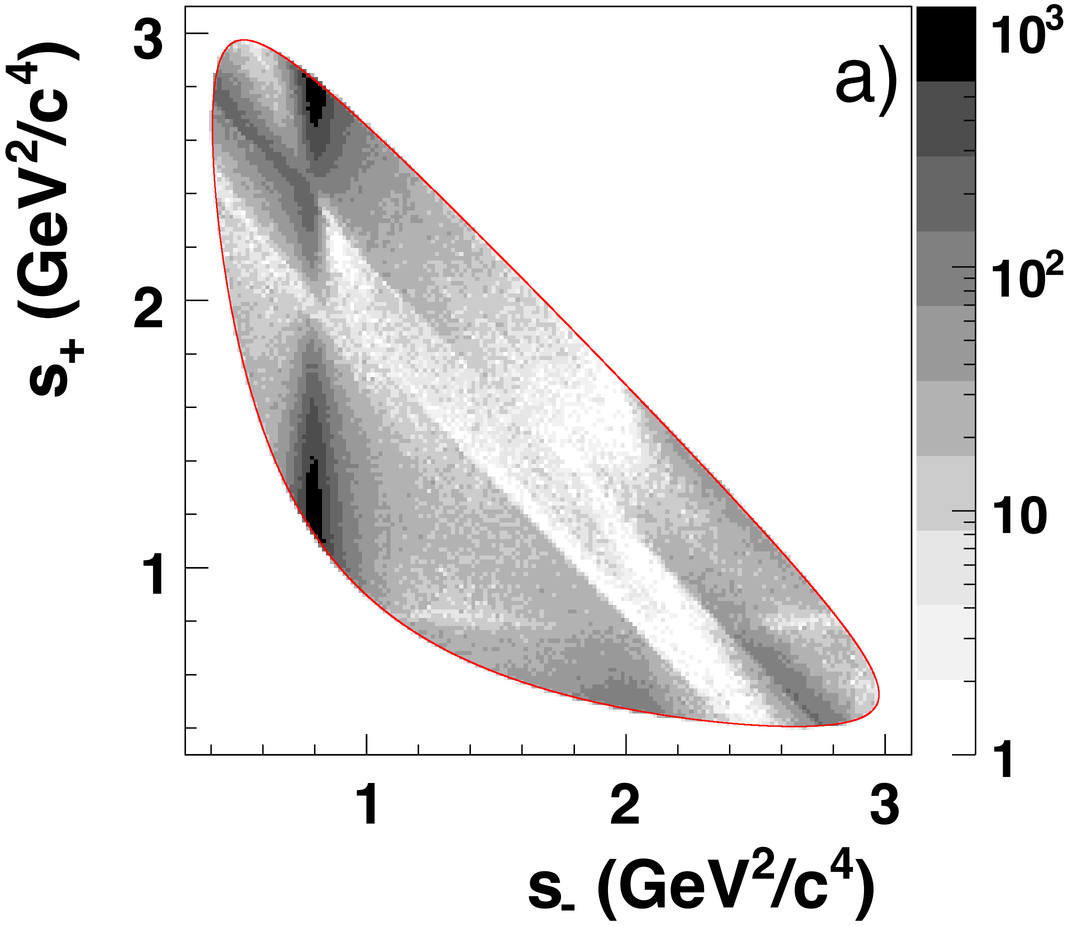
image credit:Tom Latham



BABAR Phys.Rev. Lett. 105 (2010) 081803

Three-body kinematics : DALITZ plot

- $D^0 \to K_s \pi^- \pi^+$



- $D^0 \to K^- \pi^+ \pi^0$

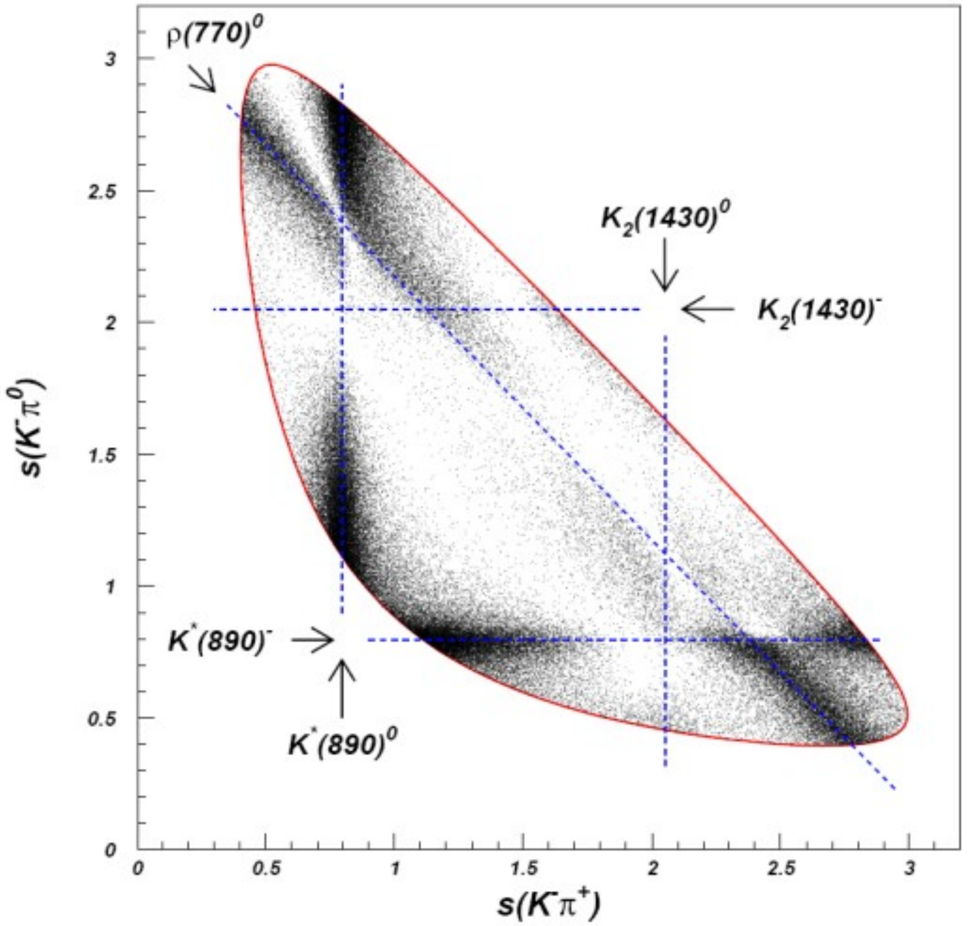


image credit:Brian Meadows

⟶ Similar final state but different interference pattern

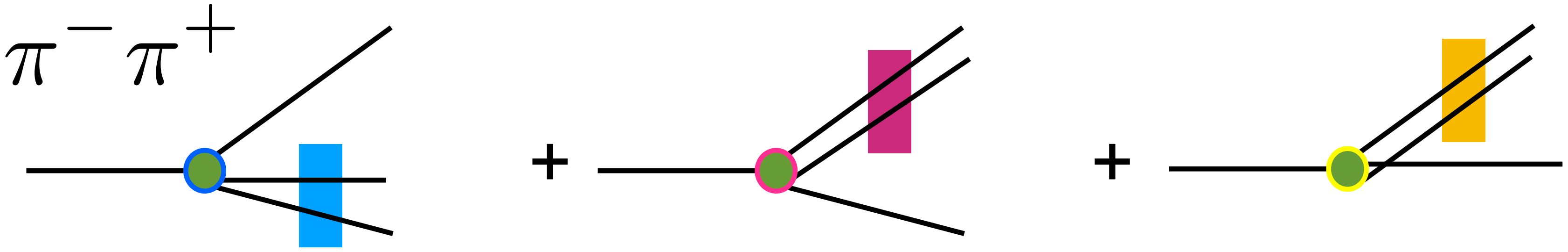
↳ different dynamics to be understood

⟶ to disentangle the interference we need amplitude analysis

- new hight sample data cannot be described only by adding resonances!

2-body x 3-body phases

- $D_s^+ \to \pi^+\pi^-\pi^+$



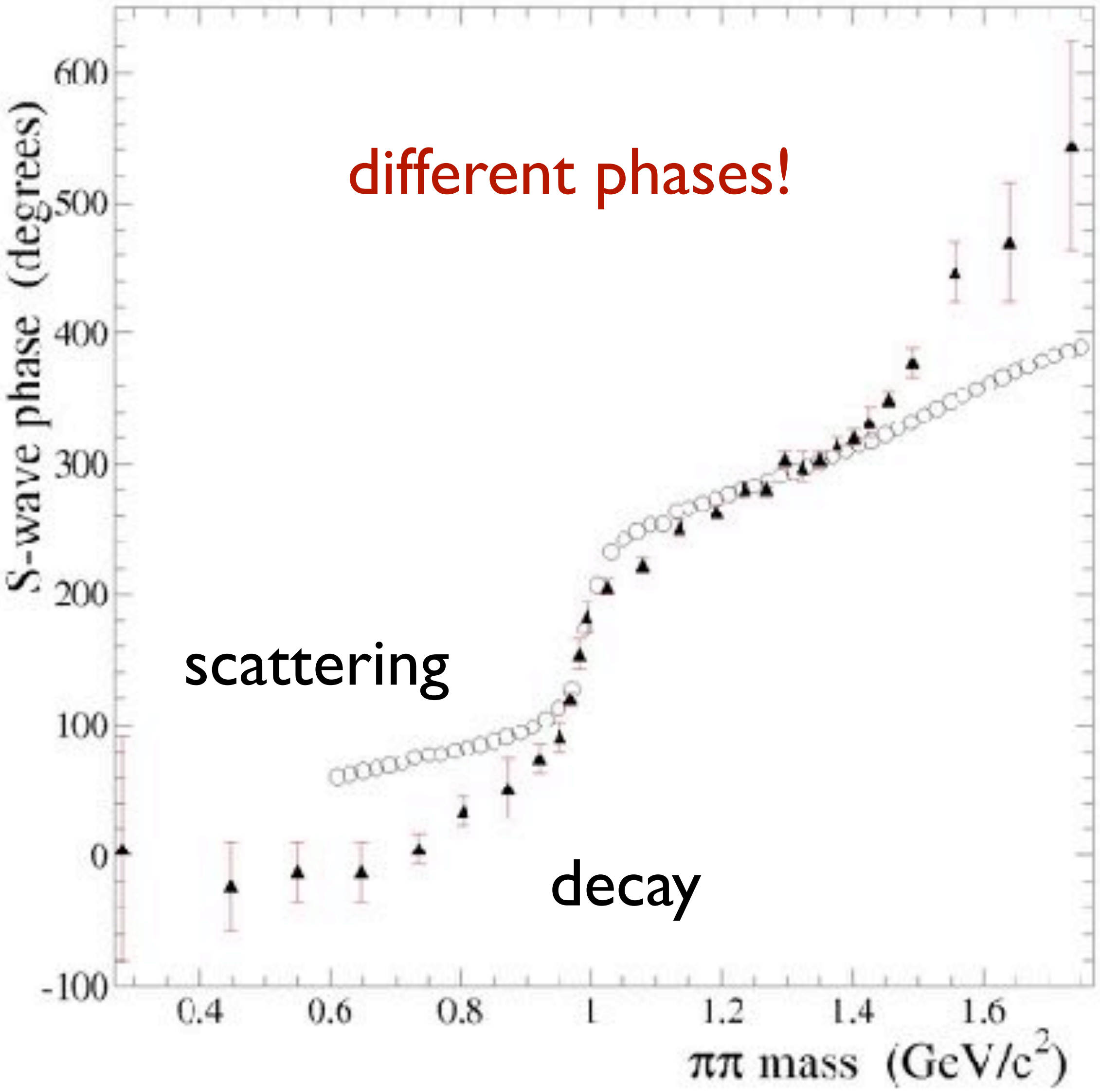
- If this picture is the reality:

It should only contain 2-body informations! → phase from decay should be the same as scattering

→ Is not as simple as it look like!

- Quantum numbers:

- 2-body amplitude: spin and isospin well defined!
- 3-body data: only spin! and $\neq$ dynamics



different phases!

scattering

decay

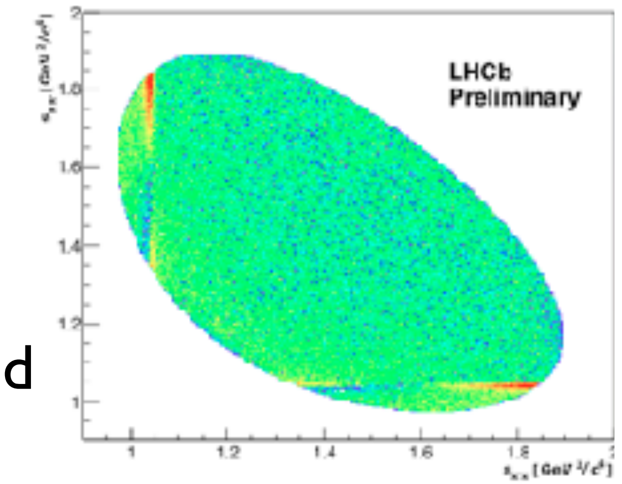
Phys.Rev. D 79 (2009) 032003

Three-body heavy meson decay

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

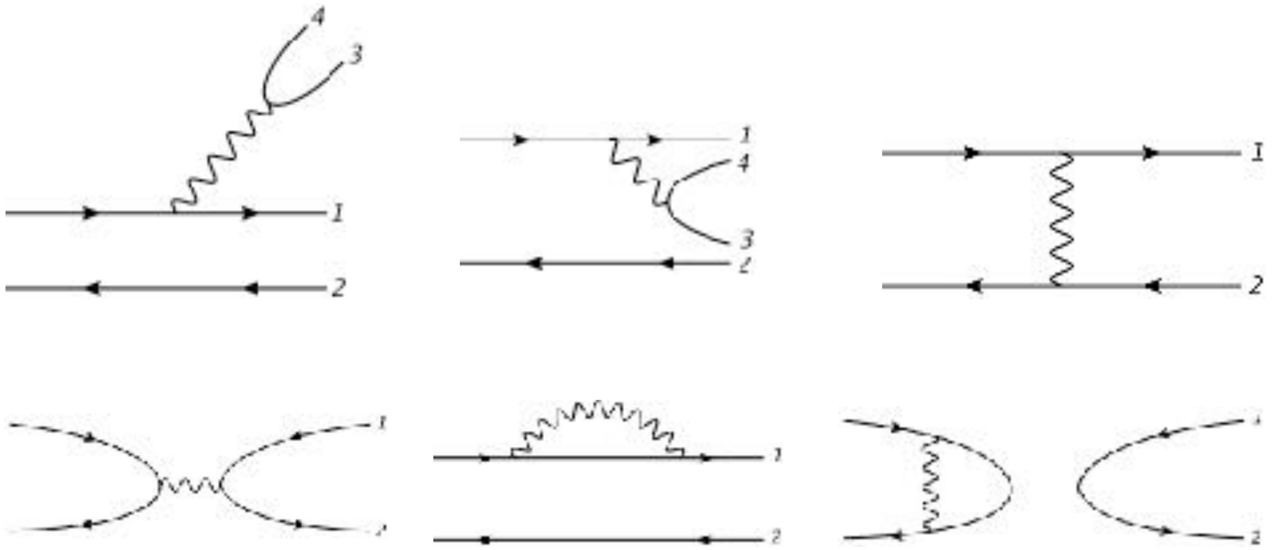
hadronize

observed

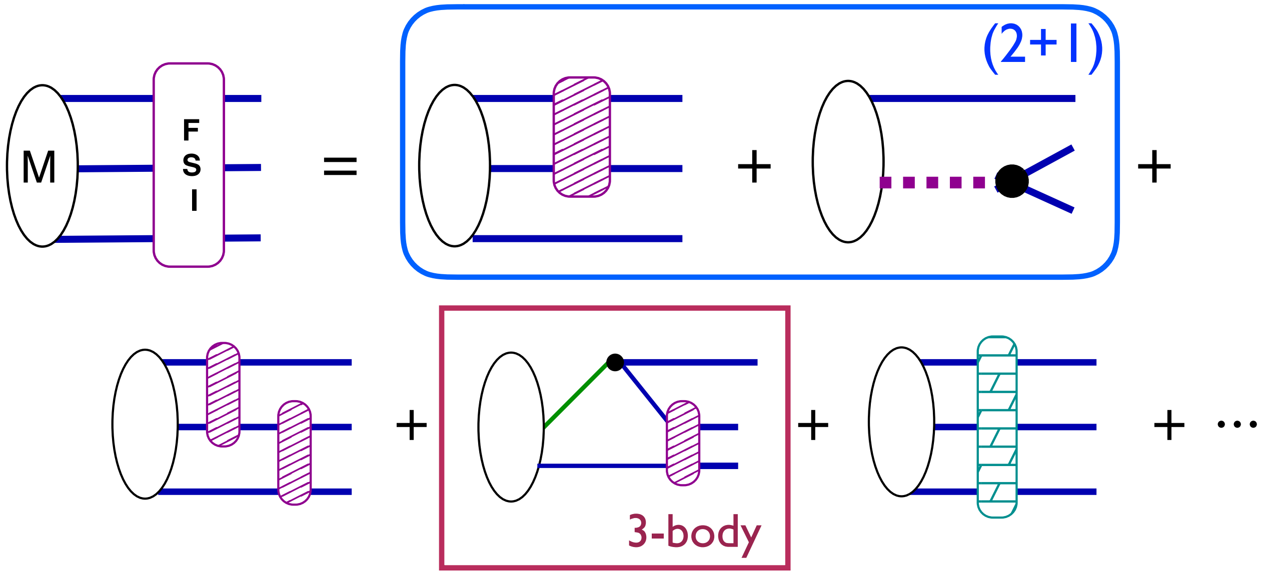


primary vertex - weak -

Final State Interactions - strong -

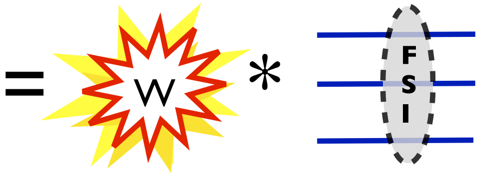


QCD, CKM coupling and phase



2-body is crucial!!!!

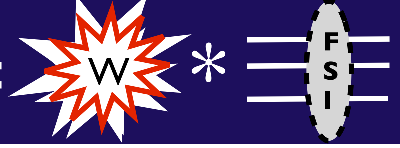
To extract information from data we need an amplitude MODEL

A = 

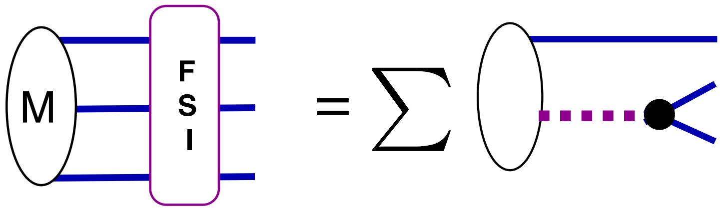
$$\frac{d\Gamma}{ds_{12}ds_{23}} = \frac{1}{(2\pi)^3}\frac{1}{32M^3}|\mathcal{A}(s_{12}, s_{23})|^2$$

dynamics

Models available A =

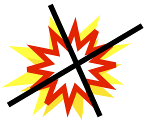


- isobar model: widely used by experimentalists
  - (2+1) approximation:



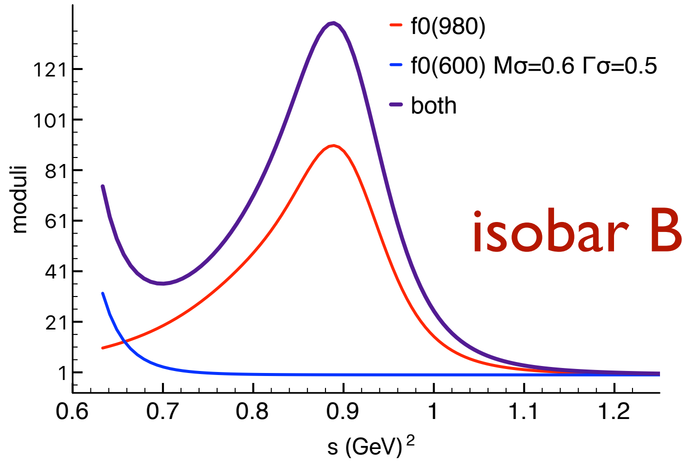
→ ignore the 3rd particle (bachelor)

$A = \sum c_k A_{k;}$ + NR { non-resonant as constant or exponential!
each resonance as Breit-Wigner $\mathrm{BW}(s_{12}) = \frac{1}{m_R^2 - s_{12} - i m_R \Gamma(s_{12})},$



weak vertex is not considered explicitly

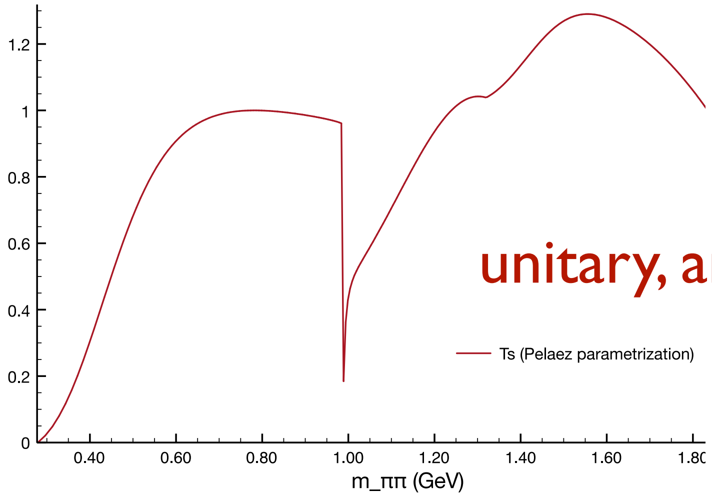
- worst problems: ππ S-wave



isobar BW

→ fit could change this interference

more than 2 scalars ←



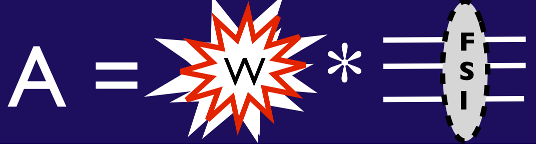
unitary, analytic,…

Pelaez, Yndurain PRD71(2005) 074016

- sum of BW violates two-body unitarity (2 res in the same channel);
- do NOT include rescattering and coupled-channels;
- free parameters are not connected with theory !

!

Models available



- movement to use better 2-body (unitarity) inputs in data analysis

  - “K-matrix" : ππ S-wave 5 coupled-channel modulated by a production amplitude

    ↳ used by Babar, LHCb, BES III- analyticity problems ! Anisovich PLB653(2007)

  - rescattering $\pi\pi \to KK$ contribution in LHCb $\begin{cases} B^\pm \to \pi^+\pi^-\pi^\pm \\ B^\pm \to K^-K^+\pi^\pm \end{cases}$ [arXiv:1909.05212; 1909.05211] [arXiv:1905.09244]

    Pelaez, Yndurain PRD71(2005) 074016

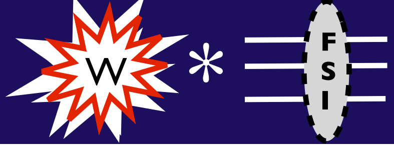
    ↳ new parametrization Pelaez, and Rodas EPJ. C78 (2018) 11, 897

→ other scalar and vector form factors available

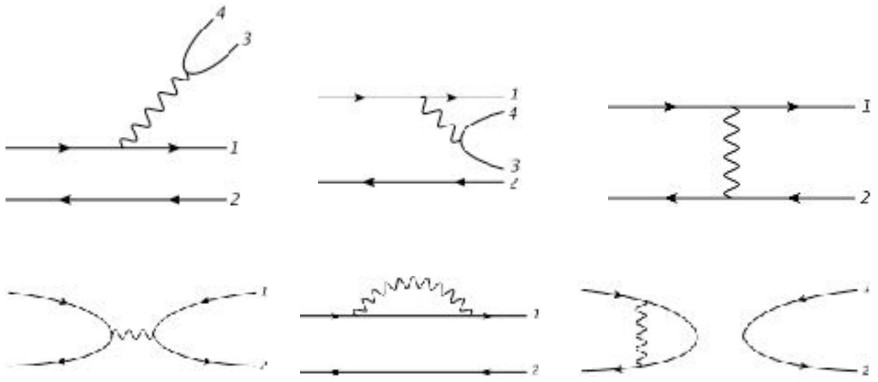
Limited to low E (2 GeV)!

$< \pi\pi \| 0 >$	scalar		Moussallam EPJ C 14, 111 (2000); Daub, Hanhart, and B. Kubis JHEP 02 (2016) 009.
	vector		Hanhart, PL B715, 170 (2012); Dumm and Roig EPJ C 73, 2528 (2013).
$< K\pi \| 0 >$	scalar		Moussallam EPJ C 53, 401 (2008); Jamin, Oller and Pich, PRD 74, 074009 (2006)
	vector		Boito, Escribano, and Jamin EPJ C 59, 821 (2009).
$< KK \| 0 >$ (no data)		Fit from 3-body data	PCM, Robilotta + LHCb JHEP 1904 (2019) 063
		extrapolate from unitarity model	Albaladejo and Moussallam EPJ C 75, 488 (2015).
		quark model with isospin symmetry	Bruch, Khodjamirian, and Kühn , EPJ C 39, 41 (2005)

Models available

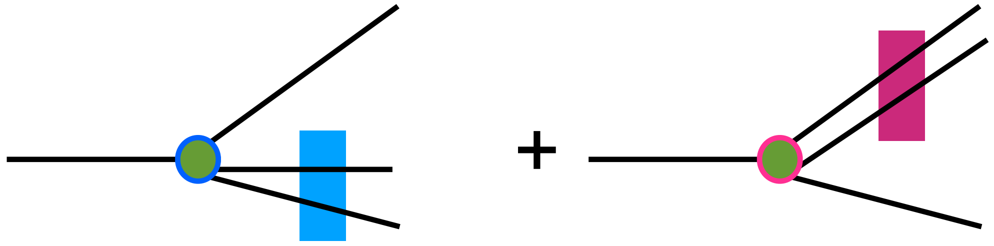
A = 

- QCD factorization approach → factorize the quark currents



Chau [Phys. Rep. 95,1(1983)]

challenging for 3-body
not all FSI and 3-body NR
scale issue with charm !



$$\mathcal{H}_{\rm eff}^{\Delta B=1} = \frac{G_F}{\sqrt{2}} \sum_{p=u,c} V_{pq}^* V_{pb} \left[C_1(\mu) O_1^p(\mu) + C_2(\mu) O_2^p(\mu) + \sum_{i=3}^{10} C_i(\mu) O_i(\mu) + \ C_{7\gamma}(\mu) O_{7\gamma}(\mu) + C_{8g}(\mu) O_{8g}(\mu) \right] + \ \text{h.c.} \ ,$$

→ ex: $B^+ \to \pi^+\pi^-\pi^+$

how to describe it?

$$\text{A} \sim \langle [\underbrace{\pi^+(p_2)\pi^-(p_3)}_{\text{R}}] \ |(\bar{u}b)_{V-A}|B^-\rangle \ \langle \pi^-(p_1)|(\bar{d}u)_{V-A}|0\rangle + \langle \pi^-(p_1)|(\bar{d}b)_{sc-ps}|B^-\rangle \ \langle [\pi^+(p_2)\underbrace{\pi^-(p_3)] \ |(\bar{d}d)_{sc+ps}|0}_{\text{FF}}\rangle$$

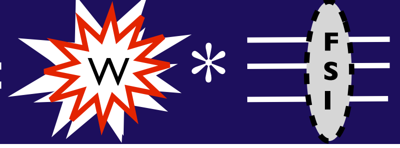
- naive factorization
  - intermediate by a resonance R;
  - FSI with scalar and vector form factors FF

↳ parametrizations for B and D→3h   Boito et al. PRD96 113003 (2017)

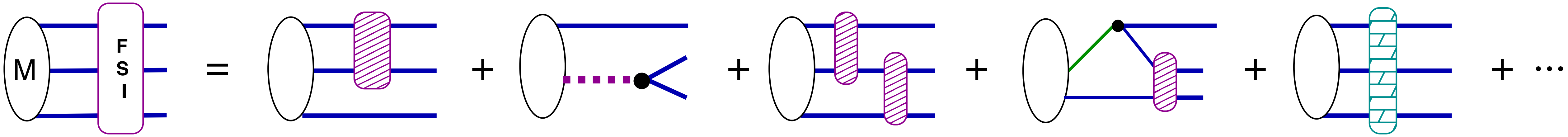
- modern QDC factorization: improvement to include "long distance"

Klein, Mannel, Virto, Keri Vos JHEP10 117 (2017)

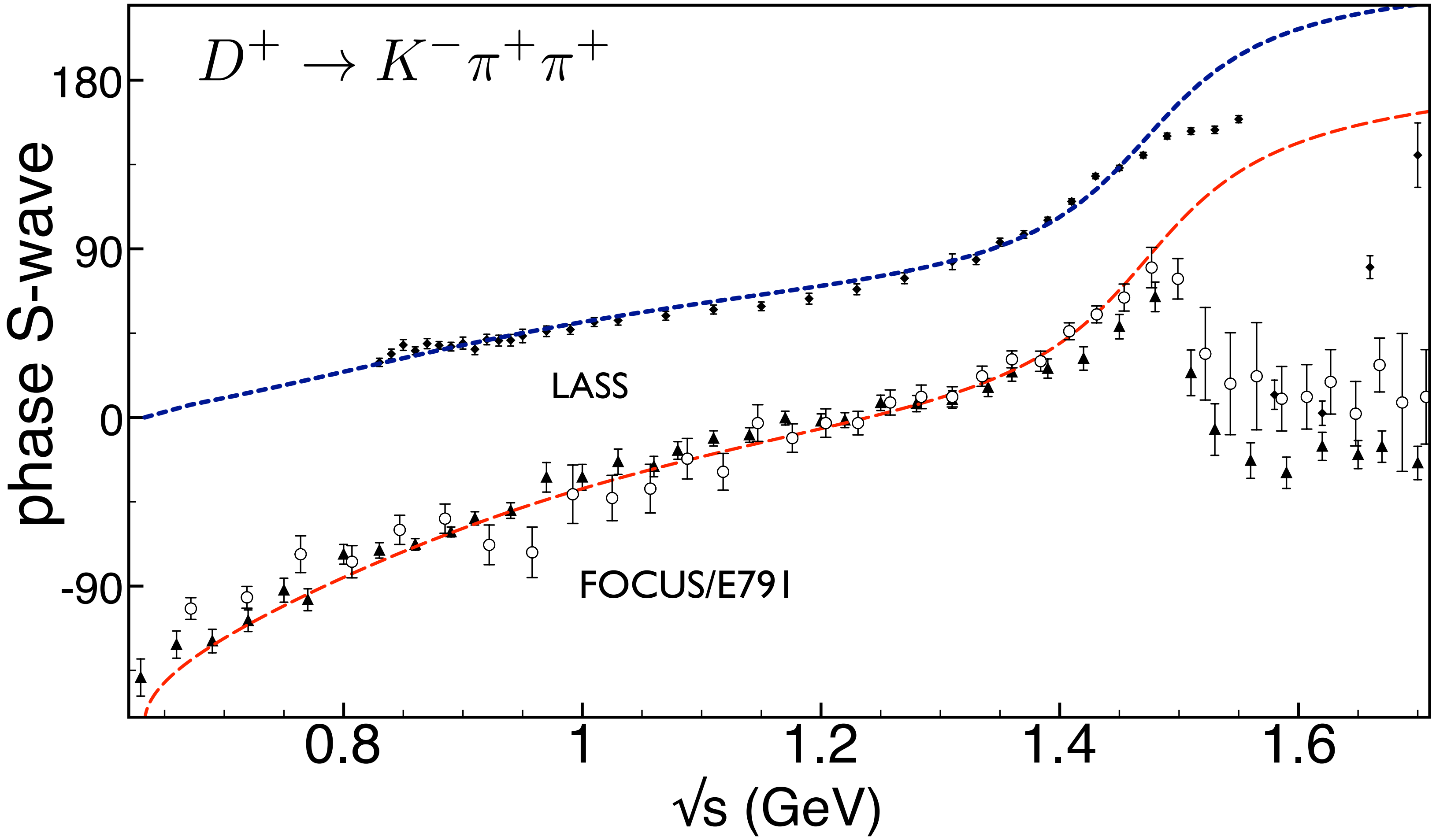
Models available

A = 

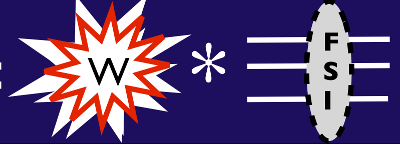
- Three-body FSI (beyond 2+1)



- shown to be relevant on charm sector



Models available

A = 

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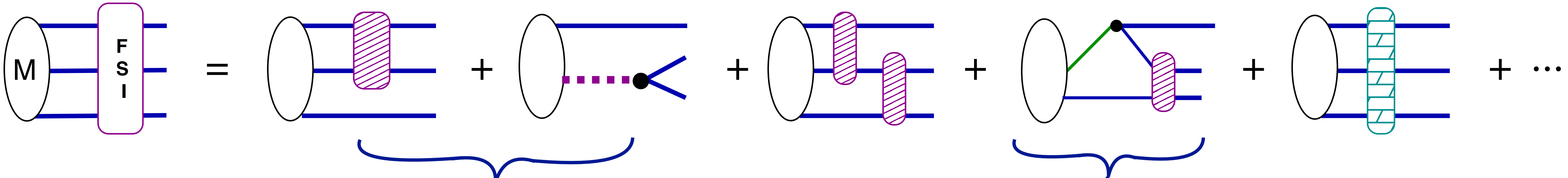
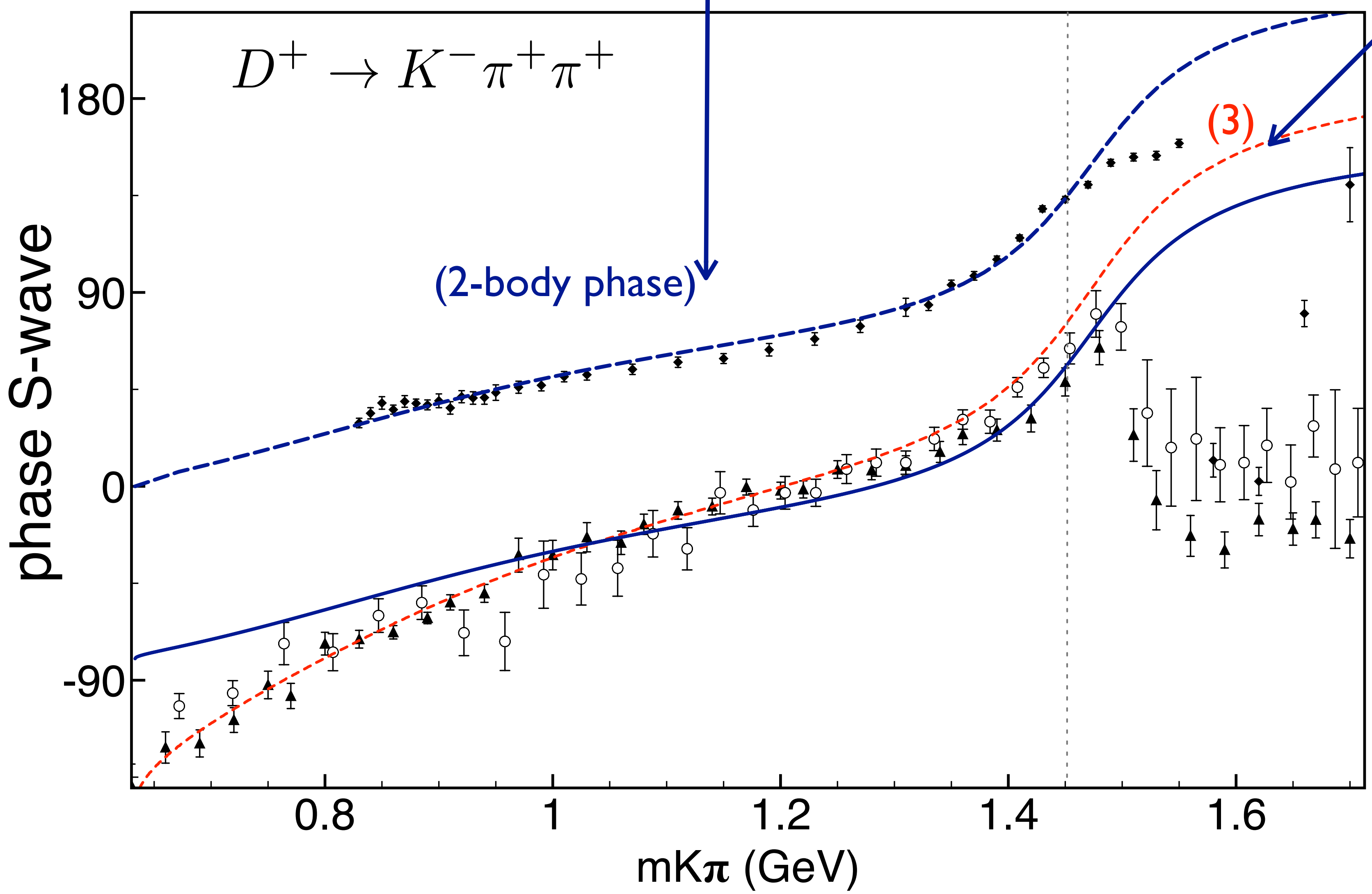


- shown to be relevant on charm sector

PRD92 094005 (2015)



- 3-body approaches

PCM et.al: PRD84 094001 (2011),
S.Nakamura PRD93 014005 (2016)
Niecknig, Kubis, JHEP10 142 (2015)

↳ 3-body FSI play a role

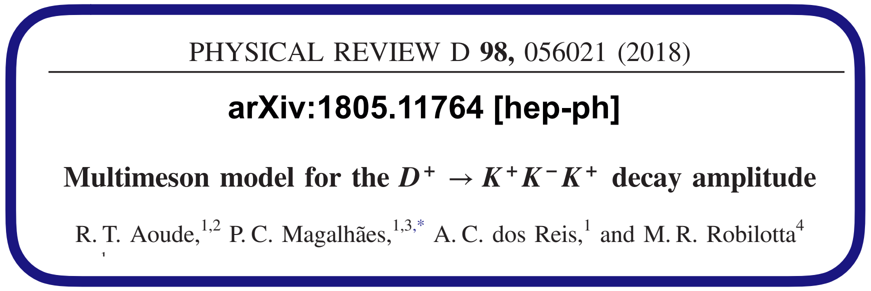
↳ data analysis…

↳ can we extract 2-body information from 3-body?

multi meson model - $D^+ \to K^-K^+K^+$

amplitude analysis for D decay

Theoretical model



PHYSICAL REVIEW D **98,** 056021 (2018)

arXiv:1805.11764 [hep-ph]

Multimeson model for the $D^+ \to K^+K^-K^+$ decay amplitude

R. T. Aoude,[1,2] P. C. Magalhães,[1,3,*] A. C. dos Reis,[1] and M. R. Robilotta[4]

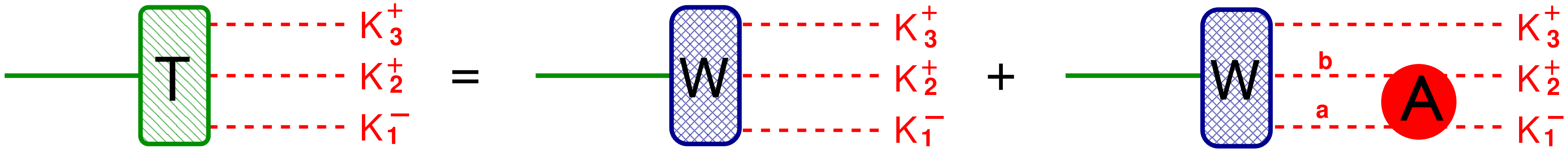
fitted to LHCb data

JHEP 1904 (2019) 063

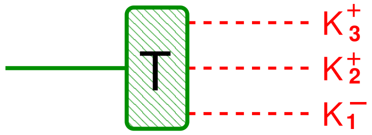
KK scattering amplitude

multi meson model - $D^+ \to K^- K^+ K^+$

Triple-M



- alternative to isobar model in amplitude analysis
- depart from a fundamental theory → Chiral **Lagrangian**
    - track the ingredients we include in our model!
    - A_{ab}^{JI} ⟶ unitary scattering amplitude for $ab \to K^+K^-$
      ⟶ full FSI: coupled channel,

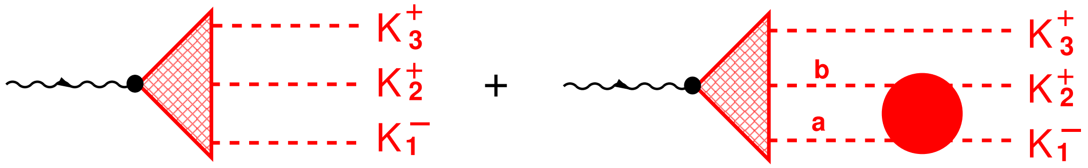


fitted to LHCb data → predict KK scattering amplitude

JHEP 1904 (2019) 063

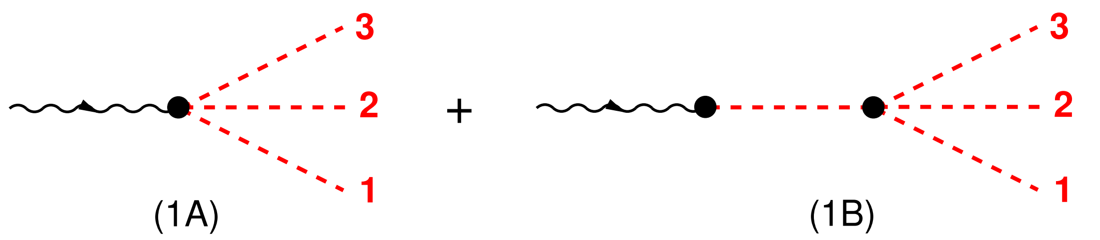
→ parameters have physical meaning: resonance masses and coupling constants

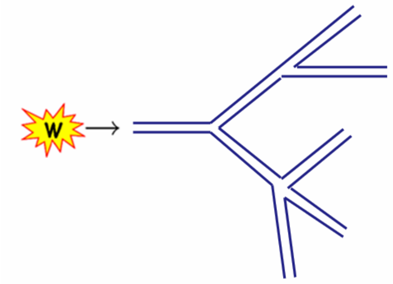
Triple - M



=

LO: non-resonant

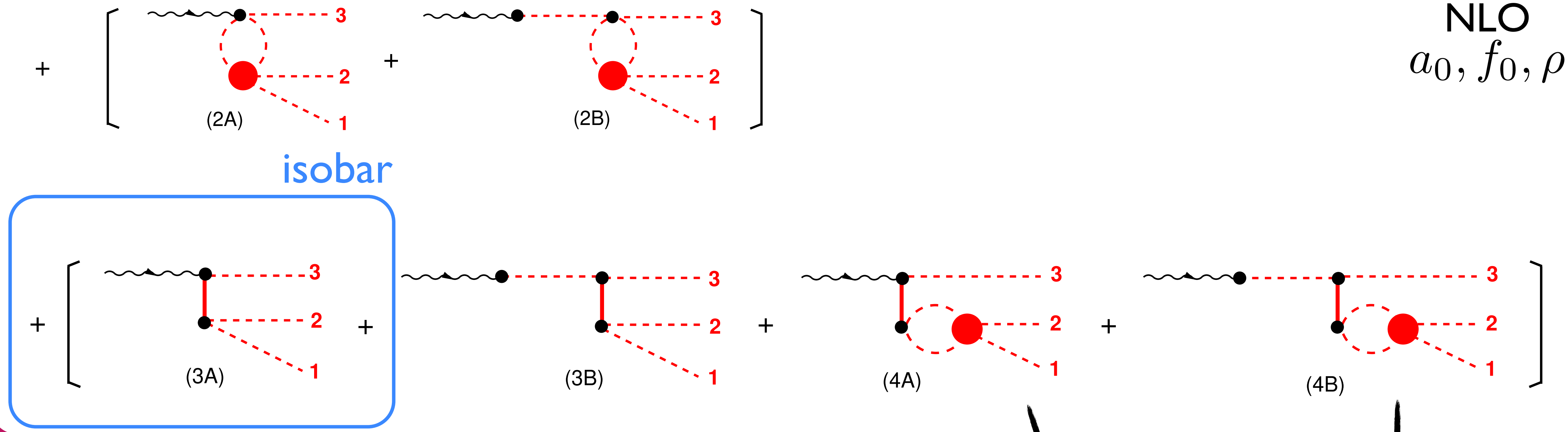




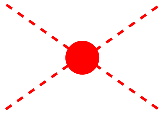
Chiral symmetry

NLO

a_0, f_0, ρ, ϕ



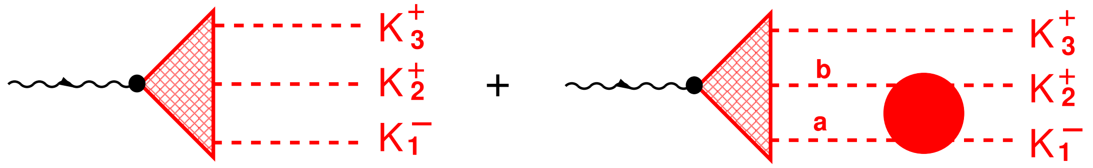
width obtained through dynamics



$K\bar{K}$ coupled-channel unitary amplitude
$\pi\pi,\ \eta\eta,\ \pi\eta,\ \rho\pi$

● isospin decomposition $[J, I = (0,1), (0,1)]$

Triple M LHCb fit



$$T^S = T^S_{NR} + T^{00} + T^{01}$$

$$T^P = T^P_{NR} + T^{11} + T^{10}$$

FF_{NR}	FF^{00}	FF^{01}	FF^{10}	FF^{11}	FF_{S-wave}
14 ± 1	29 ± 1	131 ± 2	7.1 ± 0.9	0.26 ± 0.01	94 ± 1

- strong destructive interference in S-wave

parameter	value
F	$94.3^{+2.8}_{-1.7} \pm 1.5\,\mathrm{MeV}$
m_{a_0}	$947.7^{+5.5}_{-5.0} \pm 6.6\,\mathrm{MeV}$
m_{S_o}	$992.0^{+8.5}_{-7.5} \pm 8.6\,\mathrm{MeV}$
m_{S_1}	$1330.2^{+5.9}_{-6.5} \pm 5.1\,\mathrm{MeV}$
m_ϕ	$1019.54^{+0.10}_{-0.10} \pm 0.51\,\mathrm{MeV}$
G_ϕ	$0.464^{+0.013}_{-0.009} \pm 0.007$
c_d	$-78.9^{+4.2}_{-2.7} \pm 1.9\,\mathrm{MeV}$
c_m	$106.0^{+7.7}_{-4.6} \pm 3.3\,\mathrm{MeV}$
$\tilde{c}_d$	$-6.15^{+0.55}_{-0.54} \pm 0.19\,\mathrm{MeV}$
$\tilde{c}_m$	$-10.8^{+2.0}_{-1.5} \pm 0.4\,\mathrm{MeV}$

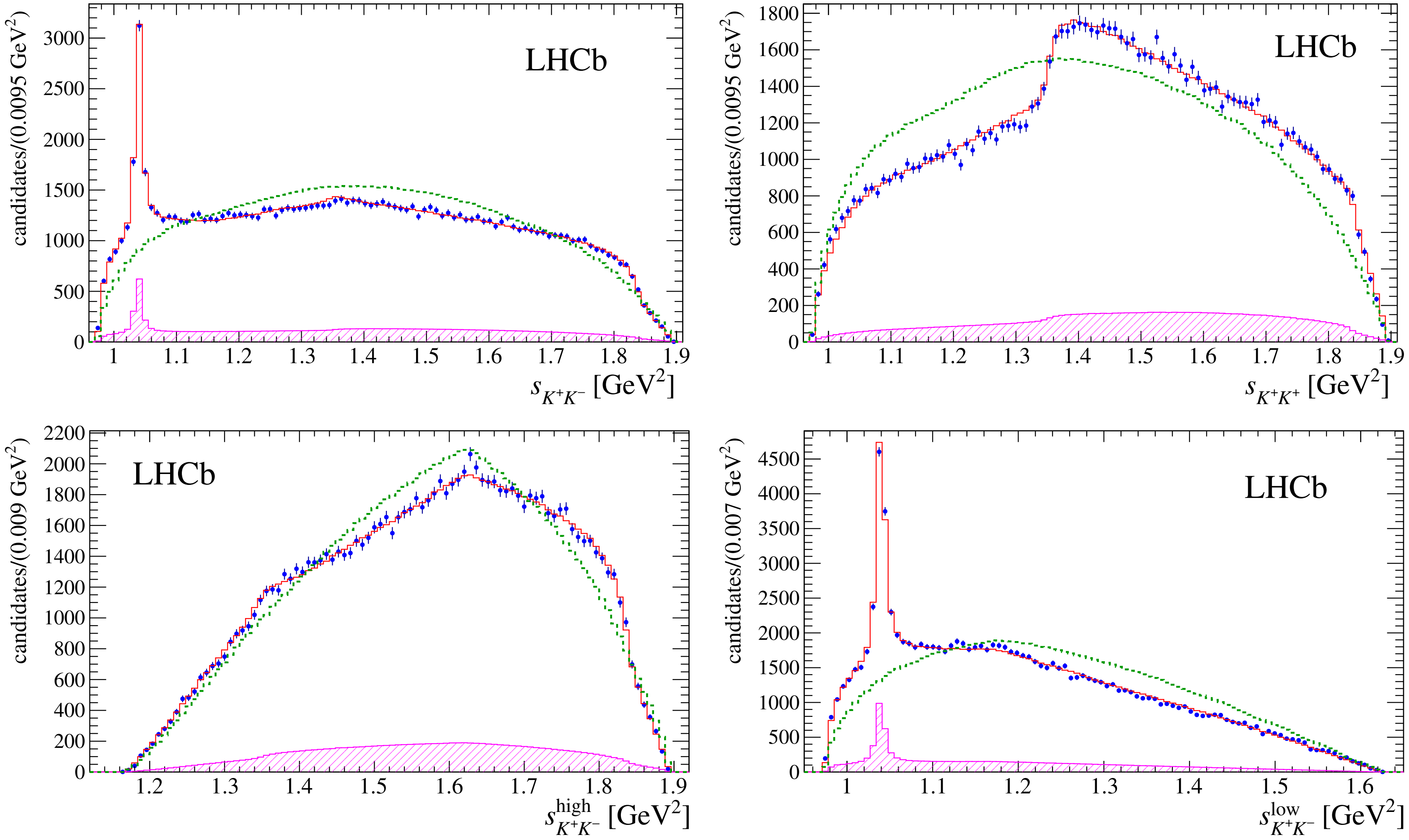


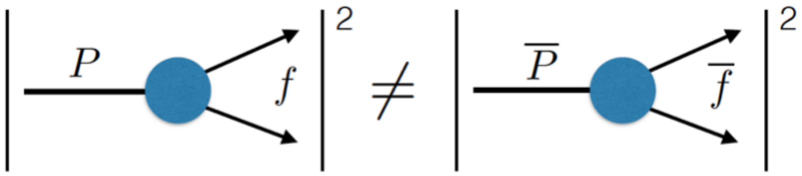
Figure 11. Projections of the Dalitz plot onto (top left) $s_{K^+K^-}$, (top right) $s_{K^+K^+}$, (bottom left) $s^{\rm high}_{K^+K^-}$ and (bottom right) $s^{\rm low}_{K^+K^-}$ axes, with the fit result with the Triple-M amplitude superimposed, whereas the dashed green line is the phase space distribution weighted by the efficiency. The magenta histogram represents the contribution from the background.

Final State Interaction in B decays as a source of CP violation

CPV on data: Puzzle!

- Charge Parity Violation

$$\Gamma(M \to f) \neq \Gamma(\bar{M} \to \bar{f})$$



  - condition to CPV

→ 2 $\neq$ amplitudes, SAME final state with strong (δ_i) and weak (ϕ_i) phase

$$\langle f \,|\, T \,|\, M \rangle = A_1\, e^{i(\delta_1+\phi_1)} + A_2\, e^{i(\delta_2+\phi_2)}$$

$$\Big\downarrow \text{CP}$$

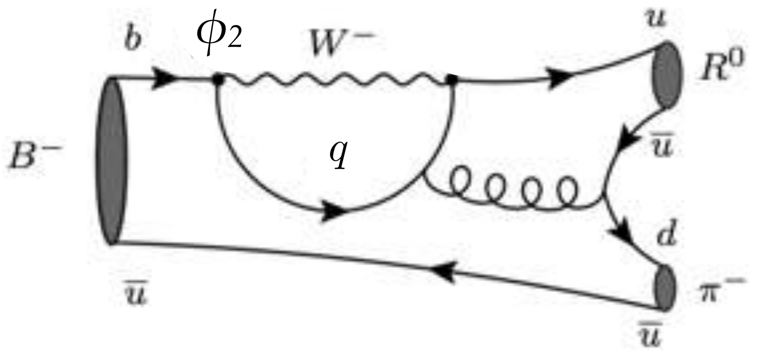
$$\langle \bar{f} \,|\, T \,|\, \bar{M} \rangle = A_1\, e^{i(\delta_1-\phi_1)} + A_2\, e^{i(\delta_2-\phi_2)}$$

$$\therefore\ \Gamma(M \to f) - \Gamma(\bar{M} \to \bar{f}) = |\langle f \,|\, T \,|\, M \rangle|^2 - |\langle \bar{f} \,|\, T \,|\, \bar{M} \rangle|^2 = -4 A_1 A_2 \sin(\delta_1 - \delta_2)\, \sin(\phi_1 - \phi_2)$$

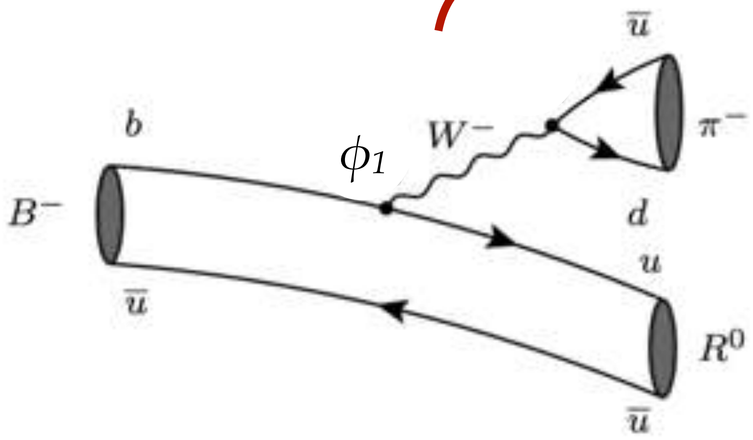
- BSS model  + 

Bander Silverman & Soni PRL 43 (1979) 242

strong phase



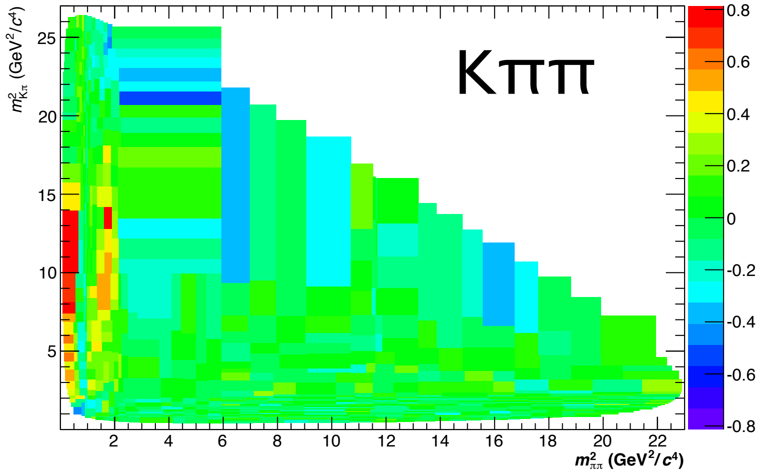
weak phase: CKM
Vub

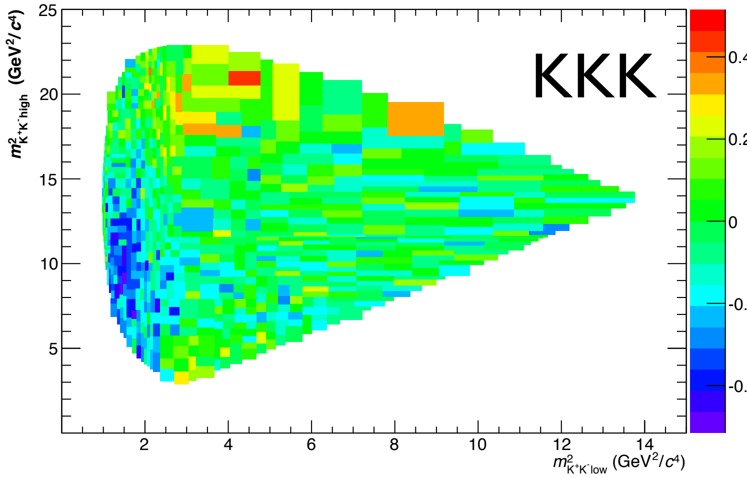


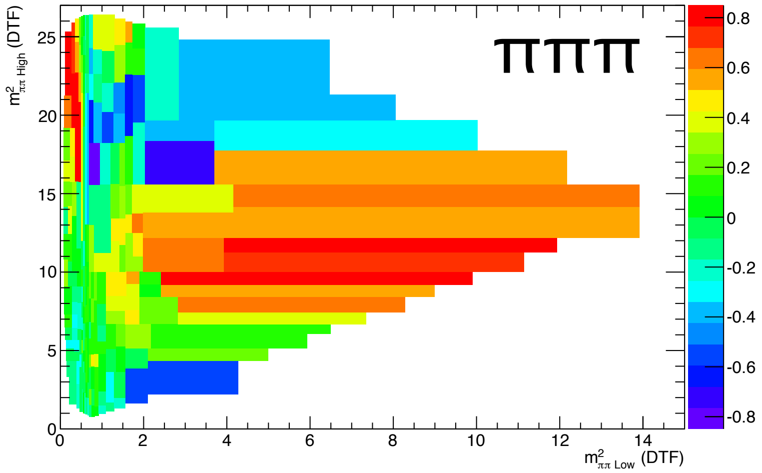
CPV on data: Puzzle!

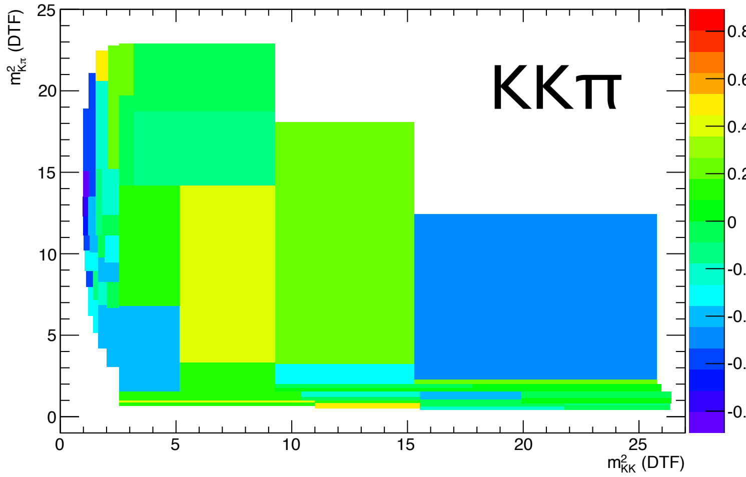
- $B^{\pm} \to h^{\pm} h^{-} h^{+}$ LHCb massive localized Acp
    - suggest dynamic effect
    - middle looks “empty" → CPV

$$A_{CP} = \frac{\Gamma(M \to f) - \Gamma(\bar{M} \to \bar{f})}{\Gamma(M \to f) + \Gamma(\bar{M} \to \bar{f})}$$









- BSS model

+

not enough!!

- hadronic interactions → strong phase

- $B^{\pm} \to \pi^{\pm}\pi^{-}\pi^{+}$ and $B^{\pm} \to \pi^{\pm}K^{-}K^{+}$ low-energy CPV with opposite signs

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

Frederico, Bediaga, Lourenço PRD89(2014)094013

Parentheses…..

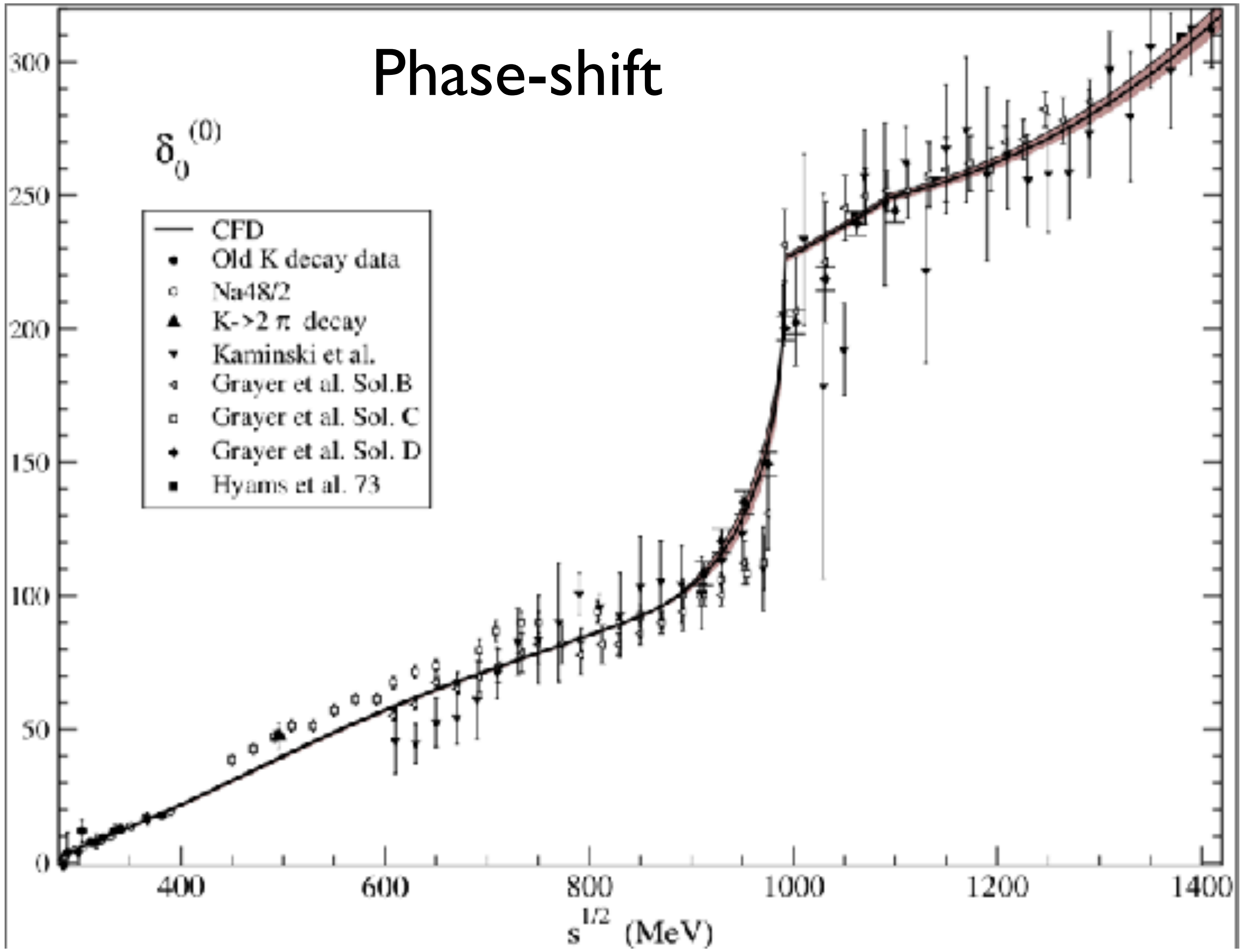
- $\pi\pi$ scattering data S-Wave

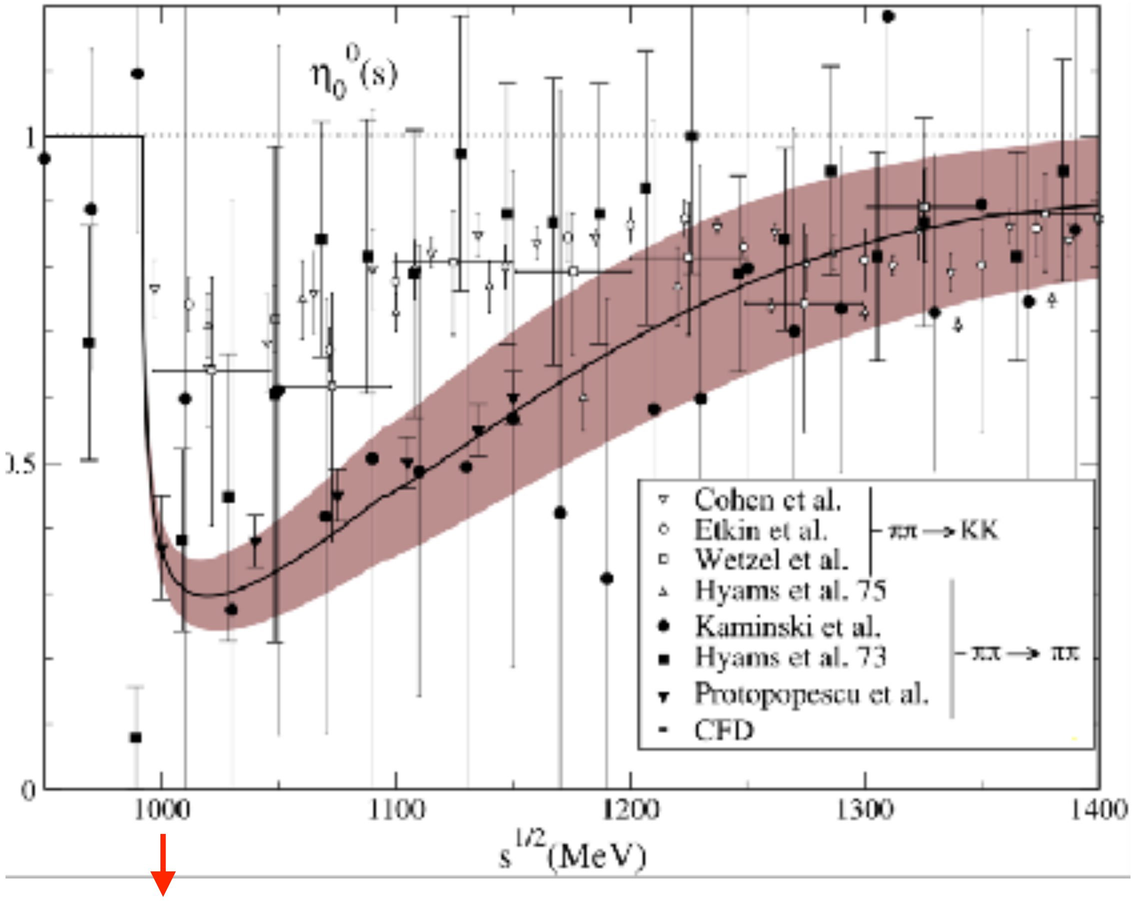
Pelaez,Yndurain PRD71(2011) 074016

  - amplitude $\hat{f}_l(s) = \left[\frac{\eta_l e^{2i\delta_l} - 1}{2i}\right].$

Inelasticity

Phase-shift





↓
KK

$$\sigma_l^{\mathrm{el}} = \frac{1}{2}\left\{\frac{1 + \eta_l^2}{2} - \eta\cos2\delta_l\right\},$$

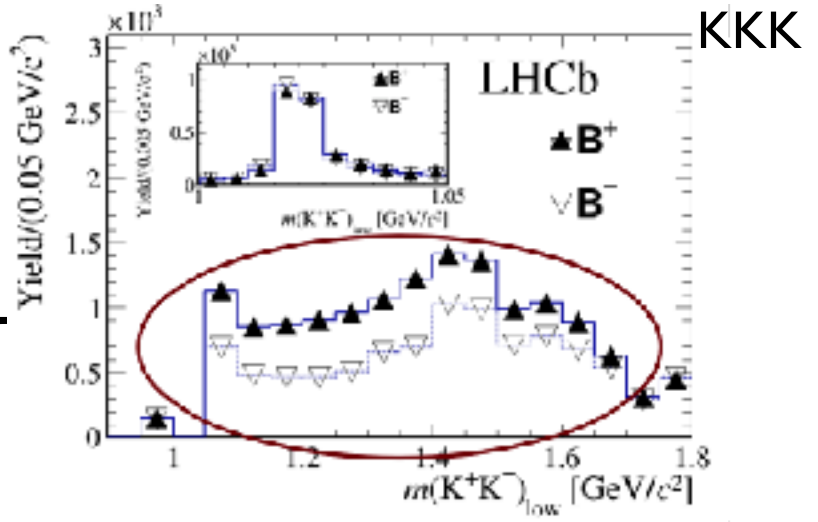
Inelasticity: one minus the probability of losing signal (1==elastic)

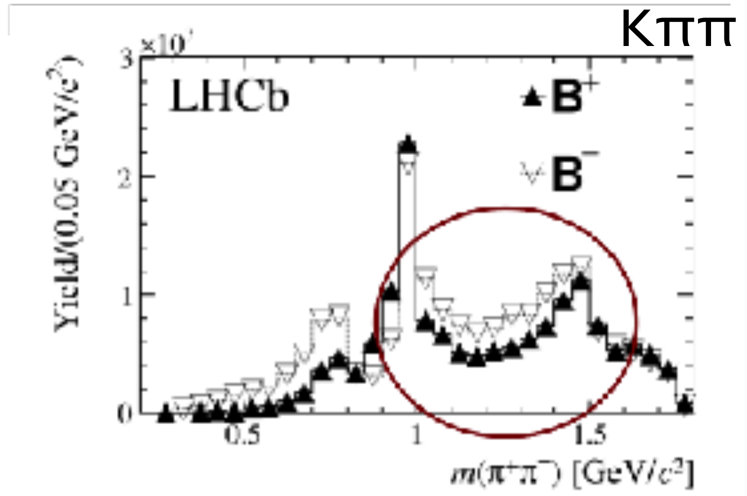
CPV on data

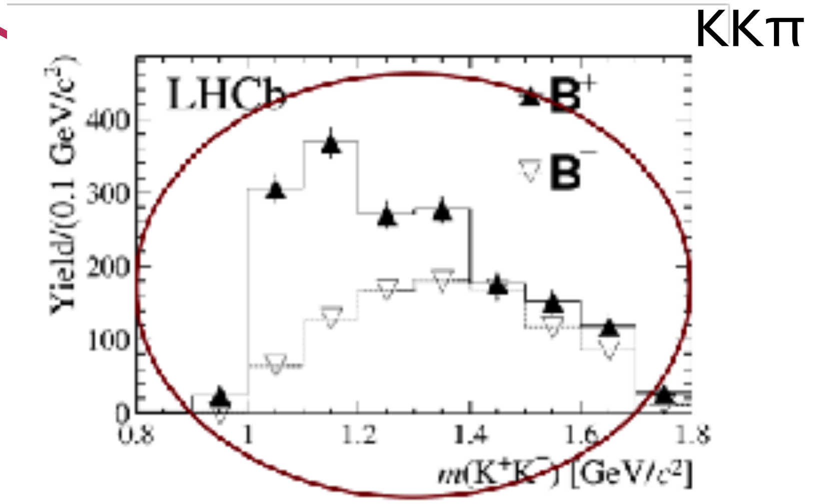
- low-energy CPV [1 - 2] GeV

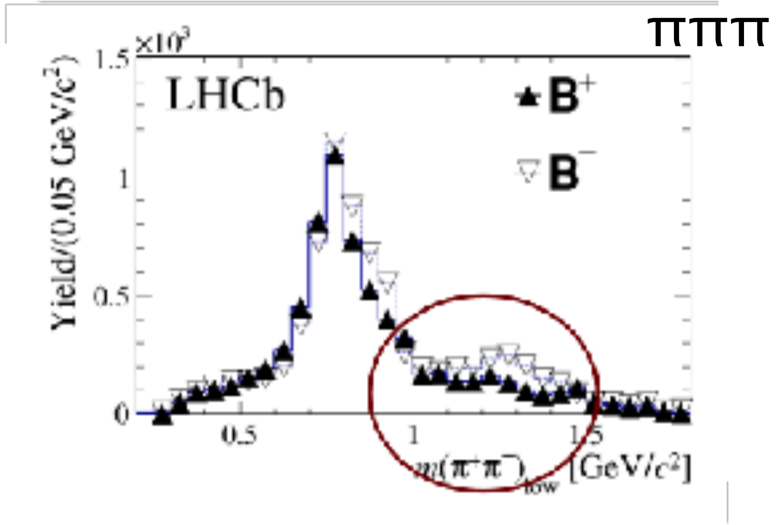
$$\boxed{\pi\pi \to KK}$$

Frederico, Bediaga & Lourenço
PRD89(2014)094013


KKK


Kππ


KKπ


πππ

- FSI → strong phase

Wolfenstein PRD43 (1991) 151

- CPT:

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

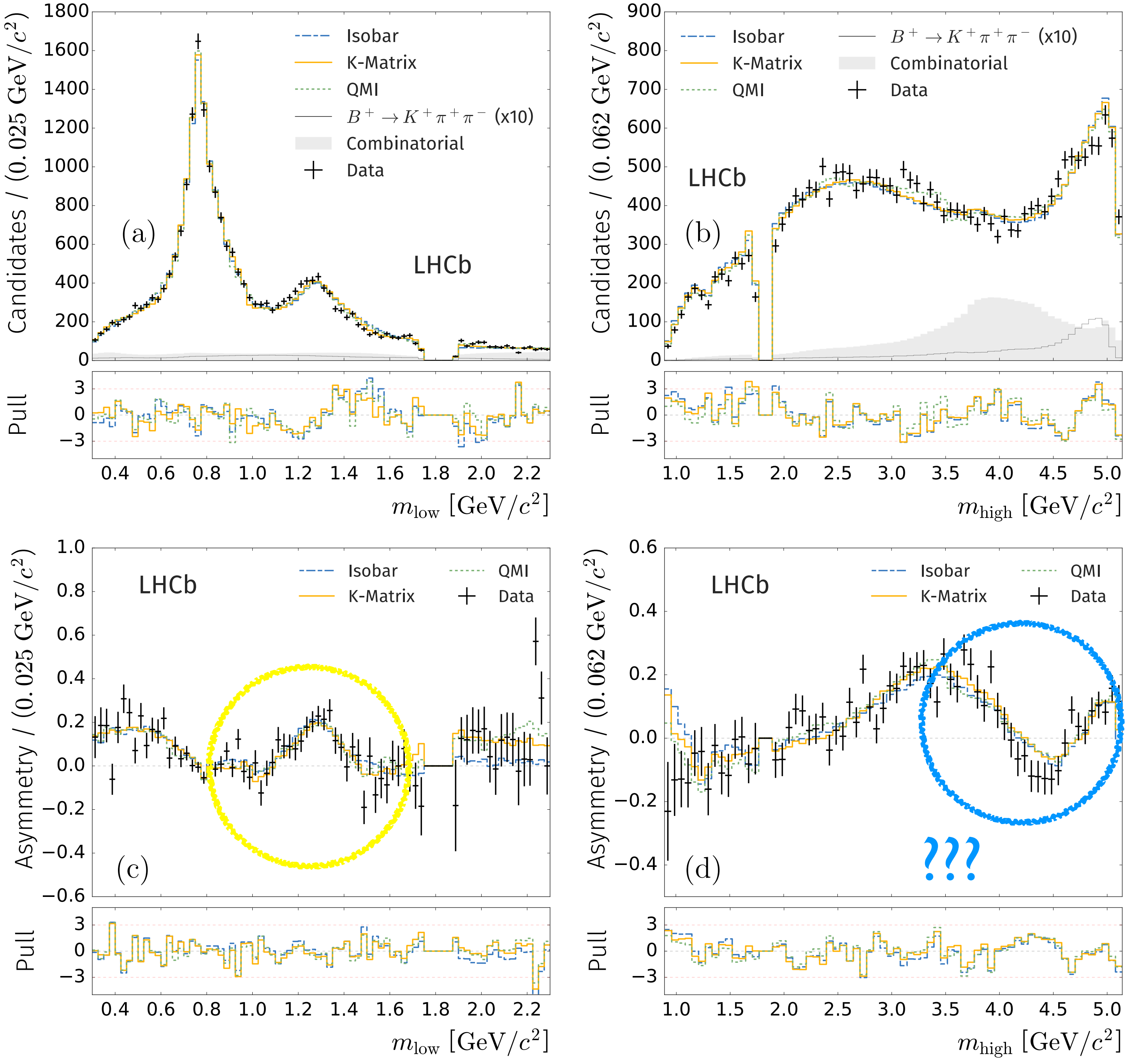
$$\Gamma_{total} = \Gamma_1 + \Gamma_2 + \Gamma_3 + \Gamma_4 + \Gamma_5 + \Gamma_6 + \ldots$$

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

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

CPV: amplitude analysis $B^{\pm} \rightarrow \pi^{-}\pi^{+}\pi^{\pm}$

- LHCb recent Amplitude analysis $B^{\pm} \rightarrow \pi^{-}\pi^{+}\pi^{\pm}$ [arXiv:1909.05212(PRD); 1909.05211(PRL)]
  - $(\pi^{-}\pi^{+})_{S-Wave}$ 3 different model:
    - ↪ σ as BW (!) + rescattering;
    - ↪ P-vector K-Matrix;
    - ↪ binned freed lineshape (QMI);



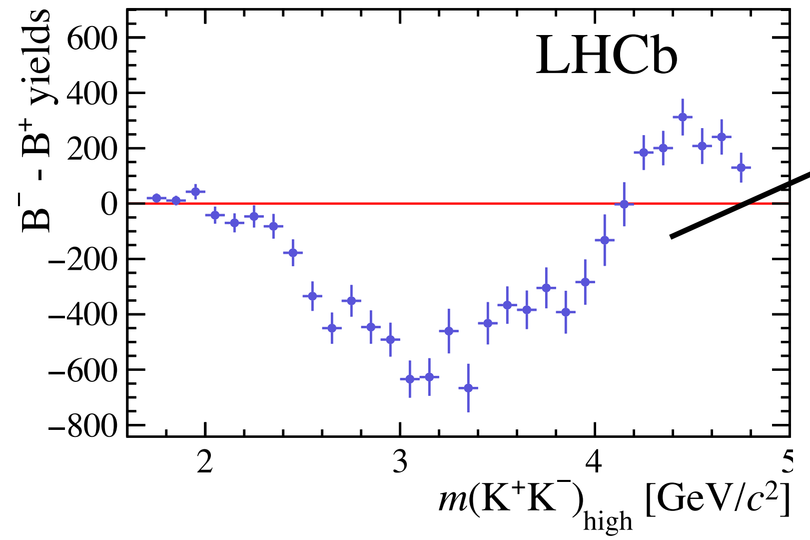
Contribution	Fit fraction (10^{-2})	A_{CP} (10^{-2})	B^+ phase (°)	B^- phase (°)
Isobar model				
$\rho(770)^0$	$55.5 \pm 0.6 \pm 2.5$	$+0.7 \pm 1.1 \pm 1.6$	—	—
$\omega(782)$	$0.50 \pm 0.03 \pm 0.05$	$-4.8 \pm 6.5 \pm 3.8$	$-19 \pm 6 \pm 1$	$+8 \pm 6 \pm 1$
$f_2(1270)$	$9.0 \pm 0.3 \pm 1.5$	$+46.8 \pm 6.1 \pm 4.7$	$+5 \pm 3 \pm 12$	$+53 \pm 2 \pm 12$
$\rho(1450)^0$	$5.2 \pm 0.3 \pm 1.9$	$-12.9 \pm 3.3 \pm 35.9$	$+127 \pm 4 \pm 21$	$+154 \pm 4 \pm 6$
$\rho_3(1690)^0$	$0.5 \pm 0.1 \pm 0.3$	$-80.1 \pm 11.4 \pm 25.3$	$-26 \pm 7 \pm 14$	$-47 \pm 18 \pm 25$
S-wave	$25.4 \pm 0.5 \pm 3.6$	$+14.4 \pm 1.8 \pm 2.1$	—	—
Rescattering	$1.4 \pm 0.1 \pm 0.5$	$+44.7 \pm 8.6 \pm 17.3$	$-35 \pm 6 \pm 10$	$-4 \pm 4 \pm 25$
σ	$25.2 \pm 0.5 \pm 5.0$	$+16.0 \pm 1.7 \pm 2.2$	$+115 \pm 2 \pm 14$	$+179 \pm 1 \pm 95$
K-matrix				
$\rho(770)^0$	$56.5 \pm 0.7 \pm 3.4$	$+4.2 \pm 1.5 \pm 6.4$	—	—
$\omega(782)$	$0.47 \pm 0.04 \pm 0.03$	$-6.2 \pm 8.4 \pm 9.8$	$-15 \pm 6 \pm 4$	$+8 \pm 7 \pm 4$
$f_2(1270)$	$9.3 \pm 0.4 \pm 2.5$	$+42.8 \pm 4.1 \pm 9.1$	$+19 \pm 4 \pm 18$	$+80 \pm 3 \pm 17$
$\rho(1450)^0$	$10.5 \pm 0.7 \pm 4.6$	$+9.0 \pm 6.0 \pm 47.0$	$+155 \pm 5 \pm 29$	$-166 \pm 4 \pm 51$
$\rho_3(1690)^0$	$1.5 \pm 0.1 \pm 0.4$	$-35.7 \pm 10.8 \pm 36.9$	$+19 \pm 8 \pm 34$	$+5 \pm 8 \pm 46$
S-wave	$25.7 \pm 0.6 \pm 3.0$	$+15.8 \pm 2.6 \pm 7.2$	—	—
QMI				
$\rho(770)^0$	$54.8 \pm 1.0 \pm 2.2$	$+4.4 \pm 1.7 \pm 2.8$	—	—
$\omega(782)$	$0.57 \pm 0.10 \pm 0.17$	$-7.9 \pm 16.5 \pm 15.8$	$-25 \pm 6 \pm 27$	$-2 \pm 7 \pm 11$
$f_2(1270)$	$9.6 \pm 0.4 \pm 4.0$	$+37.6 \pm 4.4 \pm 8.0$	$+13 \pm 5 \pm 21$	$+68 \pm 3 \pm 66$
$\rho(1450)^0$	$7.4 \pm 0.5 \pm 4.0$	$-15.5 \pm 7.3 \pm 35.2$	$+147 \pm 7 \pm 152$	$-175 \pm 5 \pm 171$
$\rho_3(1690)^0$	$1.0 \pm 0.1 \pm 0.5$	$-93.2 \pm 6.8 \pm 38.9$	$+8 \pm 10 \pm 24$	$+36 \pm 26 \pm 46$
S-wave	$26.8 \pm 0.7 \pm 2.2$	$+15.0 \pm 2.7 \pm 8.1$	—	—

- ANA for $B^{\pm} \rightarrow \pi^{\pm}K^{-}K^{+}$ [arXiv:1905.09244]

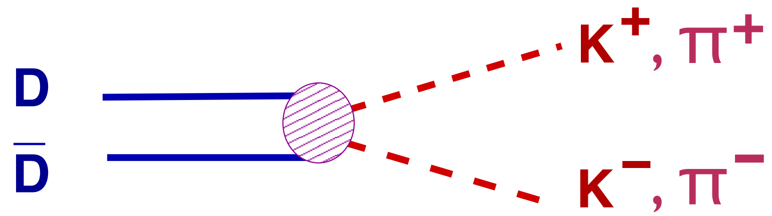
Contribution	Fit Fraction(%)	A_{CP}(%)	Magnitude (B^+/B^-)	Phase[^{o}] (B^+/B^-)
$K^*(892)^0$	$7.5 \pm 0.6 \pm 0.5$	$+12.3 \pm 8.7 \pm 4.5$	$0.94 \pm 0.04 \pm 0.02$ $1.06 \pm 0.04 \pm 0.02$	0 (fixed) 0 (fixed)
$K_0^*(1430)^0$	$4.5 \pm 0.7 \pm 1.2$	$+10.4 \pm 14.9 \pm 8.8$	$0.74 \pm 0.09 \pm 0.09$ $0.82 \pm 0.09 \pm 0.10$	$-176 \pm 10 \pm 16$ $136 \pm 11 \pm 21$
Single pole	$32.3 \pm 1.5 \pm 4.1$	$-10.7 \pm 5.3 \pm 3.5$	$2.19 \pm 0.13 \pm 0.17$ $1.97 \pm 0.12 \pm 0.20$	$-138 \pm 7 \pm 5$ $166 \pm 6 \pm 5$
$\rho(1450)^0$	$30.7 \pm 1.2 \pm 0.9$	$-10.9 \pm 4.4 \pm 2.4$	$2.14 \pm 0.11 \pm 0.07$ $1.92 \pm 0.10 \pm 0.07$	$-175 \pm 10 \pm 15$ $140 \pm 13 \pm 20$
$f_2(1270)$	$7.5 \pm 0.8 \pm 0.7$	$+26.7 \pm 10.2 \pm 4.8$	$0.86 \pm 0.09 \pm 0.07$ $1.13 \pm 0.08 \pm 0.05$	$-106 \pm 11 \pm 10$ $-128 \pm 11 \pm 14$
Rescattering	$16.4 \pm 0.8 \pm 1.0$	$-66.4 \pm 3.8 \pm 1.9$	$1.91 \pm 0.09 \pm 0.06$ $0.86 \pm 0.07 \pm 0.04$	$-56 \pm 12 \pm 18$ $-81 \pm 14 \pm 15$
$\phi(1020)$	$0.3 \pm 0.1 \pm 0.1$	$+9.8 \pm 43.6 \pm 26.6$	$0.20 \pm 0.07 \pm 0.02$ $0.22 \pm 0.06 \pm 0.04$	$-52 \pm 23 \pm 32$ $107 \pm 33 \pm 41$

CPV high energy

- CPV high mass?



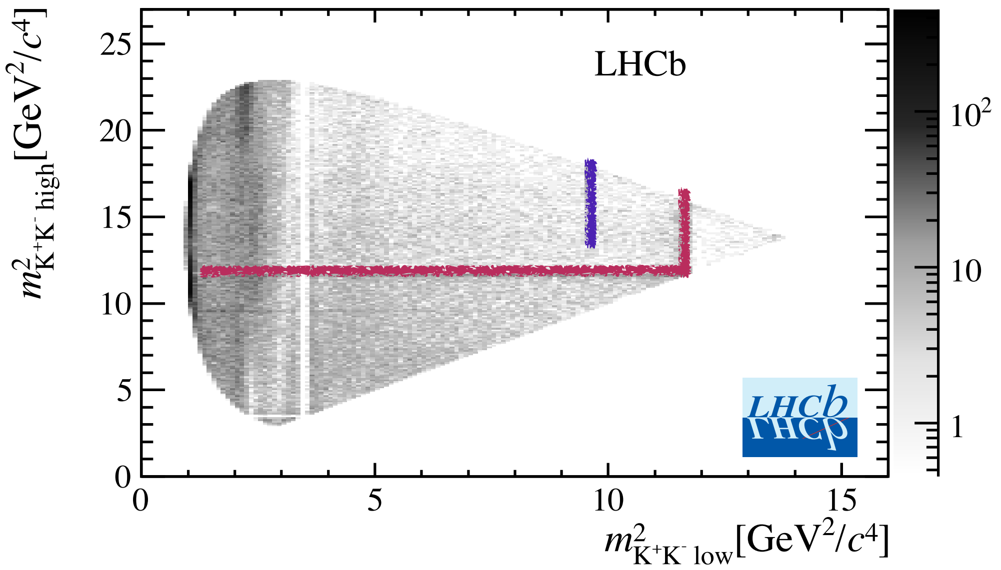
~ $D\bar{D}$ open channel →

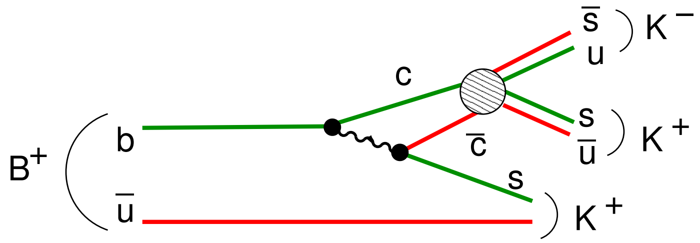


same observed in coupled-channels

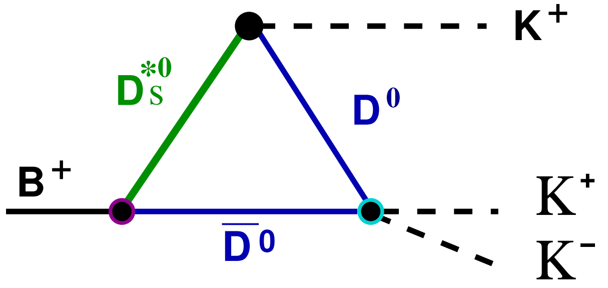
→ charm intermediate processes as source of strong phase

- $B^+ \to K^- K^+ K^+$
  - high statistic 109k
  - nonresonant → all phase-space
  - presence of charm resonances: $\underline{\chi c0}$ $\underline{J/\psi}$
  - dominated by penguin





→

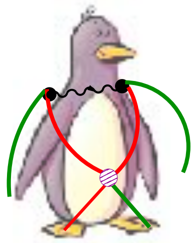


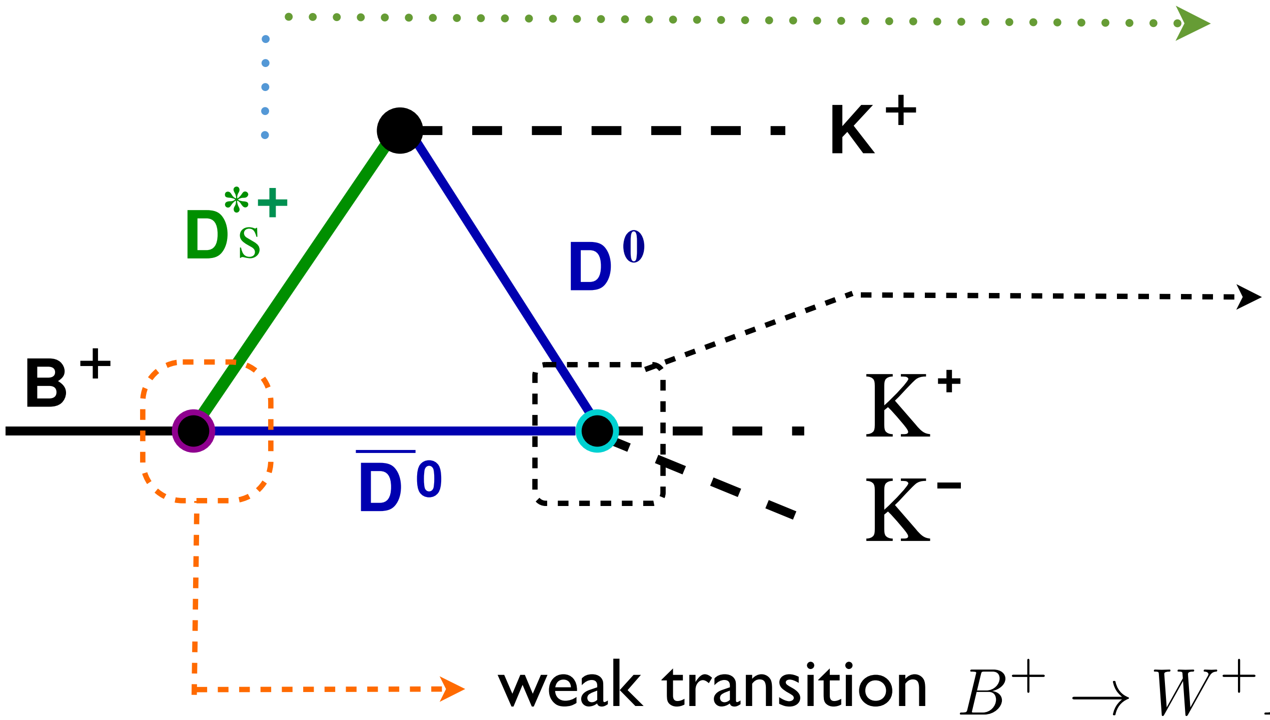
charm rescattering!

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

hadronic loop

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





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

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

phenomenological:
S- matrix unitarity + Regge theory

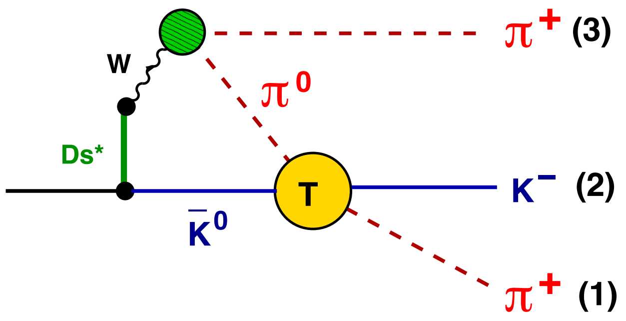
weak transition $B^+ \to W^+ \bar{D}^0$ → $C_0 \times$ form factor to regulate

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

- hadronic loop → three-body FSI - introduce new complex structures

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

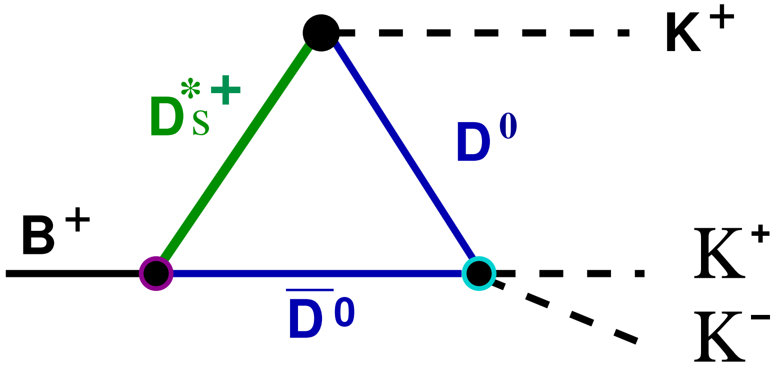
PCM & I Bediaga
arXiv:1512.09284

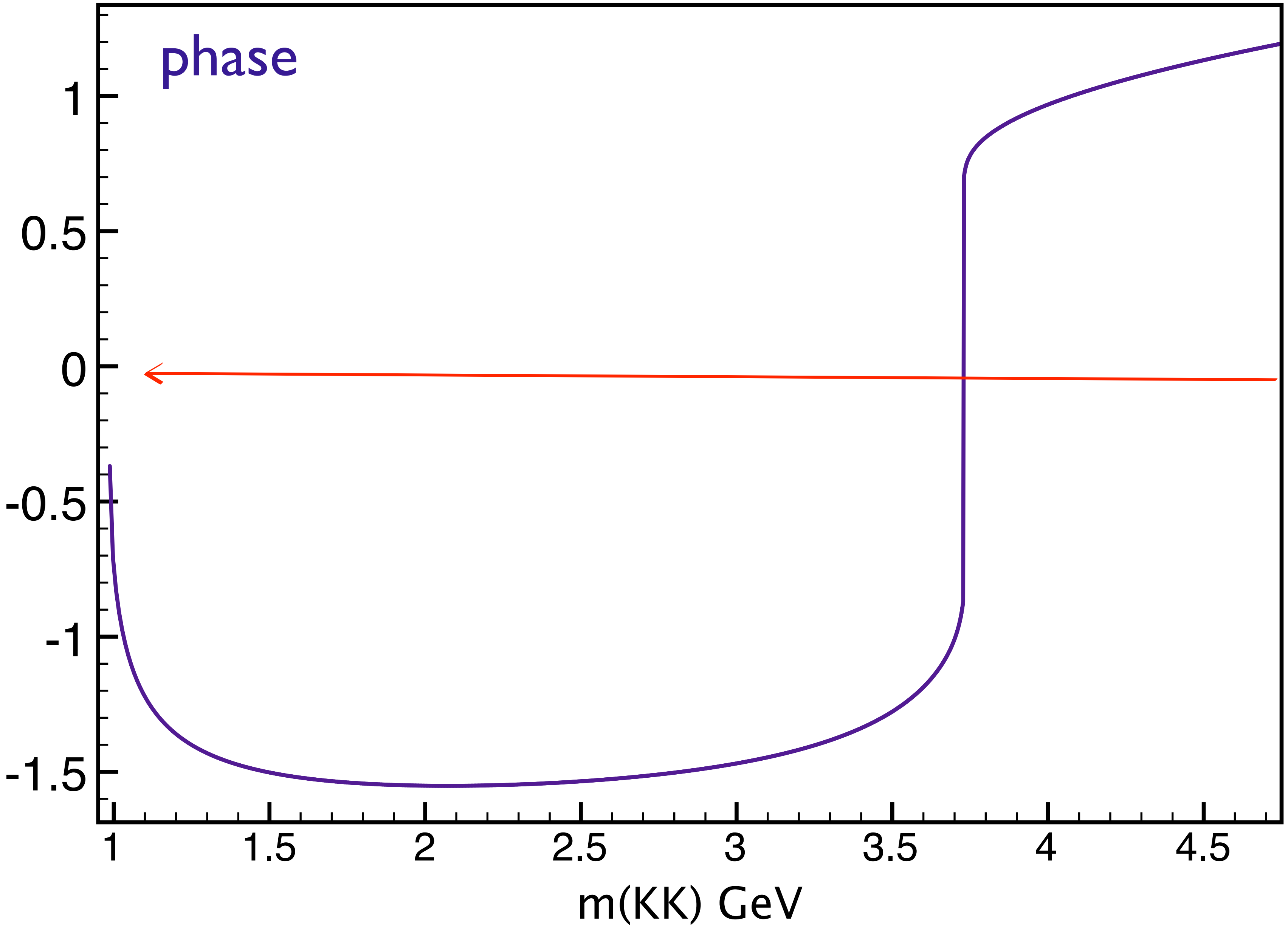


PCM & M Robilotta
PRD 92 094005 (2015) [arXiv:1504.06346]
PCM et al
PRD 84 094001 (2011) [arXiv:1105.5120]

hadronic loop

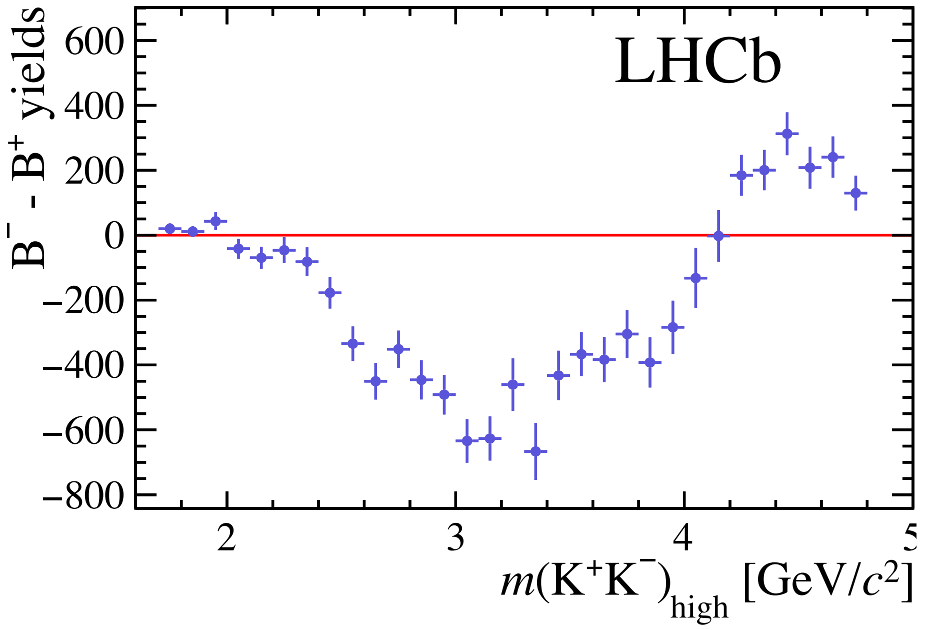
- $$A = iC\ m_a^2 \int \frac{d^4\ell}{(2\pi)^4}\, \frac{T_{\bar{D}^0 D^0 \to KK}(s_{23})\,[-2\,p_3' \cdot (p_2' - p_1)]}{\Delta_{D^{+*}}\,\Delta_{D^0}\,\Delta_{\bar{D}^0}\,\Delta_a}\,,$$





→ Phase change signal in the same region as Acp data

Promising mechanism !

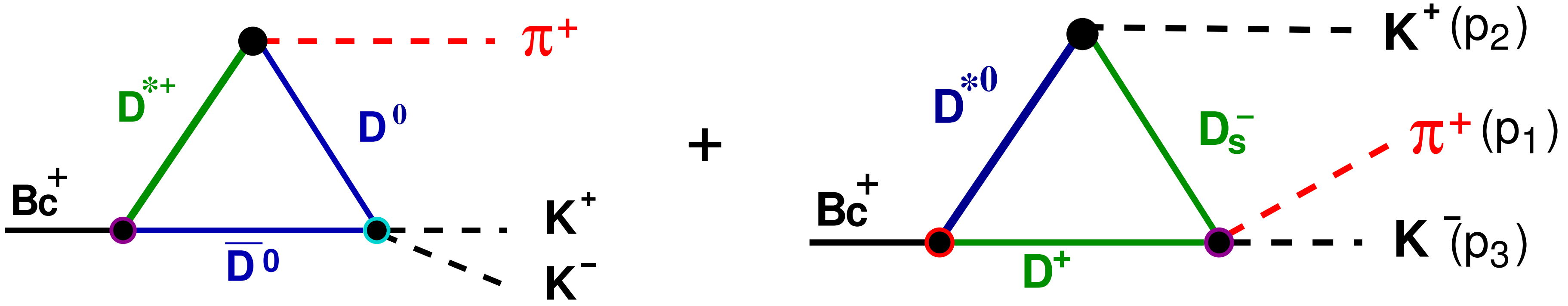


→ can explain change CPV signal in DP!!!

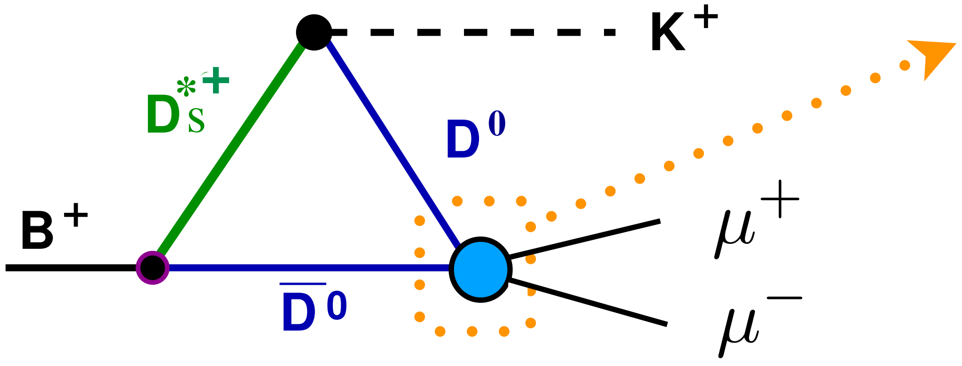
Charm rescattering elsewhere

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

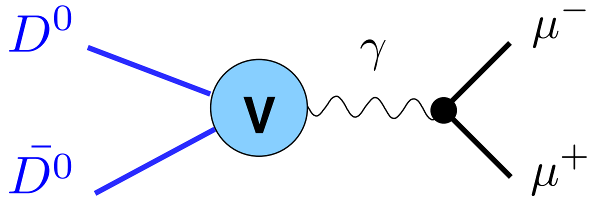
I. Bediaga, PCM, T Frederico
PLB 785 (2018) 581



Next: investigating Hadronic effect in $B \to K\mu\mu$



$\bar{D}^0 D^0 \to \gamma \to \mu^+\mu^-$



vector meson dominance

V= all vector family psi, …

How much of the anomalies can be understood as hadronic effects?

final remarks

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

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

→ Charm rescattering in under intense investigation : CPV on B, exotics, anomalies, ……

- Lots of theoretical limitations to be developed:
  - need to merge the short and long distance descriptions!
  - extend the meson-meson interaction to high E, …
- Successful examples of cooperation between theory and experiment !!!

→ Important tool !

Thank you very much!

image credit: unknown

Backup slides

FSI in three-body decay :

references

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PC Magalhães and I Bediaga   arXiv:1512.09284;

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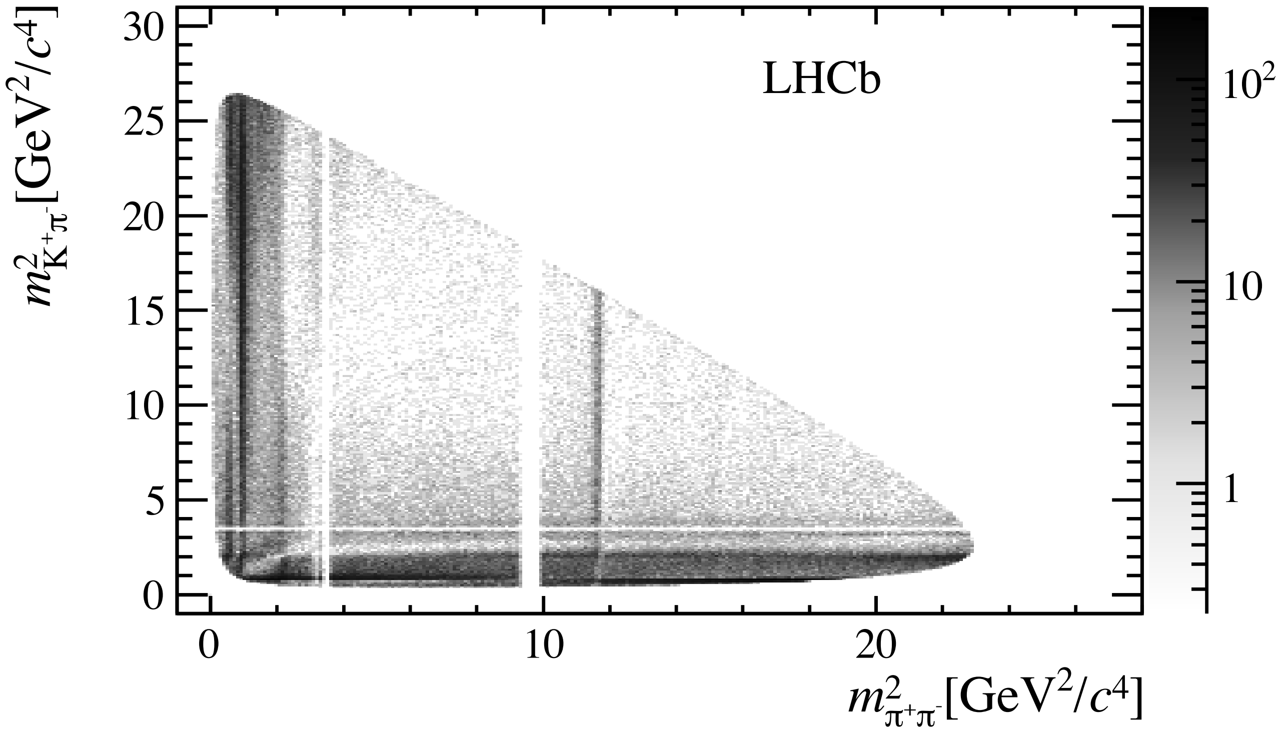
many more ...

if needed

Kpp



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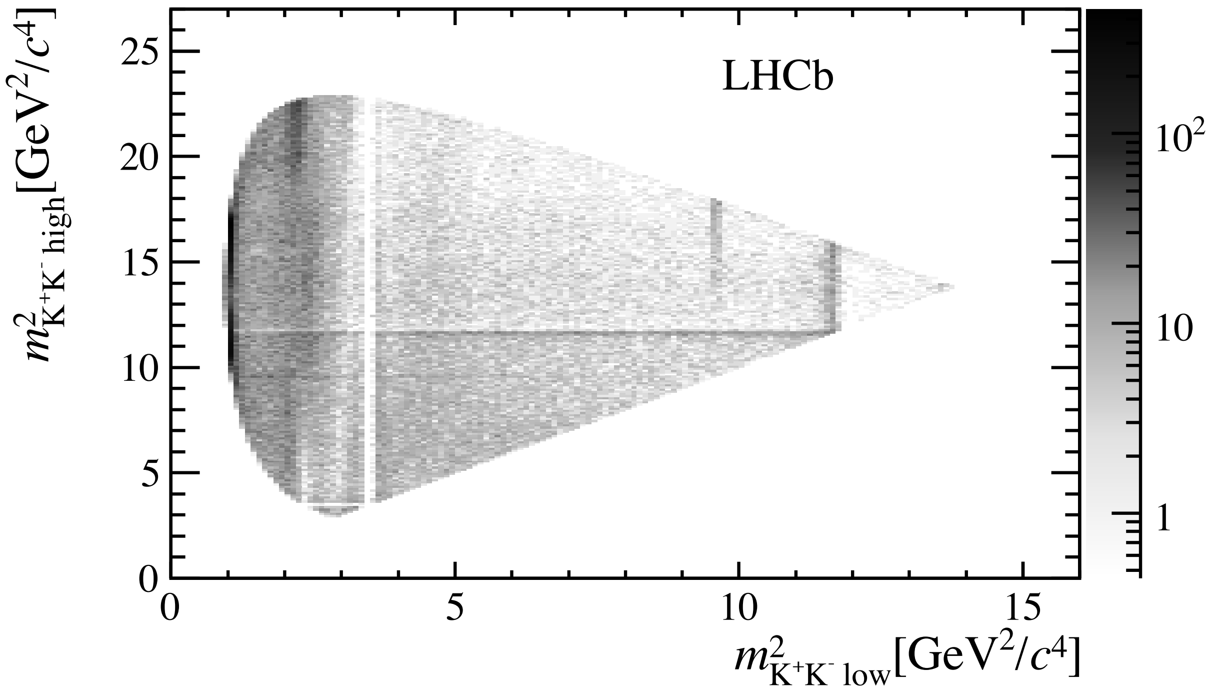

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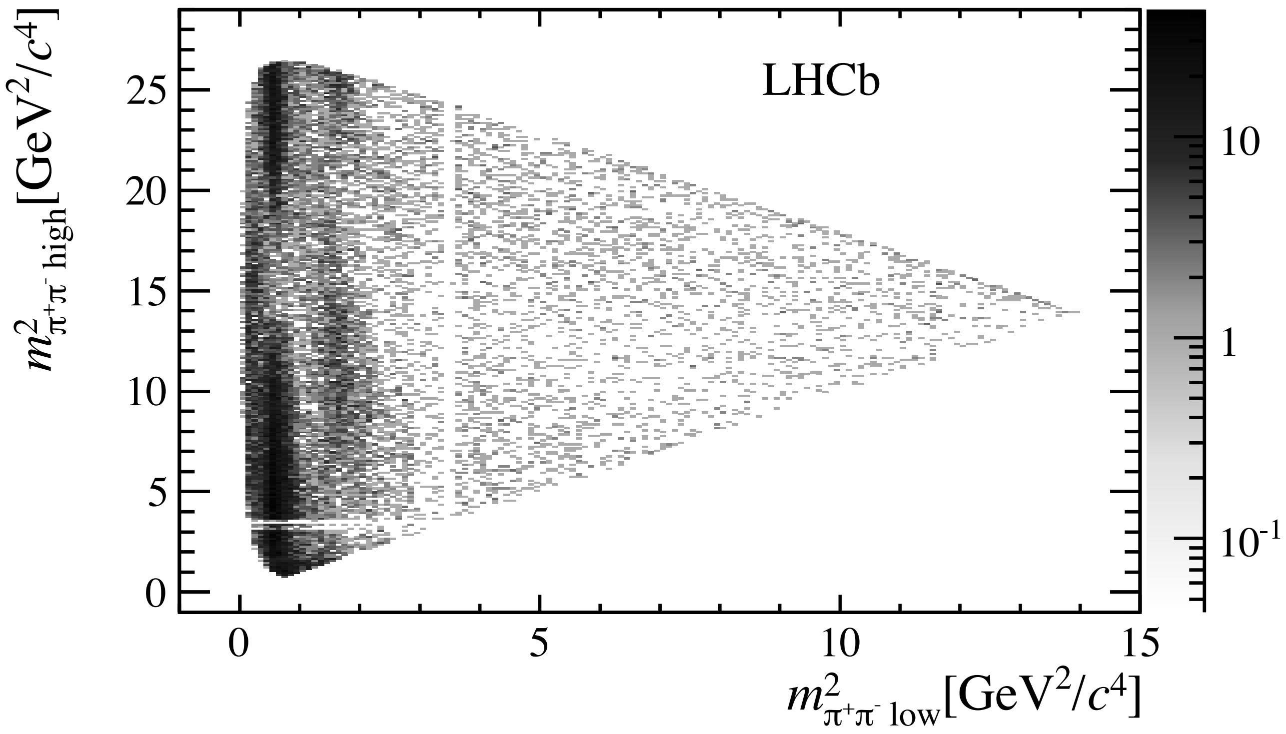

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