3 body Non-leptonic B decays II: the role of hadronic Final State Interaction

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Status and prospects of Non-leptonic B meson decays

31 May to 2 June 2022

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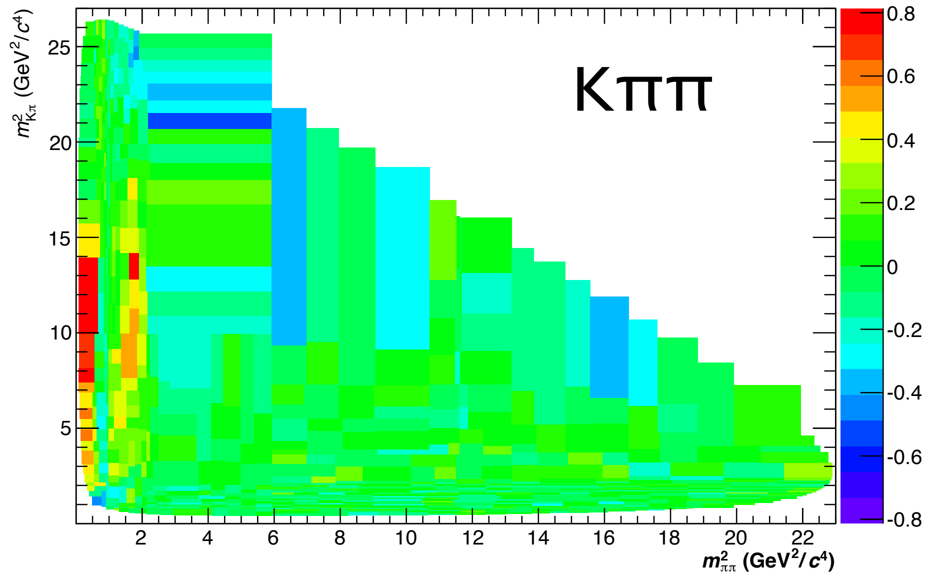
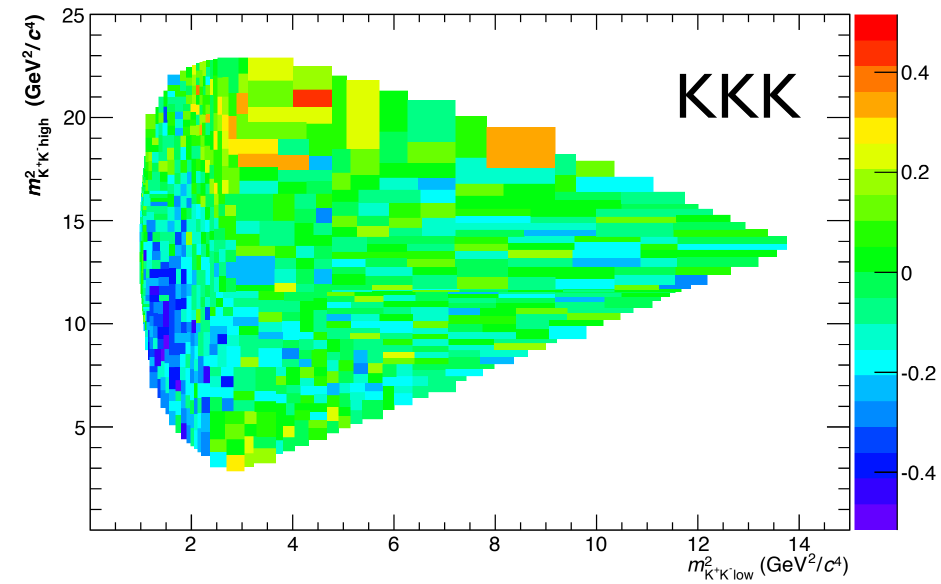
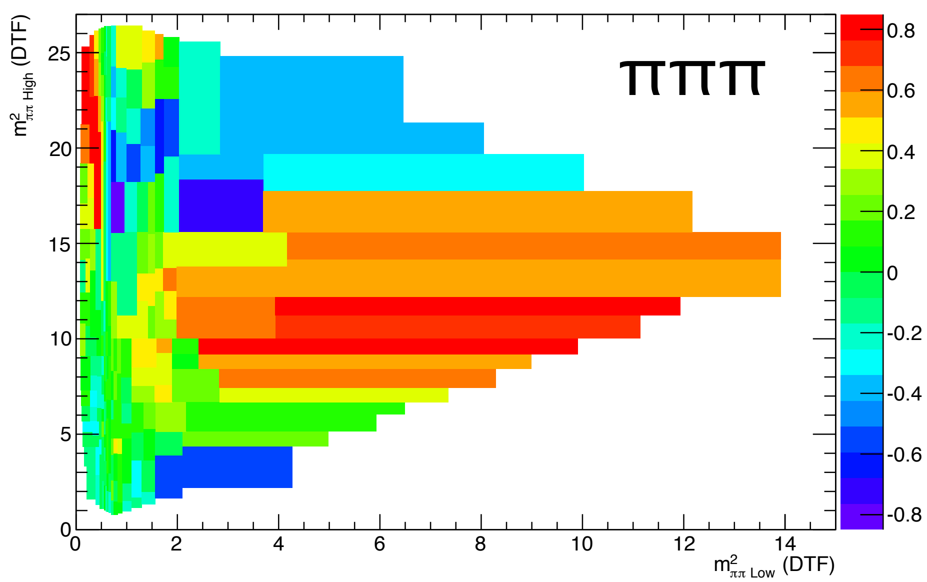
Motivation

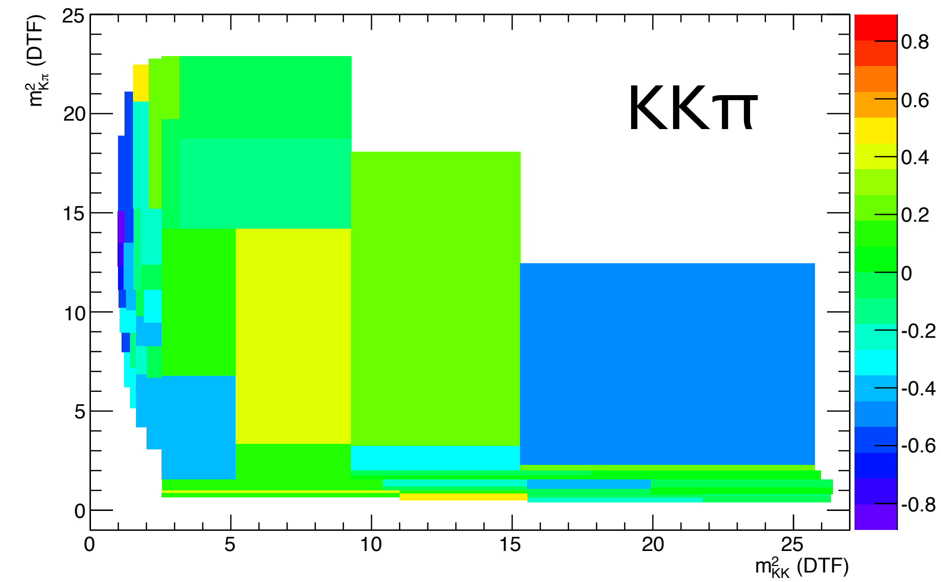
- $B^{\pm} \to h^{\pm}h^{-}h^{+}$ LHCb massive localized Acp LHCb PRD90 (2014) 112004





  - suggest dynamic effect





  - middle looks "empty"

$\downarrow$

CPV

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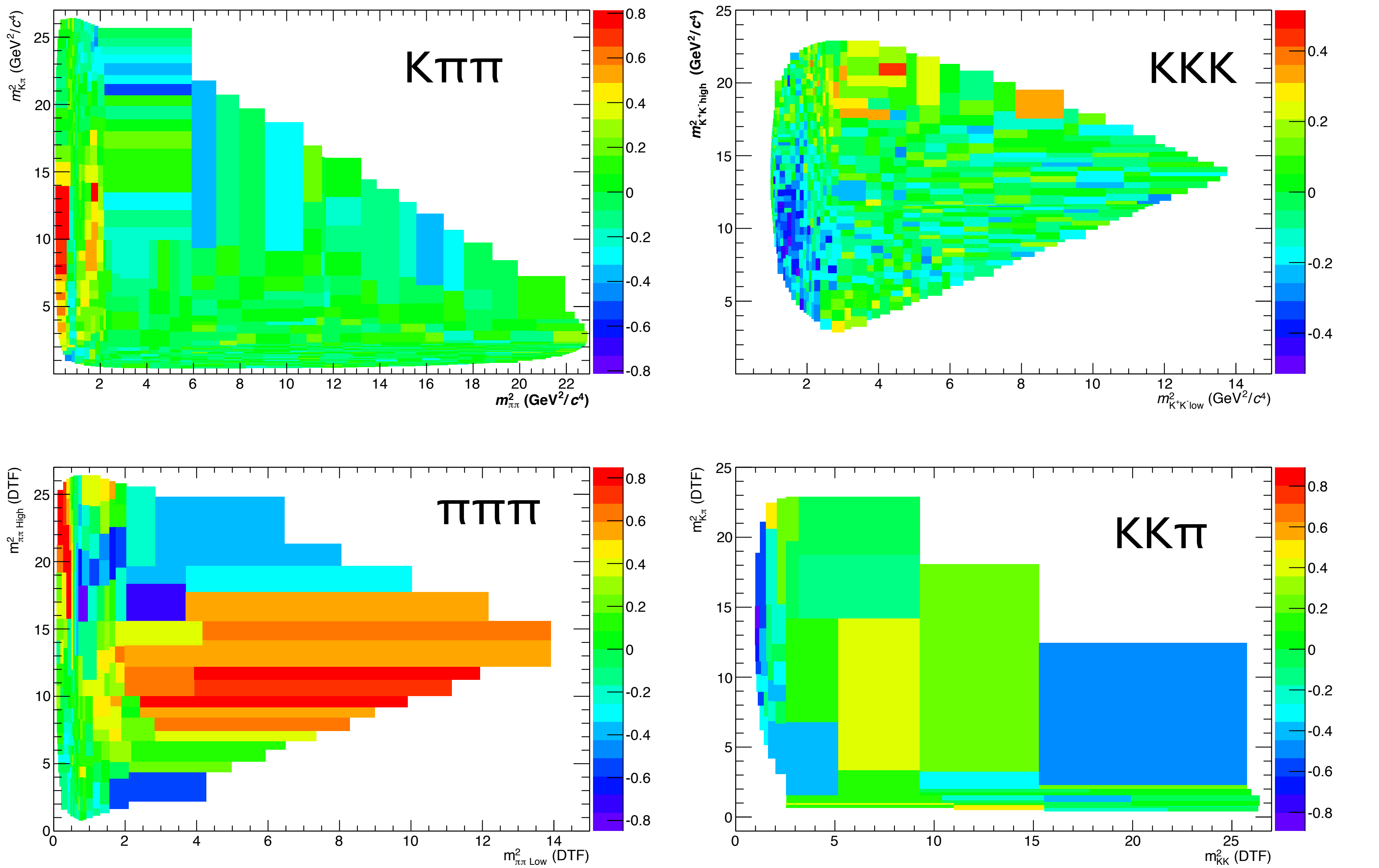

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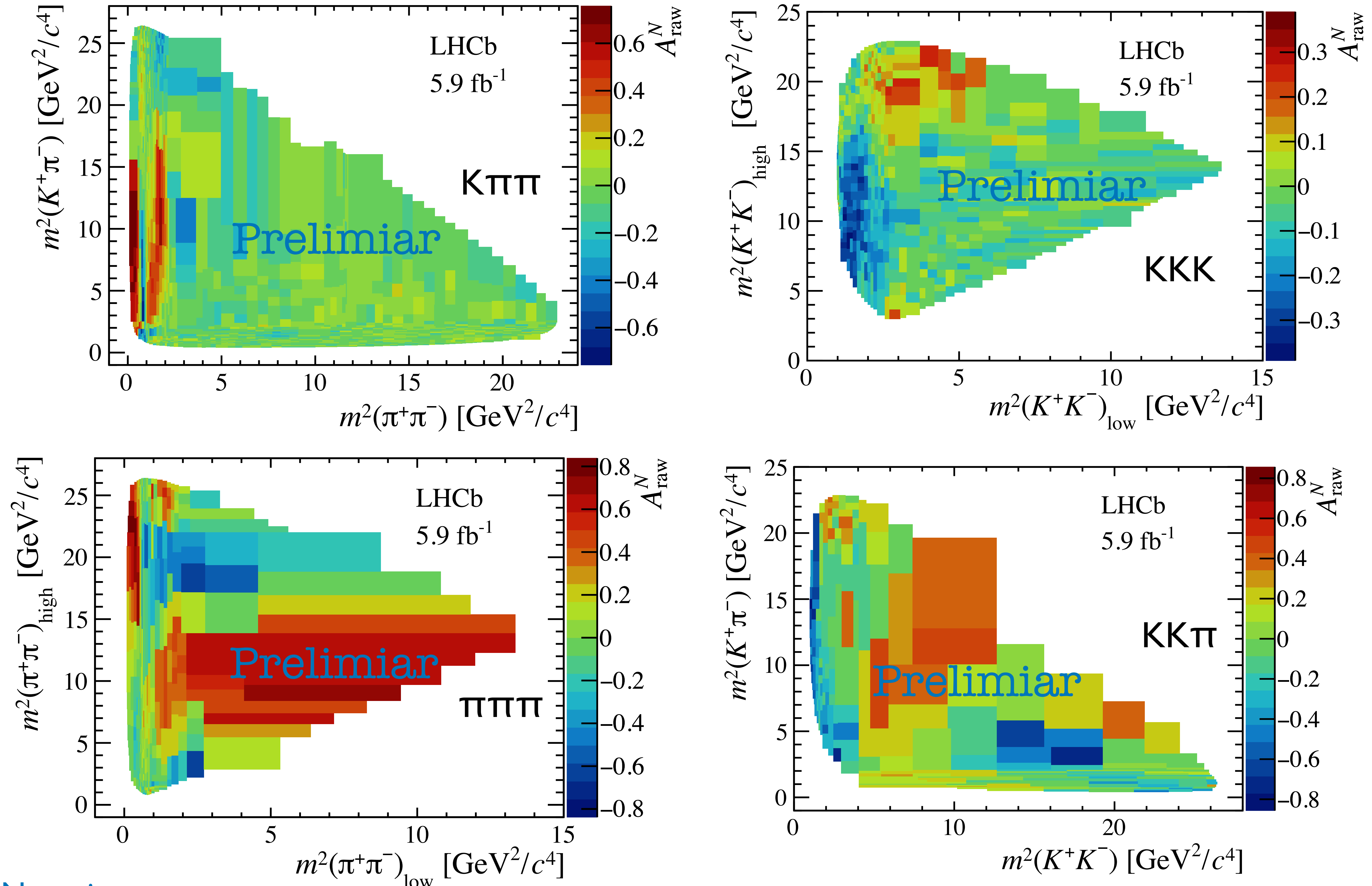
CPV

FSI as source of CP asymmetry in B decays

update Motivation

- $B^{\pm} \to h^{\pm} h^{-} h^{+}$ Run II

still massive localized Acp



link to CERN seminar

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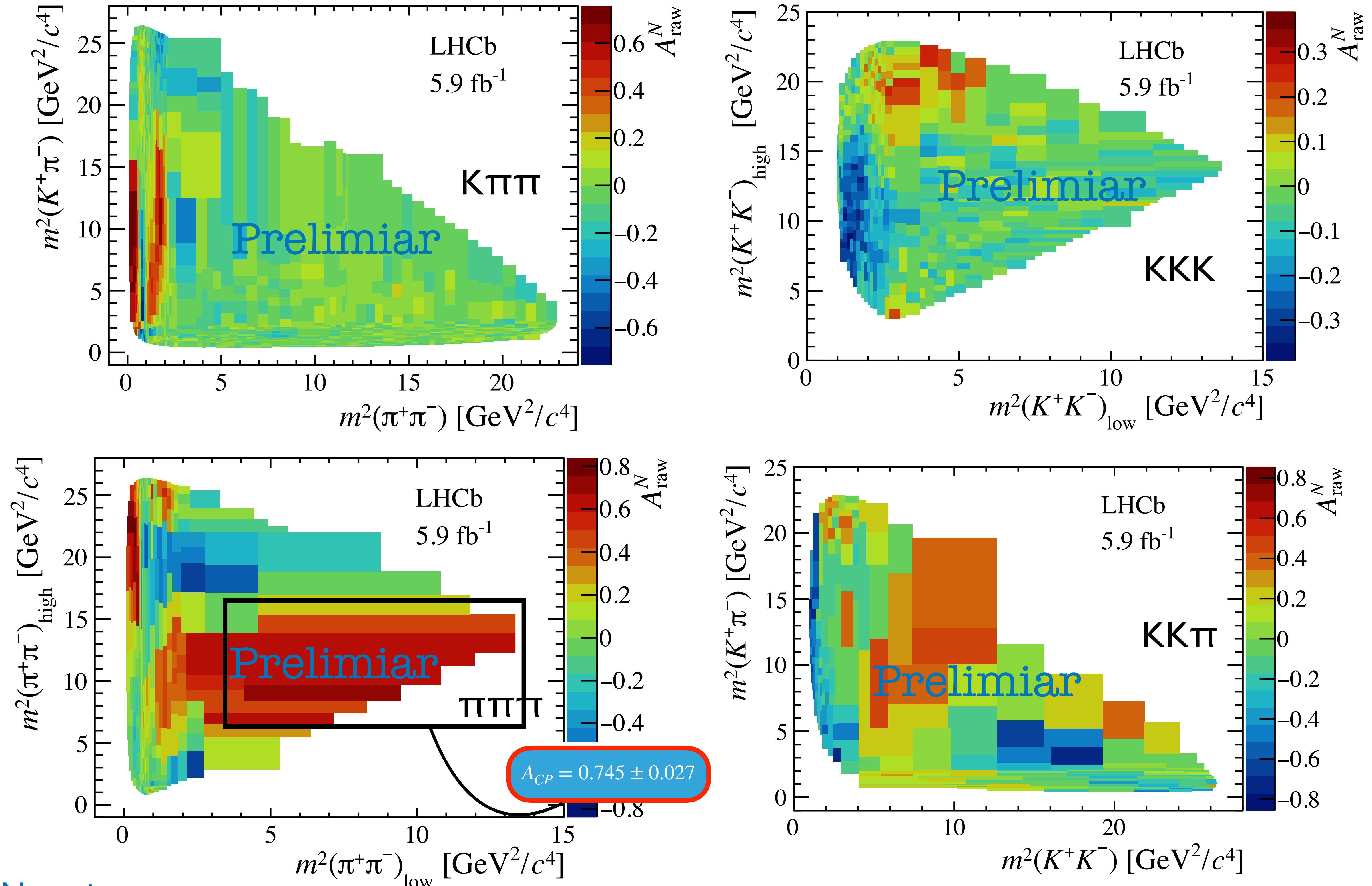

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- condition to CPV

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

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

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

- CPV at quark level: BSS model Bander Silverman & Soni PRL 43 (1979) 242

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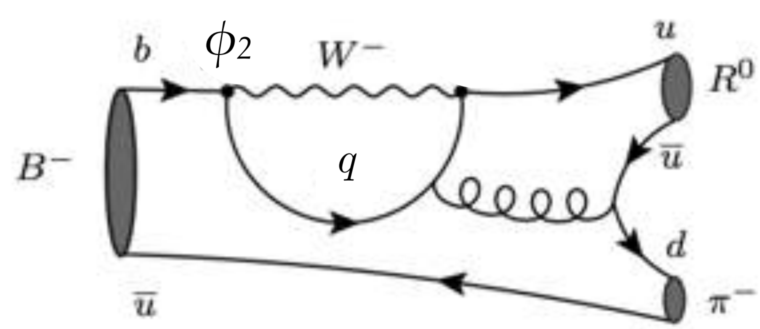

strong phase

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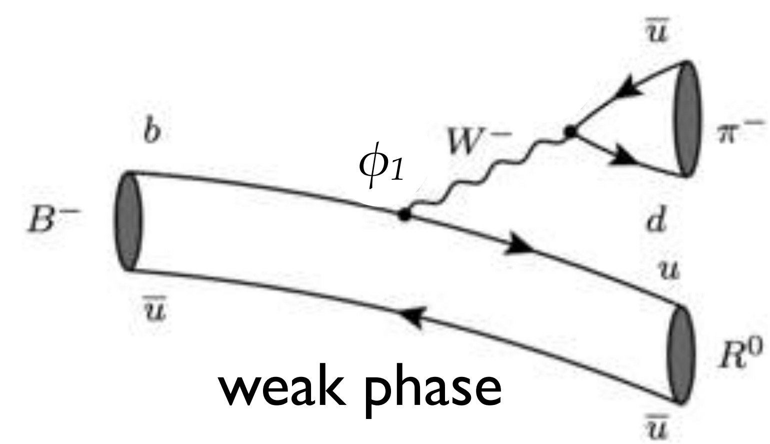

weak phase

CPV on data: Puzzle!

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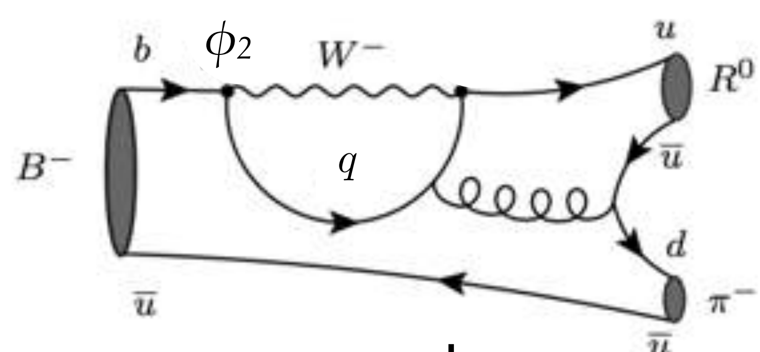

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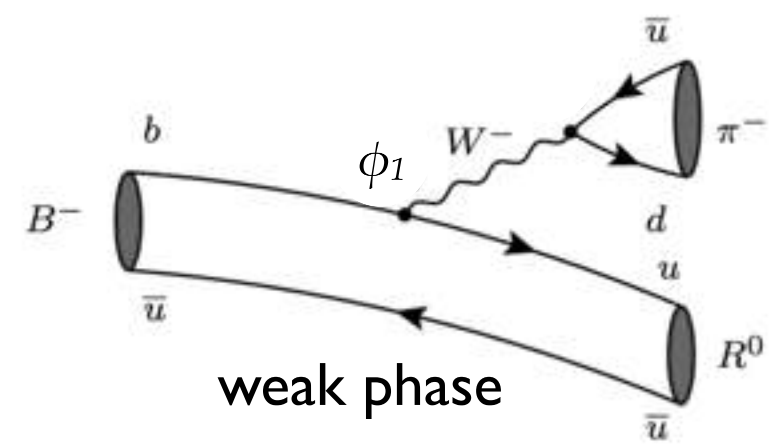
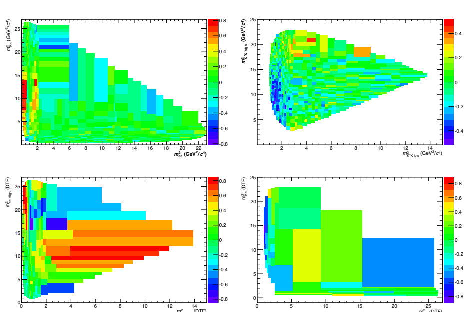


weak phase

  - **Not enough to explain**



hadronic interactions as source of strong phase

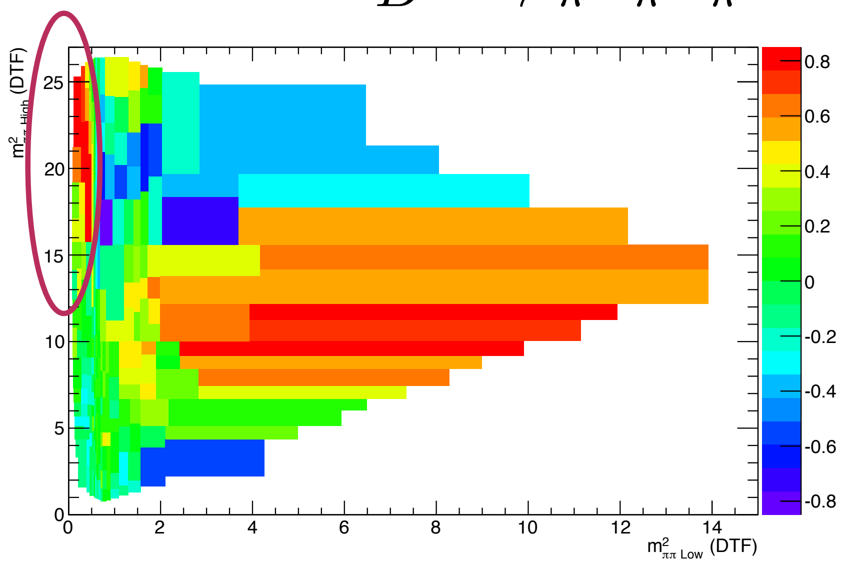
rescattering as a CPV mechanism

- CPT must be preserved

$$\sum \Delta\Gamma_{CP} = 0$$

CPV in one channel should be compensated by another, same quantum #, with opposite sign

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



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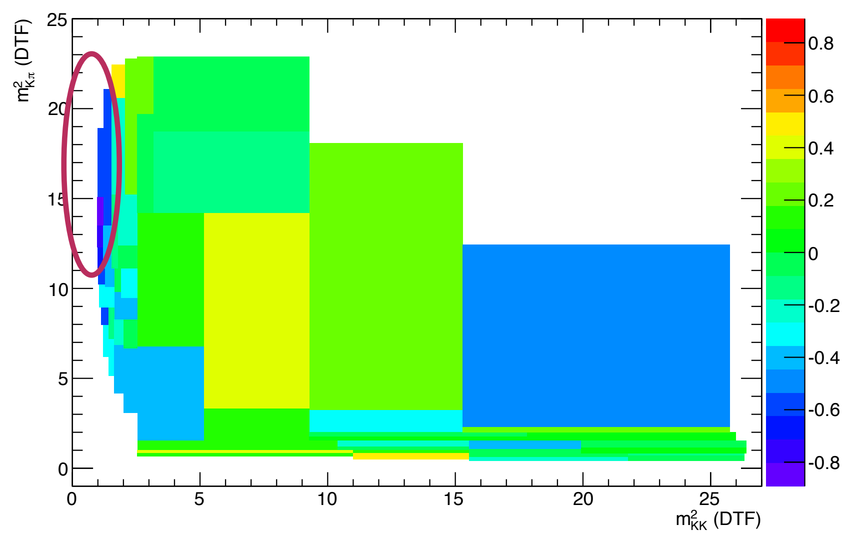

rescattering $\pi\pi \to KK$

CPV at [1 -1.6] GeV

Frederico, Bediaga, Lourenço
PRD89(2014)094013

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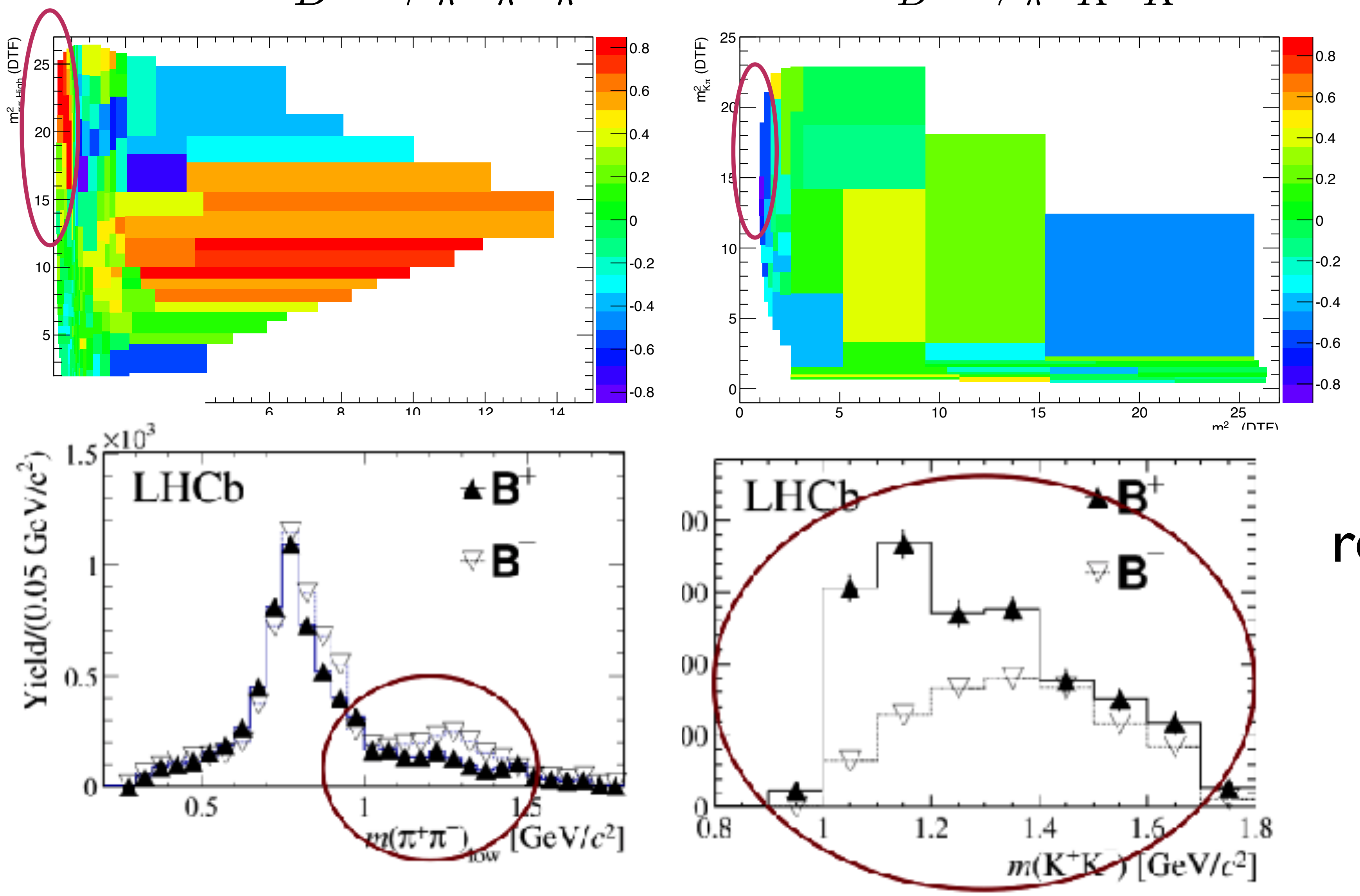

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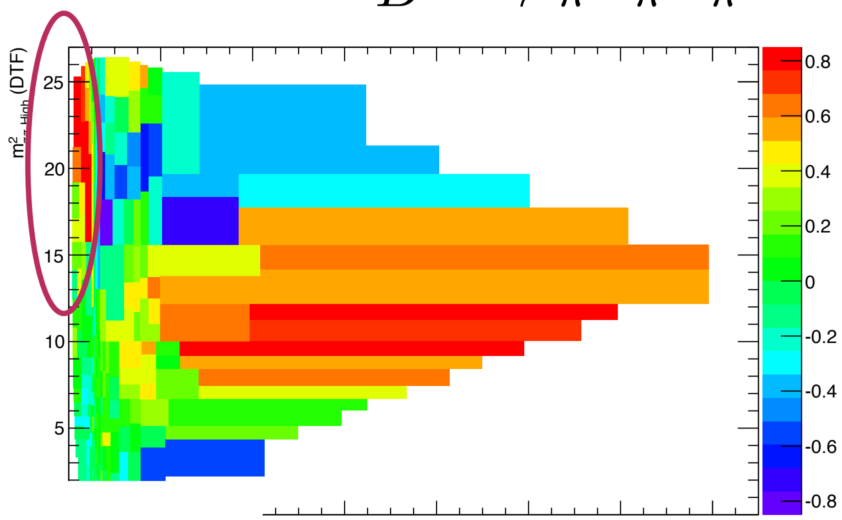

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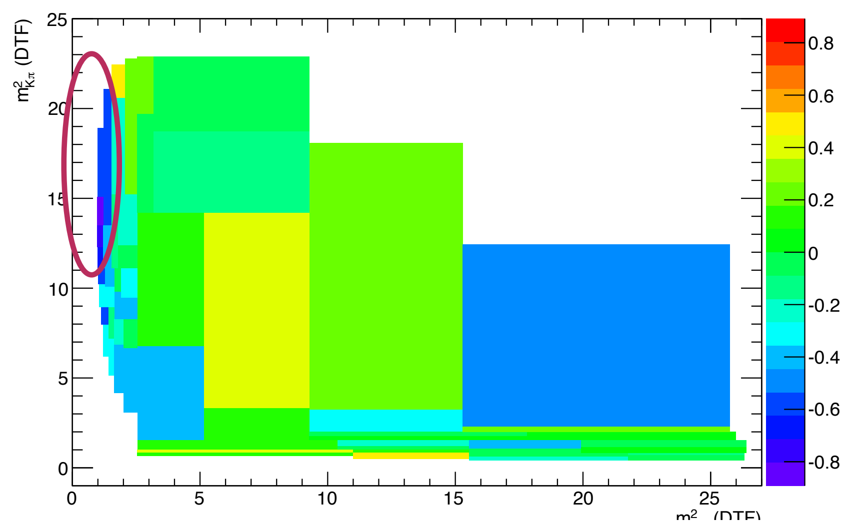

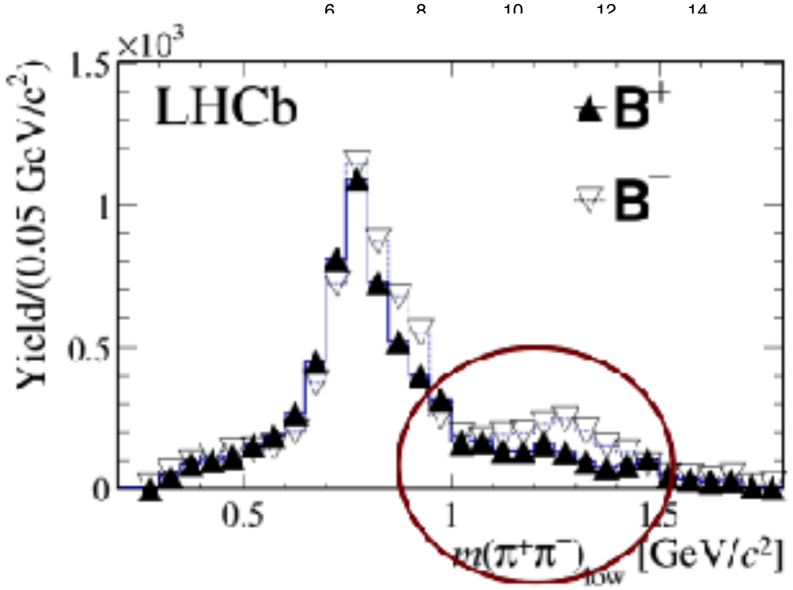

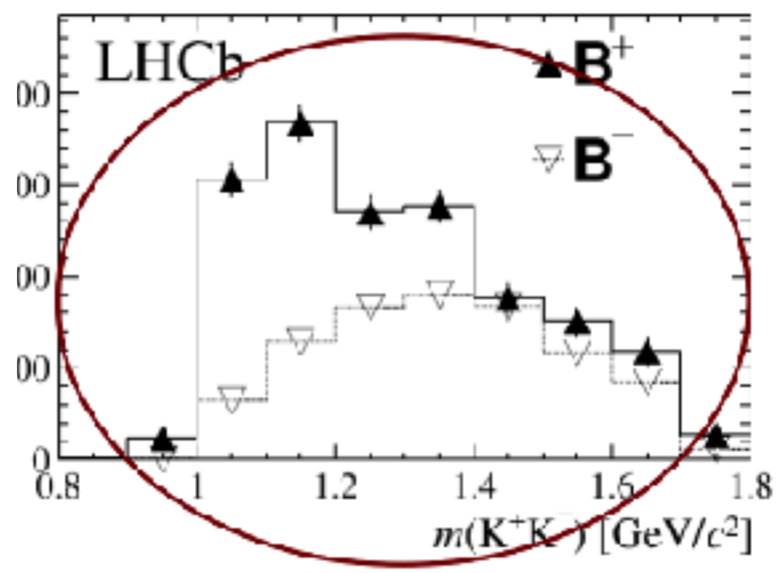

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CPV at [1 -1.6] GeV

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- confirmed by LHCb Amplitude Analysis $B^\pm \to \pi^-\pi^+\pi^\pm$ and $B^\pm \to \pi^\pm K^- K^+$

PRD101 (2020) 012006; PRL 124 (2020) 031801 PRL 123 (2019) 231802

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

- LHCb Amplitude analysis $B^{\pm} \to \pi^- \pi^+ \pi^{\pm}$ PRD101 (2020) 012006; PRL 124 (2020) 031801
  - $(\pi^- \pi^+)_{S-Wave}$ 3 different model:
    - ↳ σ as BW (!) + rescattering;
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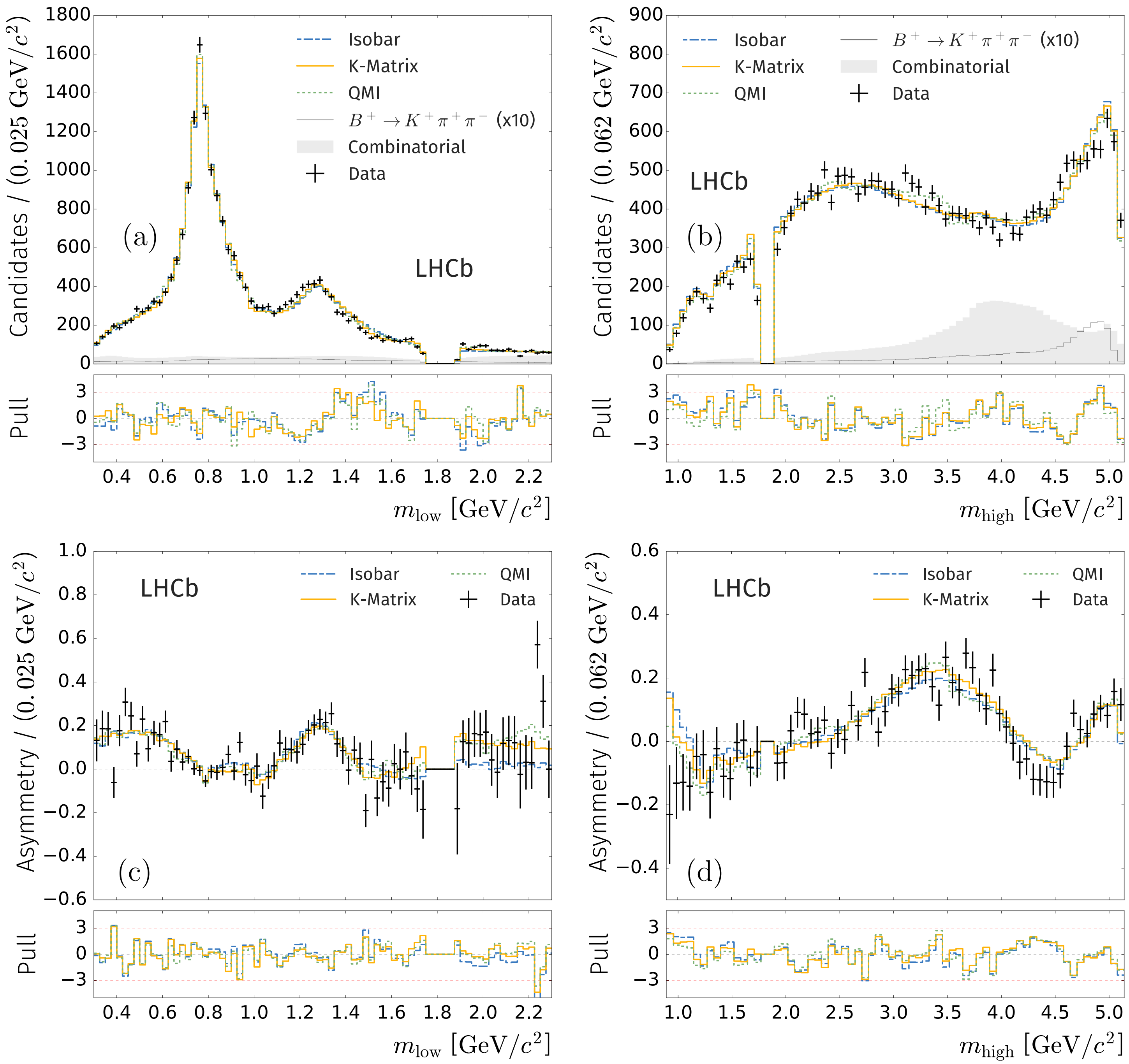

Contribution	Fit fraction (10^{-2})	A_{CP} (10^{-2})	B^+ phase (°)	B^- phase (°)
Isobar model				
$\rho(770)^0$	$55.5 \pm 0.6 \pm 2.5$	$+0.7 \pm 1.1 \pm 1.6$	—	—
$\omega(782)$	$0.50 \pm 0.03 \pm 0.05$	$-4.8 \pm 6.5 \pm 3.8$	$-19 \pm 6 \pm 1$	$+8 \pm 6 \pm 1$
$f_2(1270)$	$9.0 \pm 0.3 \pm 1.5$	$+46.8 \pm 6.1 \pm 4.7$	$+5 \pm 3 \pm 12$	$+53 \pm 2 \pm 12$
$\rho(1450)^0$	$5.2 \pm 0.3 \pm 1.9$	$-12.9 \pm 3.3 \pm 35.9$	$+127 \pm 4 \pm 21$	$+154 \pm 4 \pm 6$
$\rho_3(1690)^0$	$0.5 \pm 0.1 \pm 0.3$	$-80.1 \pm 11.4 \pm 25.3$	$-26 \pm 7 \pm 14$	$-47 \pm 18 \pm 25$
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 $B^{\pm} \to \pi^{\pm} K^- K^+$ PRL 123 (2019) 231802

Contribution	Fit Fraction(%)	A_{CP}(%)	Magnitude (B^+/B^-)	Phase[°] (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	$16.4 \pm 0.8 \pm 1.0$	$-66.4 \pm 3.8 \pm 1.9$	$1.91 \pm 0.09 \pm 0.06$ $0.86 \pm 0.07 \pm 0.04$	$-56 \pm 12 \pm 18$ $-81 \pm 14 \pm 15$
$\phi(1020)$	$0.3 \pm 0.1 \pm 0.1$	$+9.8 \pm 43.6 \pm 26.6$	$0.20 \pm 0.07 \pm 0.02$ $0.22 \pm 0.06 \pm 0.04$	$-52 \pm 23 \pm 32$ $107 \pm 33 \pm 41$

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- LHCb Amplitude analysis $B^{\pm} \to \pi^{-}\pi^{+}\pi^{\pm}$ — PRD101 (2020) 012006; PRL 124 (2020) 031801
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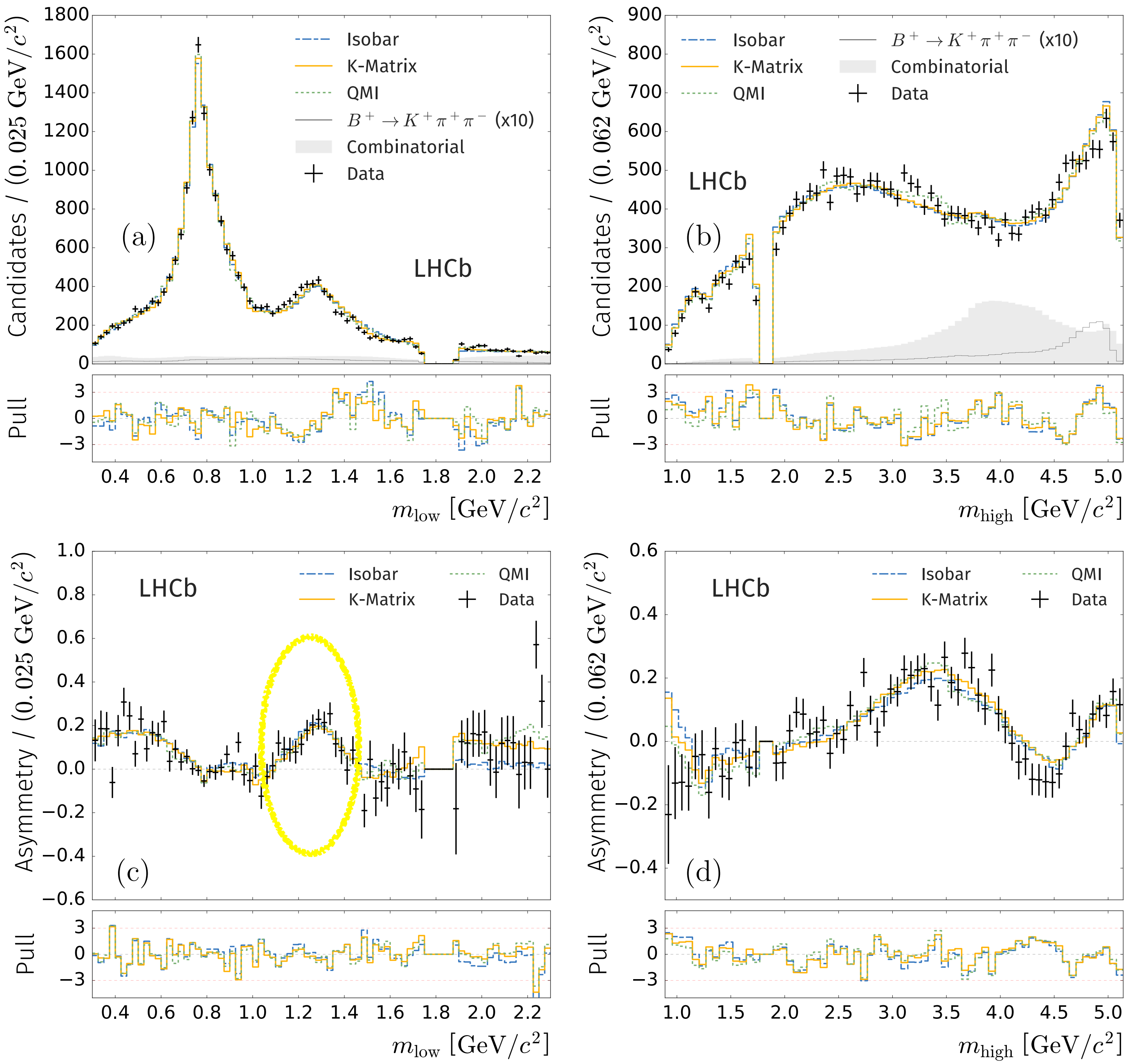

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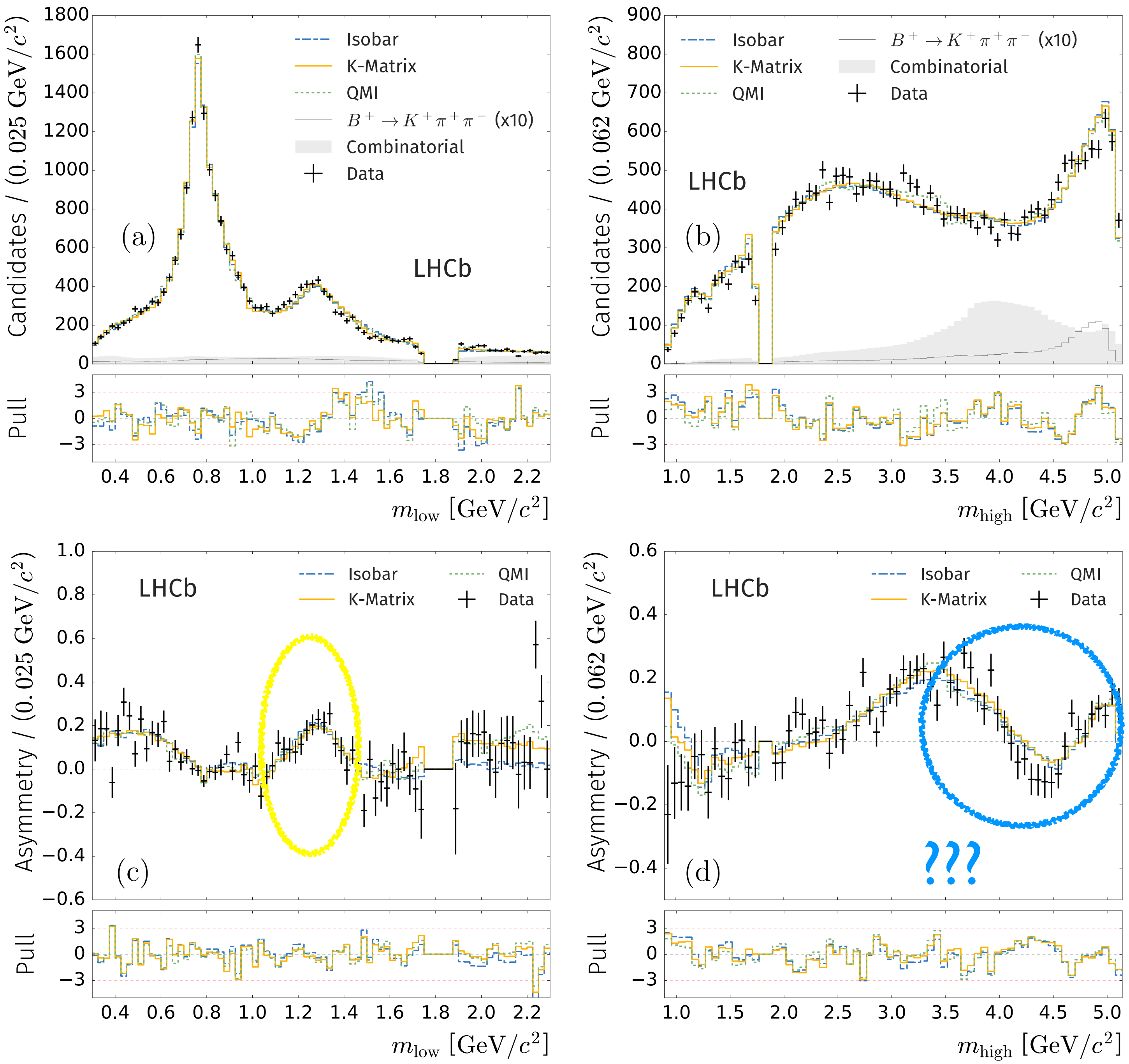

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$\rho_3(1690)^0$	$0.5 \pm 0.1 \pm 0.3$	$-80.1 \pm 11.4 \pm 25.3$	$-26 \pm 7 \pm 14$	$-47 \pm 18 \pm 25$
S-wave	$25.4 \pm 0.5 \pm 3.6$	$+14.4 \pm 1.8 \pm 2.1$	—	—
Rescattering	$1.4 \pm 0.1 \pm 0.5$	$+44.7 \pm 8.6 \pm 17.3$	$-35 \pm 6 \pm 10$	$-4 \pm 4 \pm 25$
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	$26.8 \pm 0.7 \pm 2.2$	$+15.0 \pm 2.7 \pm 8.1$	—	—

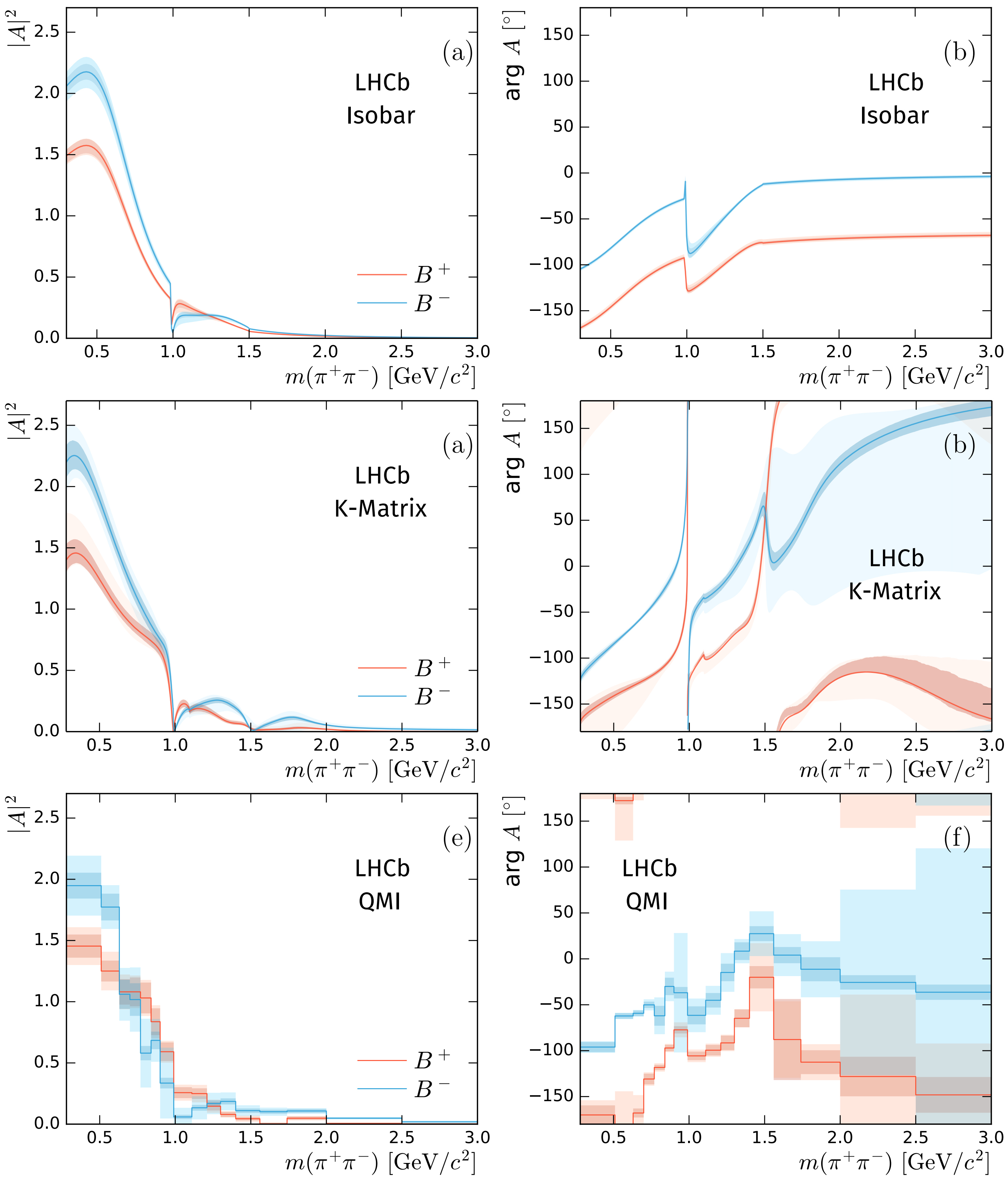
- ANA for $B^{\pm} \to \pi^{\pm}K^{-}K^{+}$ PRL 123 (2019) 231802

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

CPV: amplitude analysis $B^\pm \to \pi^-\pi^+\pi^\pm$

- Amplitude analysis $B^\pm \to \pi^-\pi^+\pi^\pm$

PRD101 (2020) 012006; PRL 124 (2020) 031801



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	$25.2 \pm 0.5 \pm 5.0$	$+16.0 \pm 1.7 \pm 2.2$	$+115 \pm 2 \pm 14$	$+179 \pm 1 \pm 95$
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$\rho(770)^0$	$56.5 \pm 0.7 \pm 3.4$	$+4.2 \pm 1.5 \pm 6.4$	—	—
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$\rho(1450)^0$	$10.5 \pm 0.7 \pm 4.6$	$+9.0 \pm 6.0 \pm 47.0$	$+155 \pm 5 \pm 29$	$-166 \pm 4 \pm 51$
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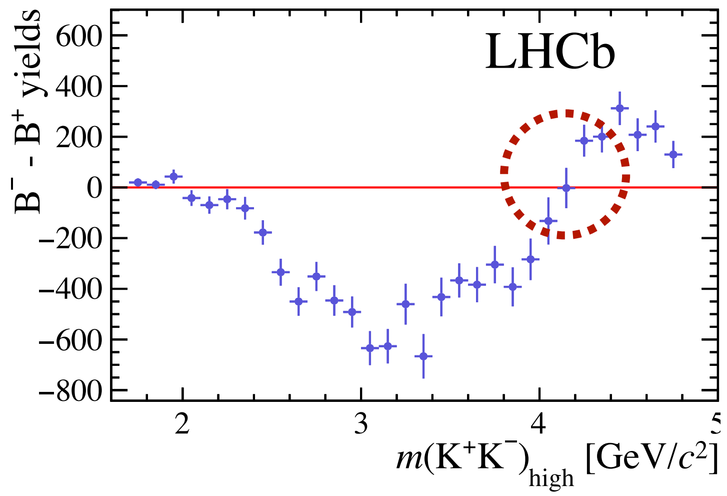
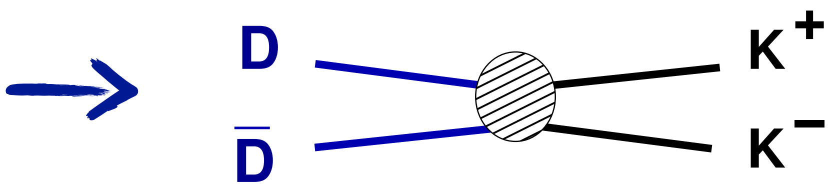
$\rho(1450)^0$	$7.4 \pm 0.5 \pm 4.0$	$-15.5 \pm 7.3 \pm 35.2$	$+147 \pm 7 \pm 152$	$-175 \pm 5 \pm 171$
$\rho_3(1690)^0$	$1.0 \pm 0.1 \pm 0.5$	$-93.2 \pm 6.8 \pm 38.9$	$+8 \pm 10 \pm 24$	$+36 \pm 26 \pm 46$
S-wave	$26.8 \pm 0.7 \pm 2.2$	$+15.0 \pm 2.7 \pm 8.1$	—	—

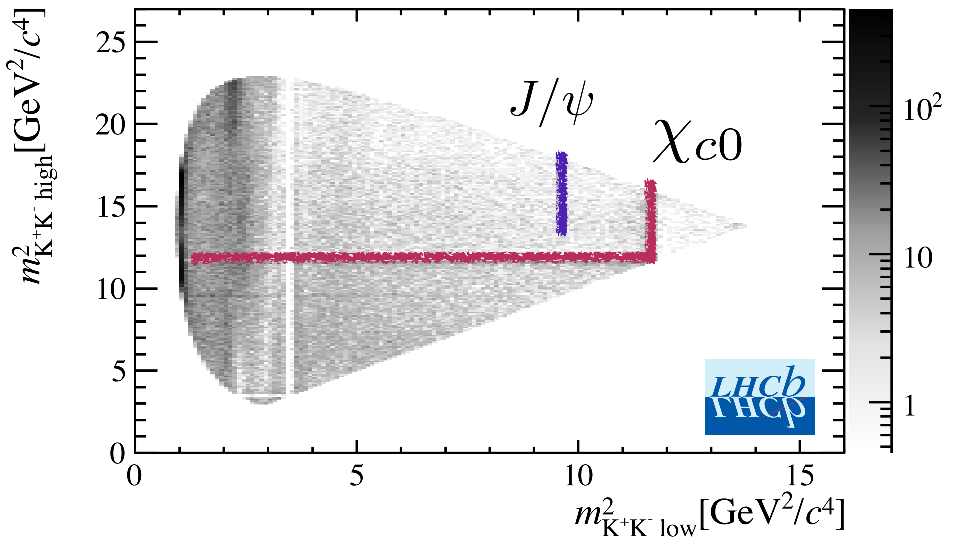
- FSI effect present at low energy!

CPV high energy

- $B^+ \to K^- K^+ K^+$
  - $\mathcal{A}_{cp}$ change sign ~ $D\bar{D}$ open channel







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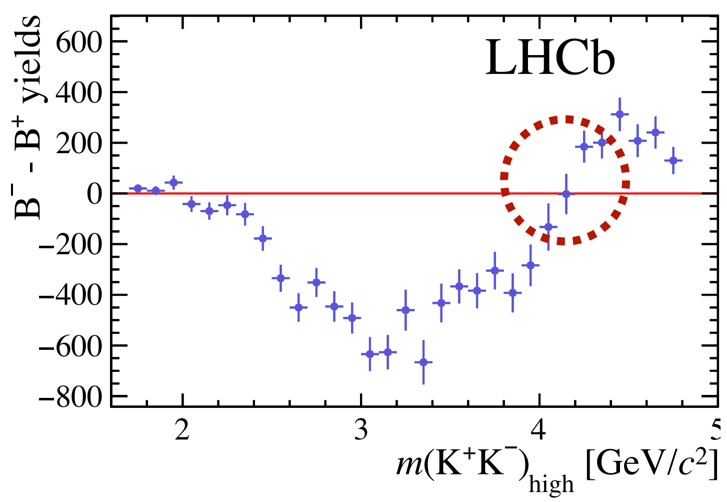
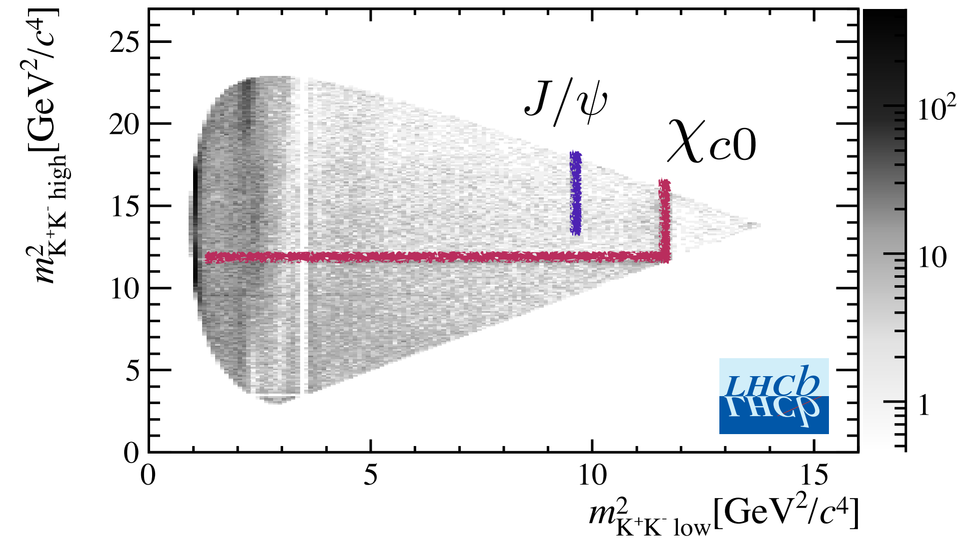
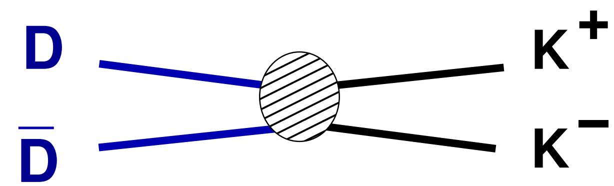
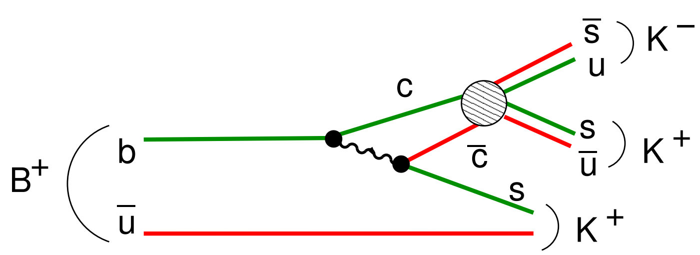


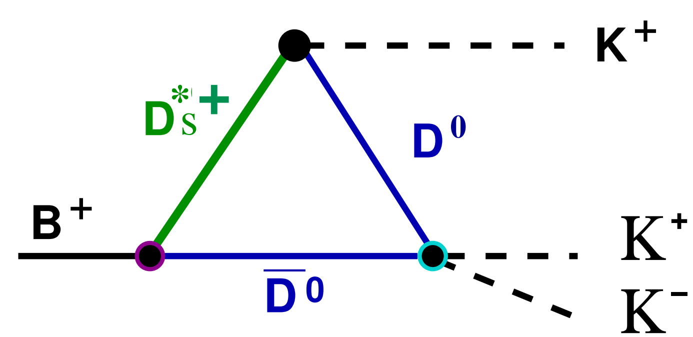




  - charm intermediate processes as source of strong phase

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





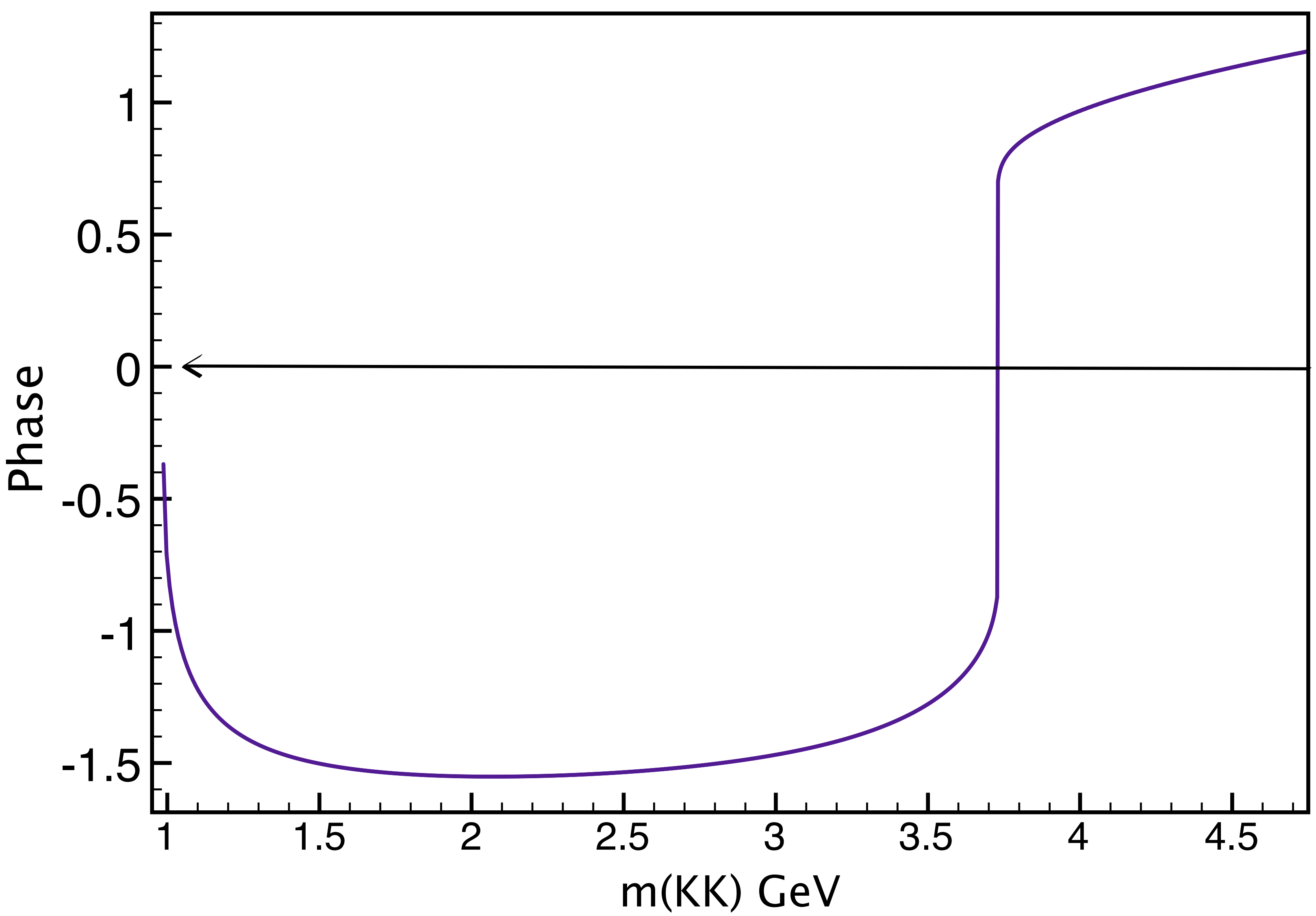
  - even dynamically suppressed $Br\left[B \to D D_s^*\right]$ ~1% → 1000 x $Br\left[B \to KKK\right]$

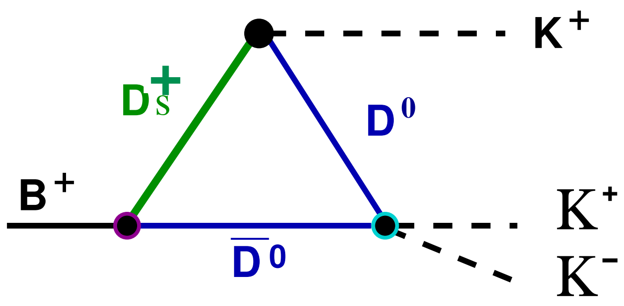
- hadronic loop technique $D^+ \to \pi^+ K^- \pi^+$

PCM & M Robilotta PRD 92 094005 (2015)
PCM et al PRD 84 094001 (2011)

hadronic loop results for $B^{\pm} \to K^{\pm} K^{-} K^{+}$

- Triangle hadronic loop with charm rescattering can generate a phase that change signal near DD threshold





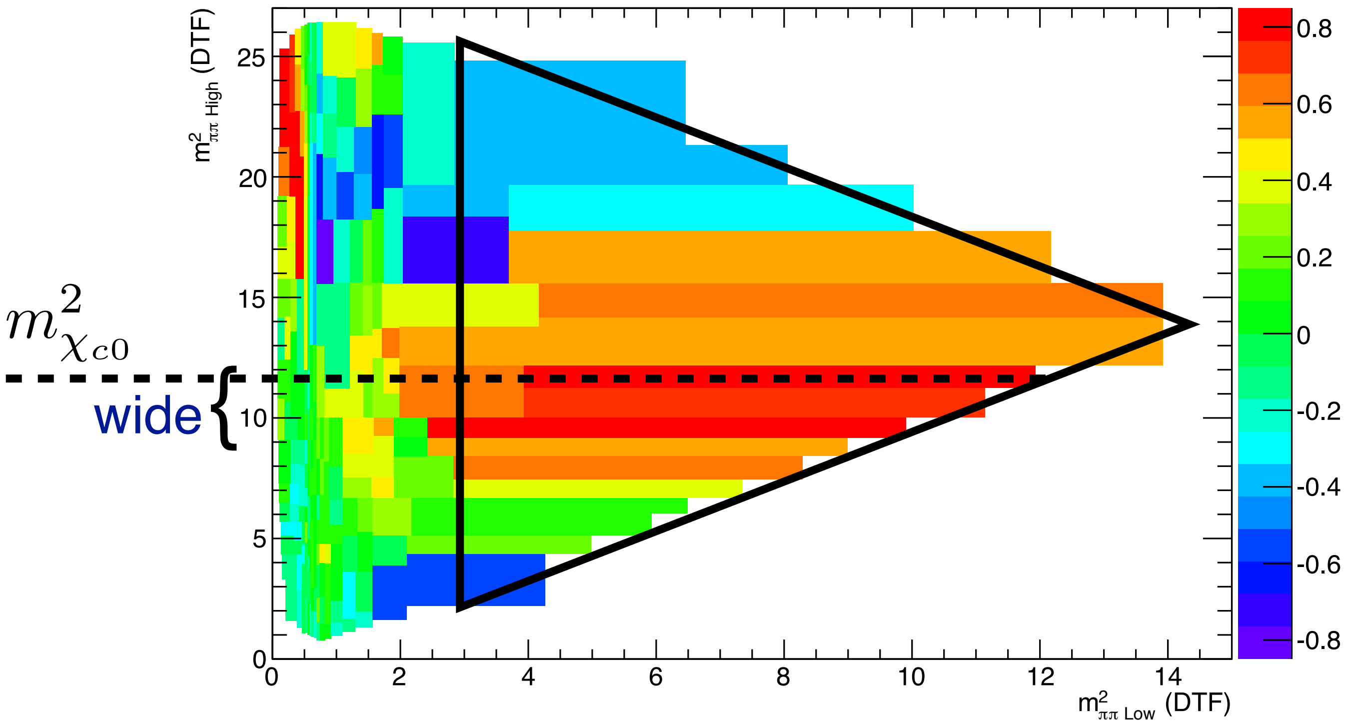
- how this can be translated to the observable CPV?

we need inference with weak-phase!

Bediaga, Frederico, PCM - PLB 806 (2020) 135490

- high mass CPV study in $B^\pm \to \pi^\pm\pi^-\pi^+$
  - Focus on $m^2_{\pi\pi} > 3\,GeV^2$
    ↳ avoid low energy resonances
  - include χ_{c0} (expected in Run II)

Run I

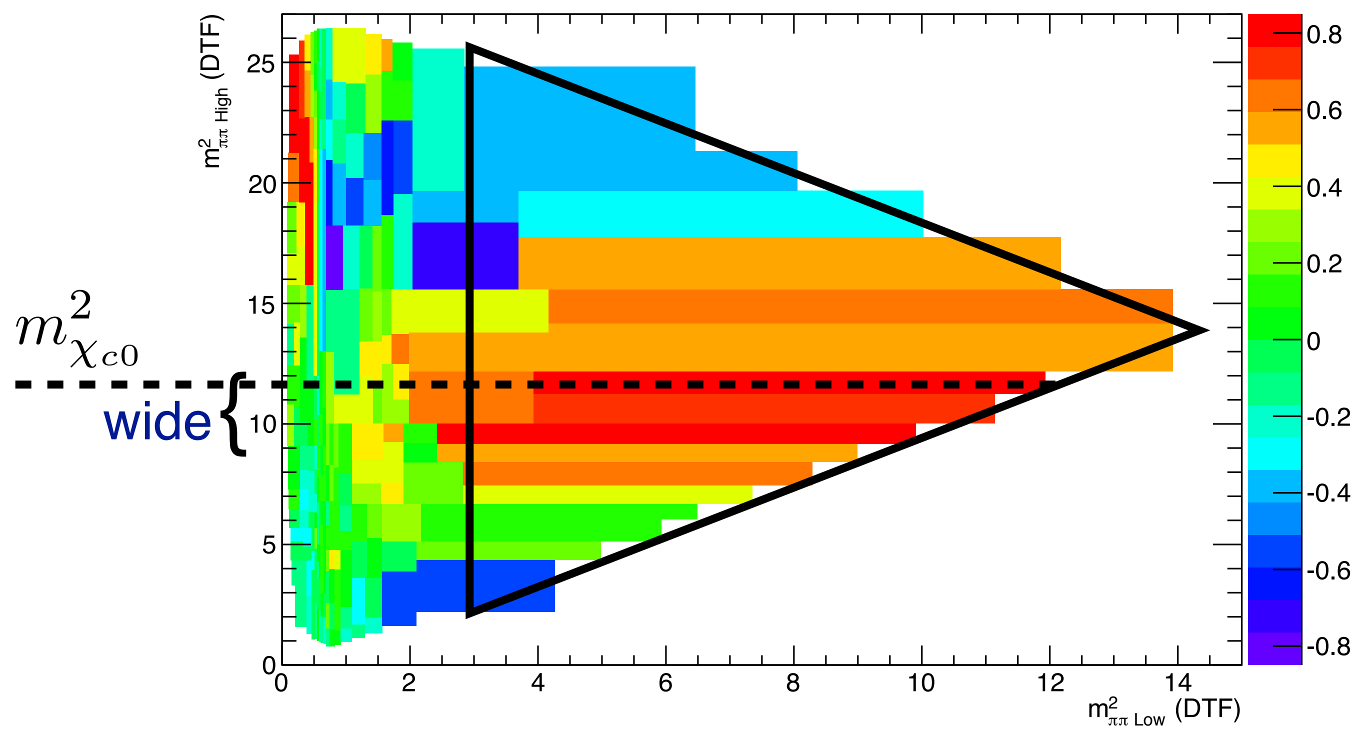


charm rescattering in $B^{\pm} \to \pi^{\pm}\pi^{-}\pi^{+}$

Bediaga, Frederico, PCM - PLB 806 (2020) 135490

- high mass CPV study in $B^{\pm} \to \pi^{\pm}\pi^{-}\pi^{+}$

Run I



  - Focus on $m^2_{\pi\pi} > 3\, GeV^2$
    ↳ avoid low energy resonances
  - include χ_{c0} (expected in Run II)

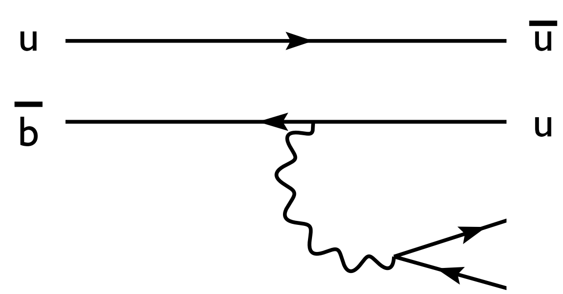
- Important data features
  - data shows a huge CP asymmetry around $m^2_{\chi_{c0}} = 11.65\, GeV^2$
  - wide CP asymmetry: same source for a nonresonant amplitude and χ_{c0}
    ↳ charm loop and χ_{c0}

Amplitude model

- Amplitude Model for $B^{\pm} \to \pi^{\pm}\pi^{-}\pi^{+}$ high mass $m^2_{\pi\pi} > 3\,GeV^2$

$$A_{B^{\pm}\to\pi^-\pi^+\pi^{\pm}}(s_{12}, s_{23}) = A^{\pm}_{tree}(s_{12}, s_{23}) + A_{D\bar{D}}(s_{12}, s_{23})$$

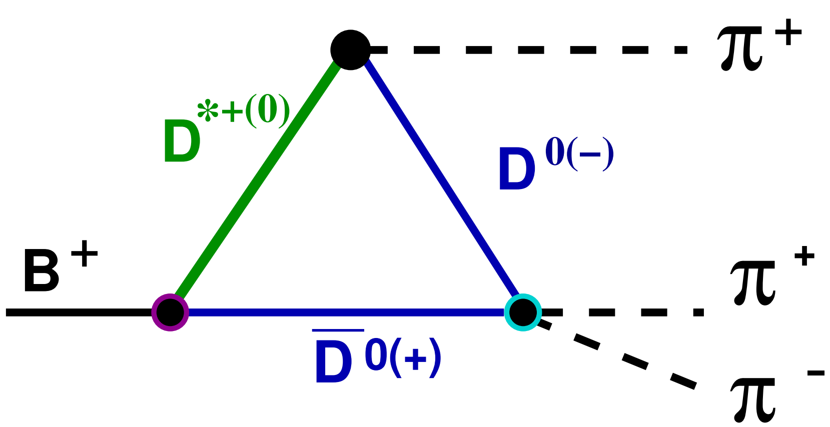
  - $A^{\pm}_{tree} = a_0\, e^{\pm i\gamma}$: weak phase γ from the dominant $b \to u$ tree diagram



→ Nonresonant (only resonances tails)

→ a_0 is complex (strong phase)

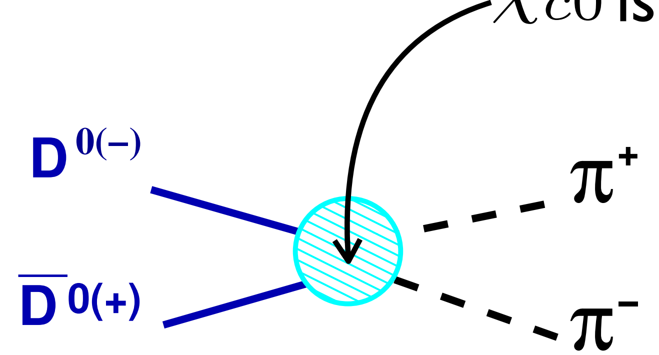
  - $A_{D\bar{D}}$ charm rescattering with χ_{c0} : source of strong phase variation



→ similar triangle loop

χ_{c0} is a pole bellow threshold

→

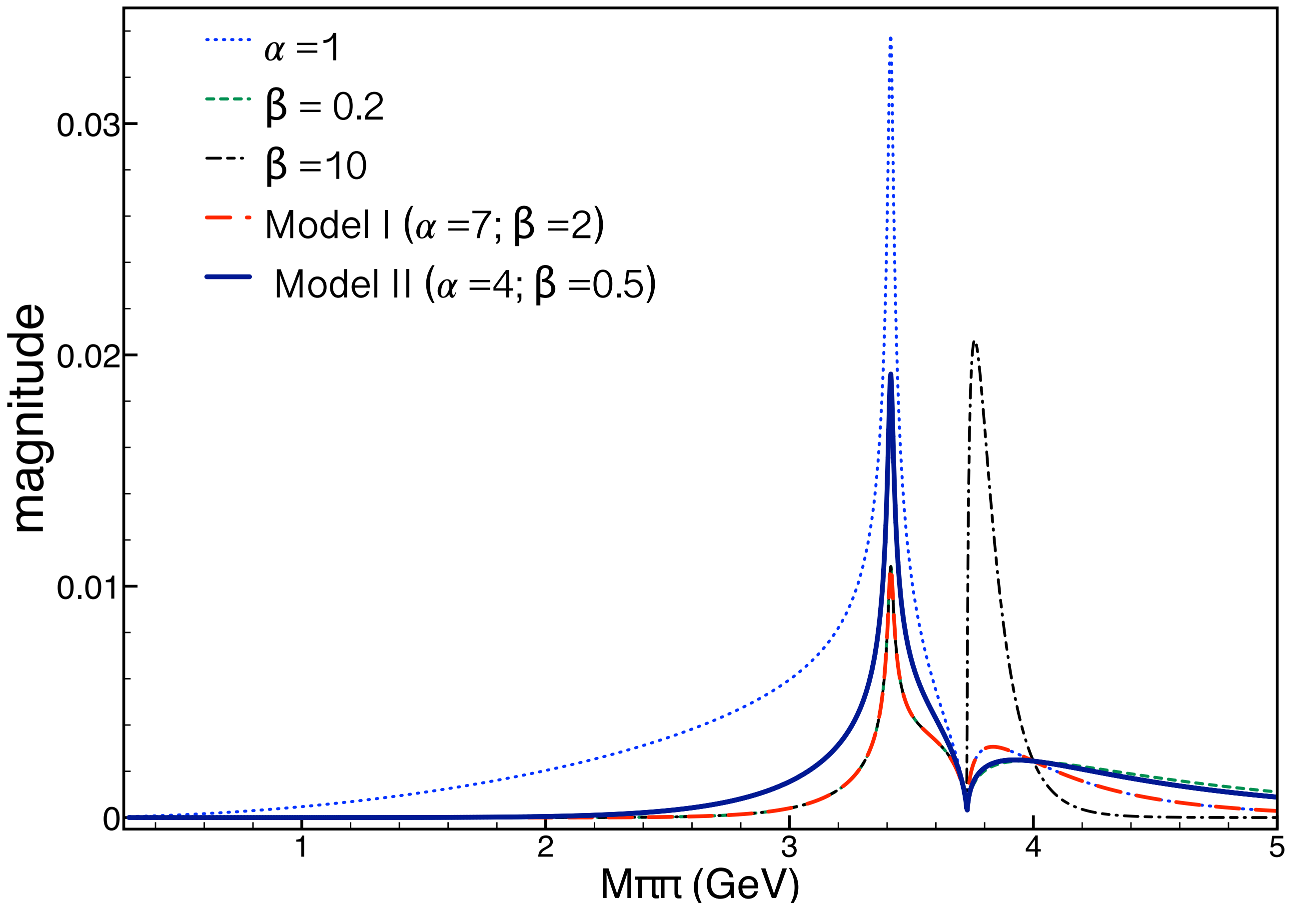


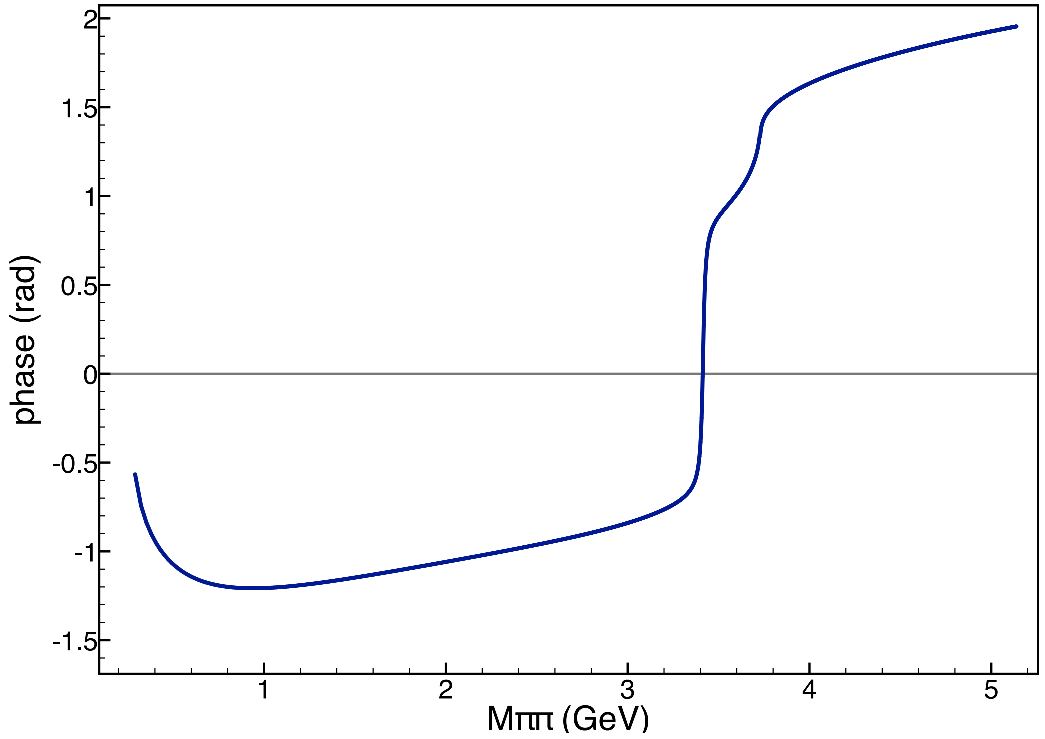
phenomenological $D\bar{D} \to \pi^+\pi^-$ amplitude

- unitary coupled-channel S-matrix $= \begin{pmatrix} \eta\, e^{2i\delta_1} & \boxed{i\sqrt{1-\eta^2}\, e^{i(\delta_1+\delta_2)}} \\ i\sqrt{1-\eta^2}\, e^{i(\delta_1+\delta_2)} & \eta\, e^{2i\delta_2} \end{pmatrix}$

  → χ_{c0} (3414) : a pole bellow $D\bar{D}$ threshold in δ_2

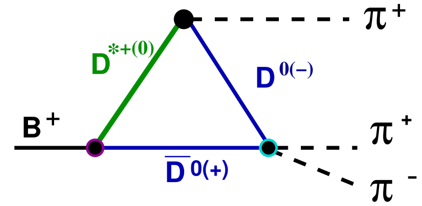
- amplitude features:
  - χ_{c0} peak superposed to a wide bump below threshold;
  - zero at $D\bar{D}$ threshold
  - phase jump at $D\bar{D}$ threshold





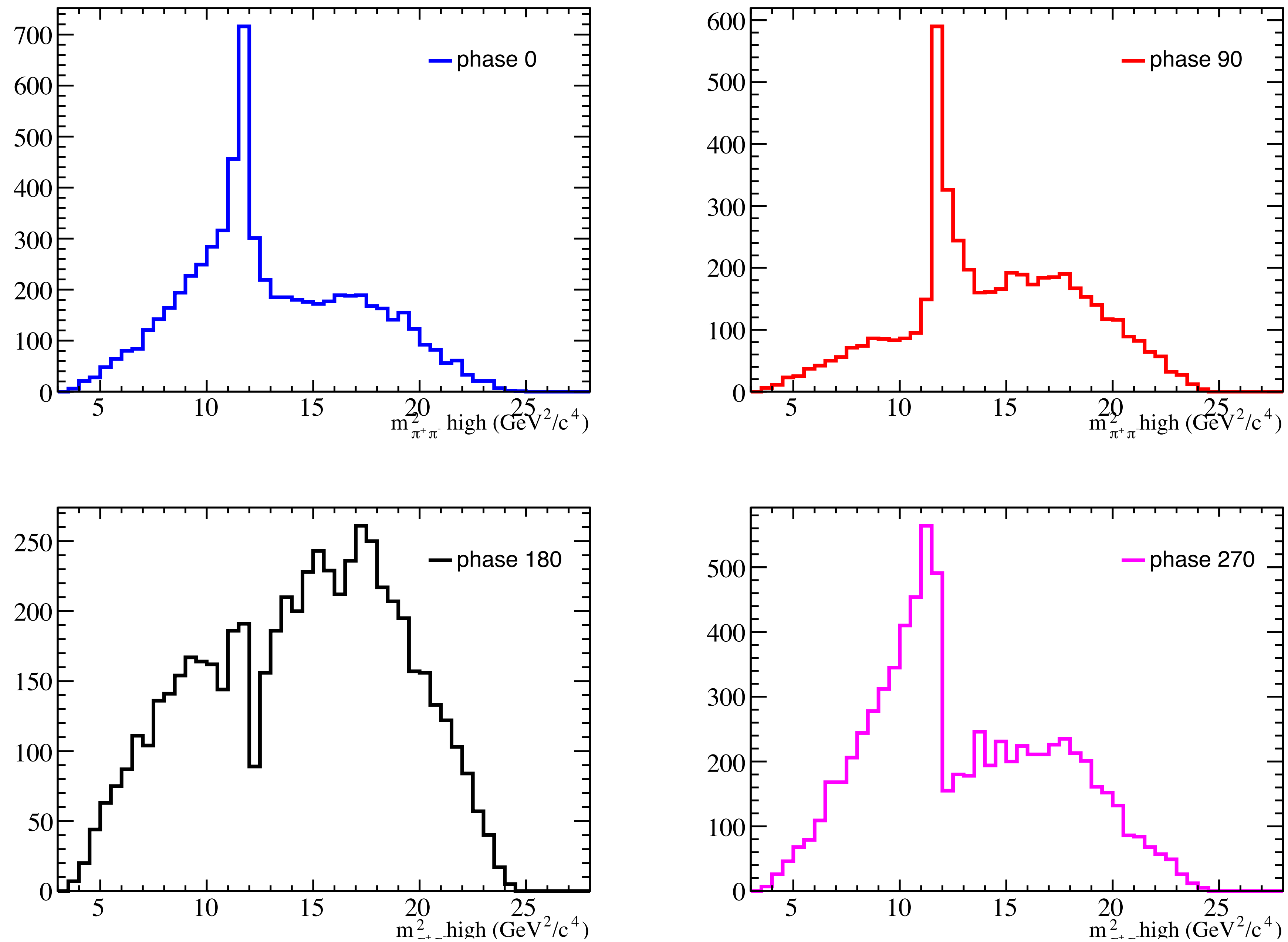
→ parameters should be fitted

Amplitudes Interference

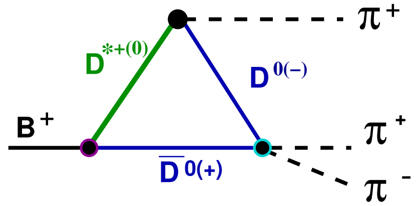
- $A_{B^\pm\to\pi^-\pi^+\pi^\pm}(s_{12}, s_{23}) =$ 

$+ \quad a_0\, e^{\pm i\gamma}$ $\quad [\, a_0 = 2\, e^{i\delta_s}\,]$

  - total phase difference between them can result different pattern



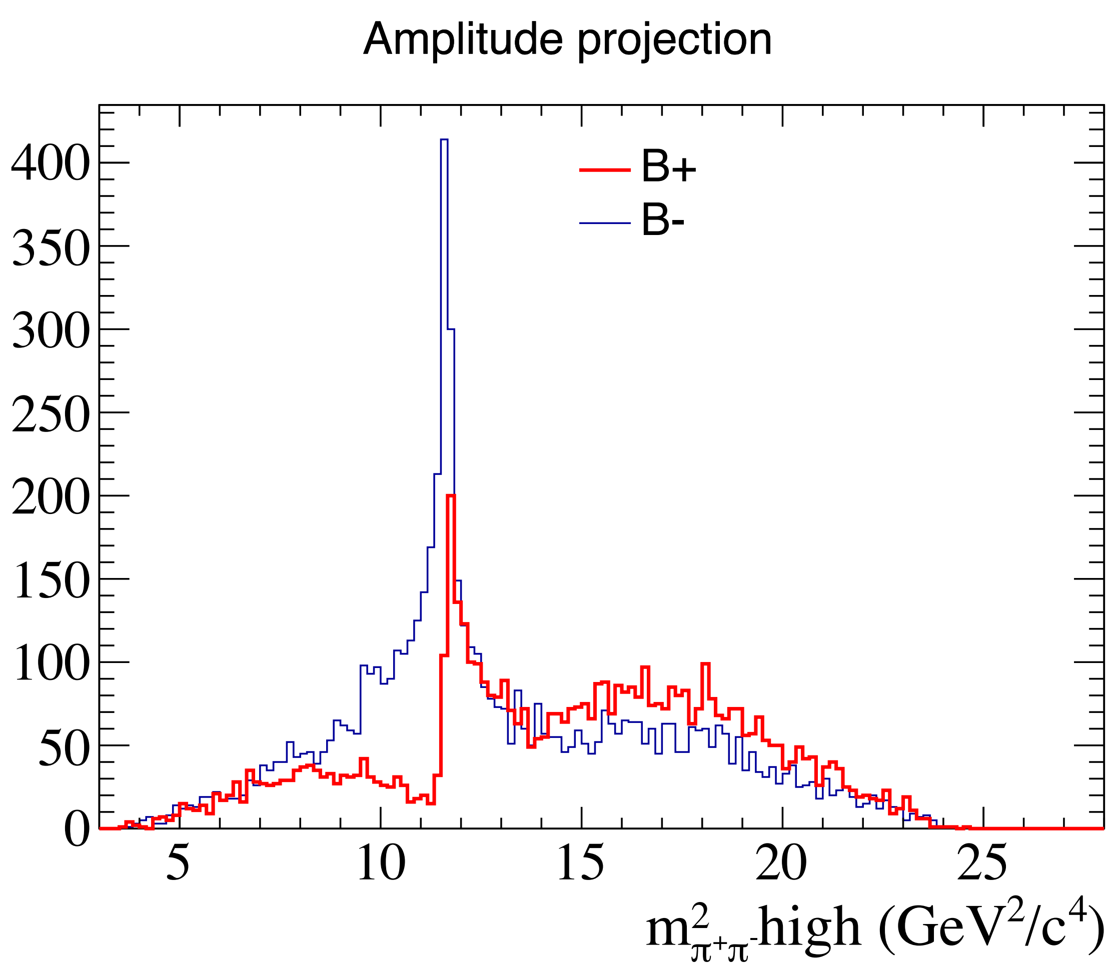
charm rescattering in $B^\pm \to \pi^\pm\pi^-\pi^+$

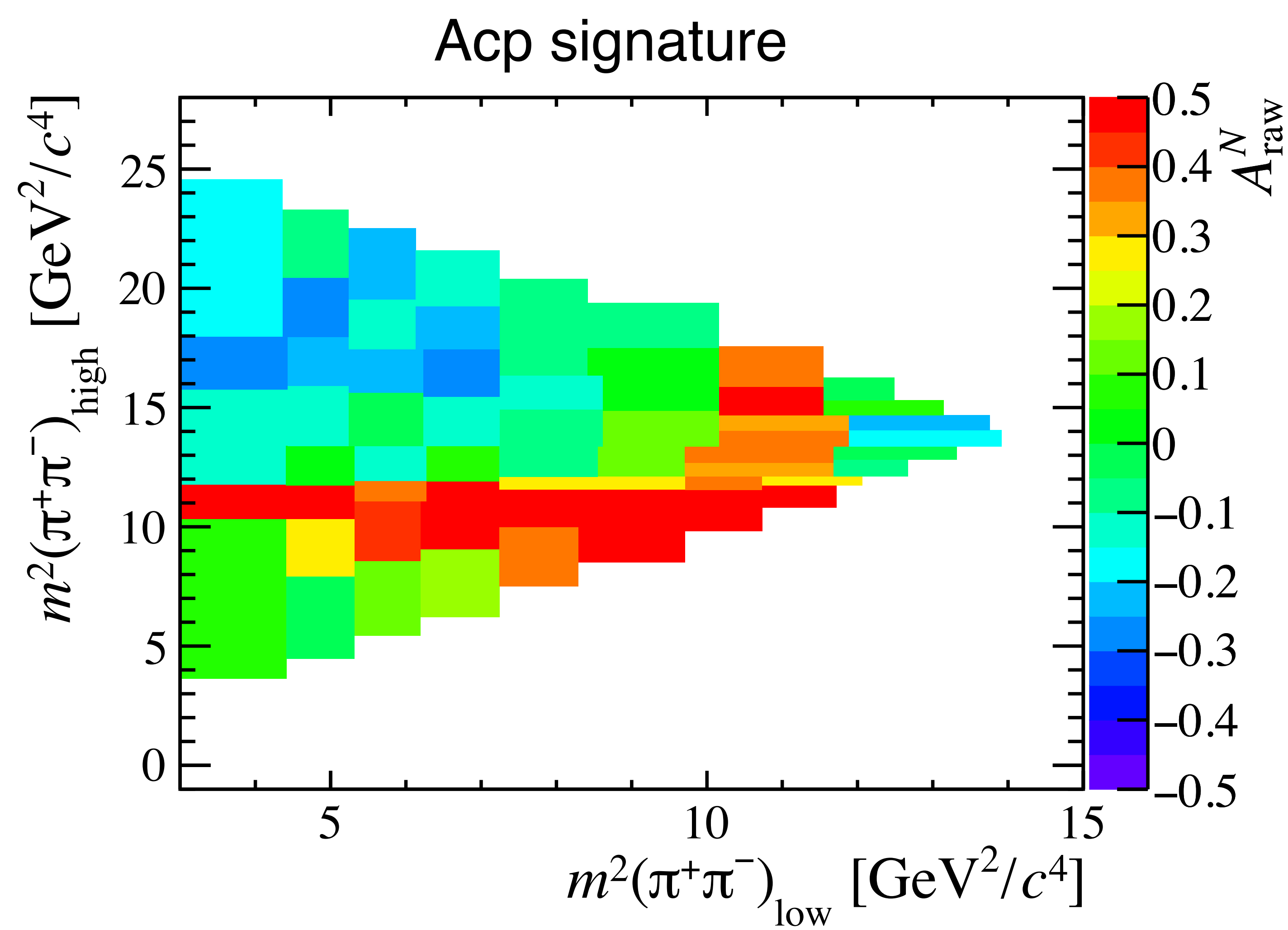
- $A_{B^\pm\to\pi^-\pi^+\pi^\pm}(s_{12}, s_{23}) =$ 

$+ \quad a_0\, e^{\pm i\gamma}$

$$\boxed{\begin{aligned} \gamma &= 70^o \\ a_0 &= 2\, e^{i(\delta_s = 45^o)} \end{aligned}}$$

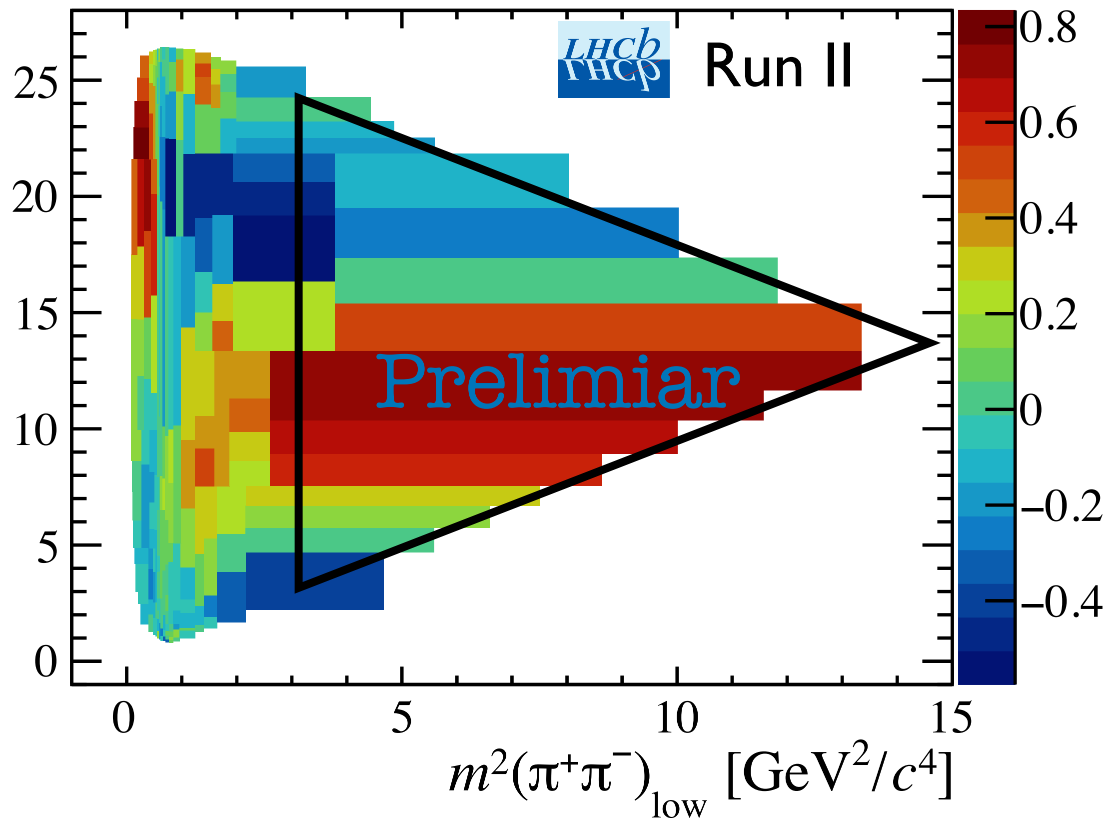
- the goal was to reproduce the main observed CPV characteristics

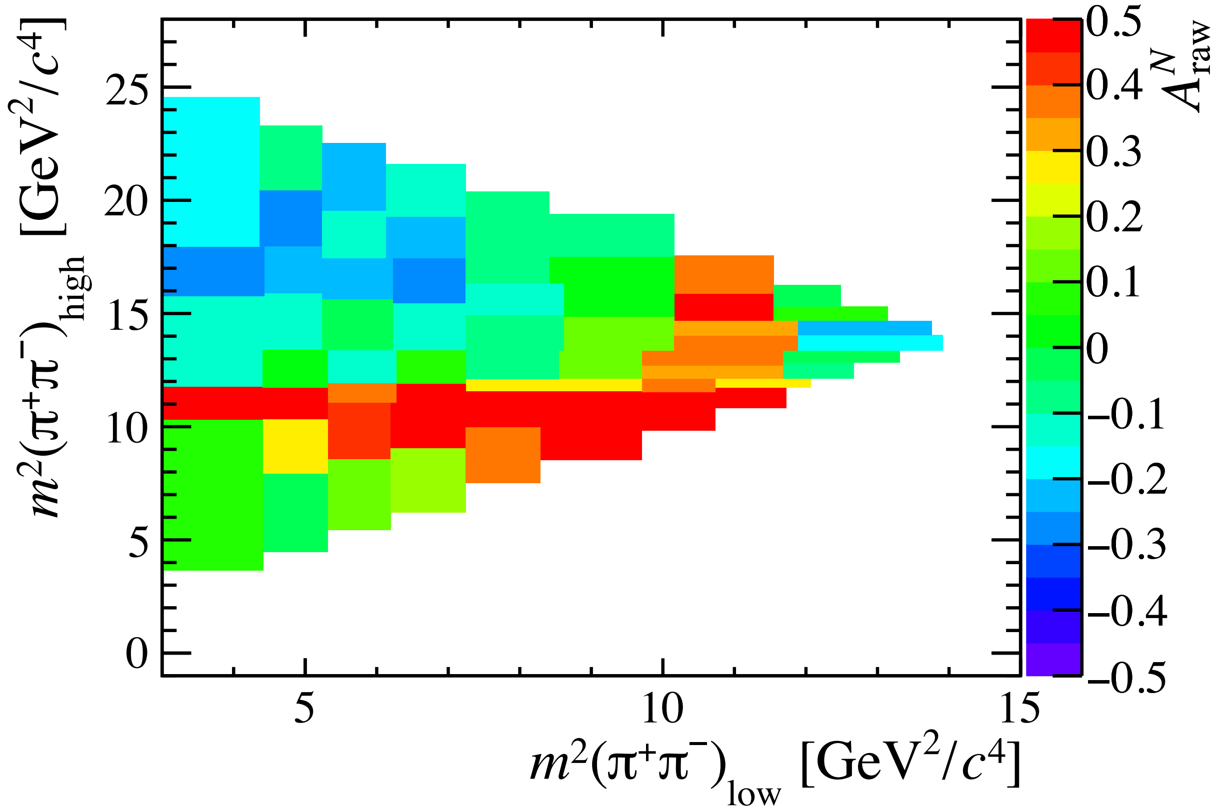


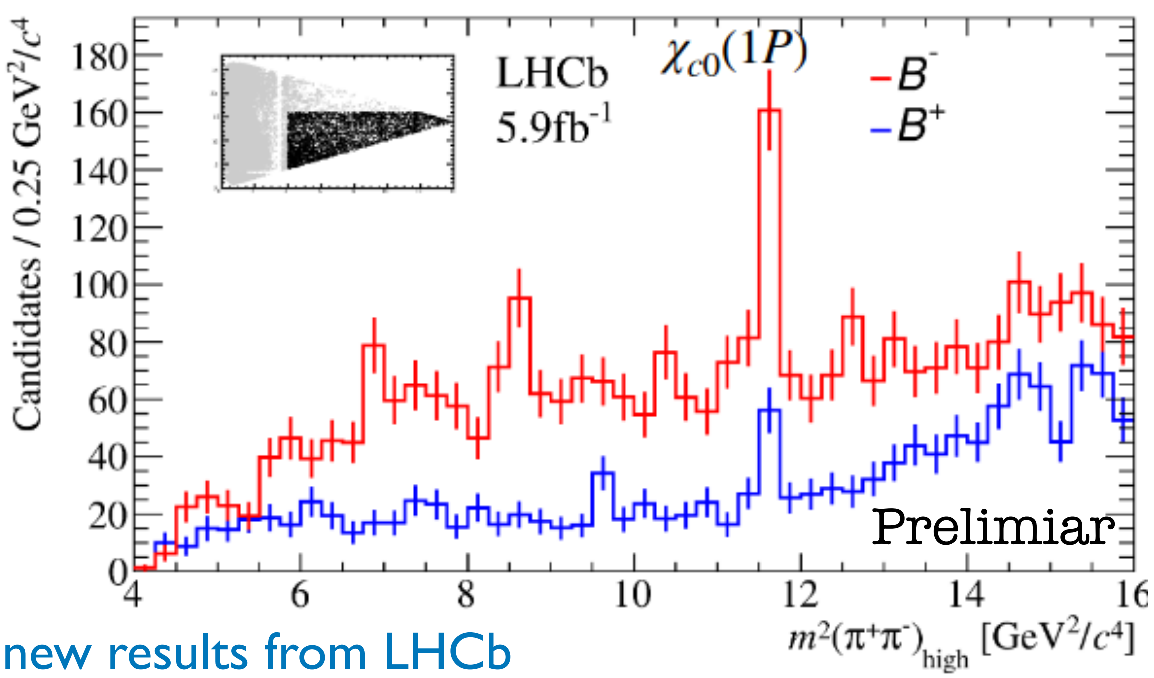


- we still have free parameters to vary

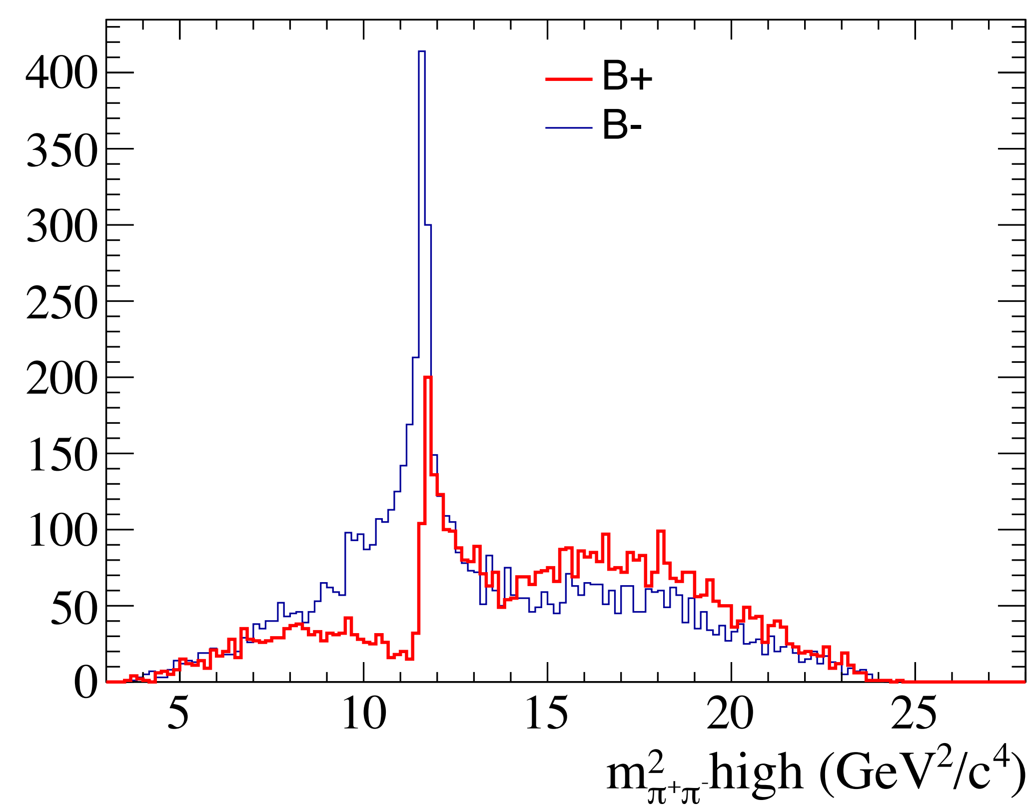
charm rescattering in $B^{\pm} \to \pi^{\pm}\pi^{-}\pi^{+}$



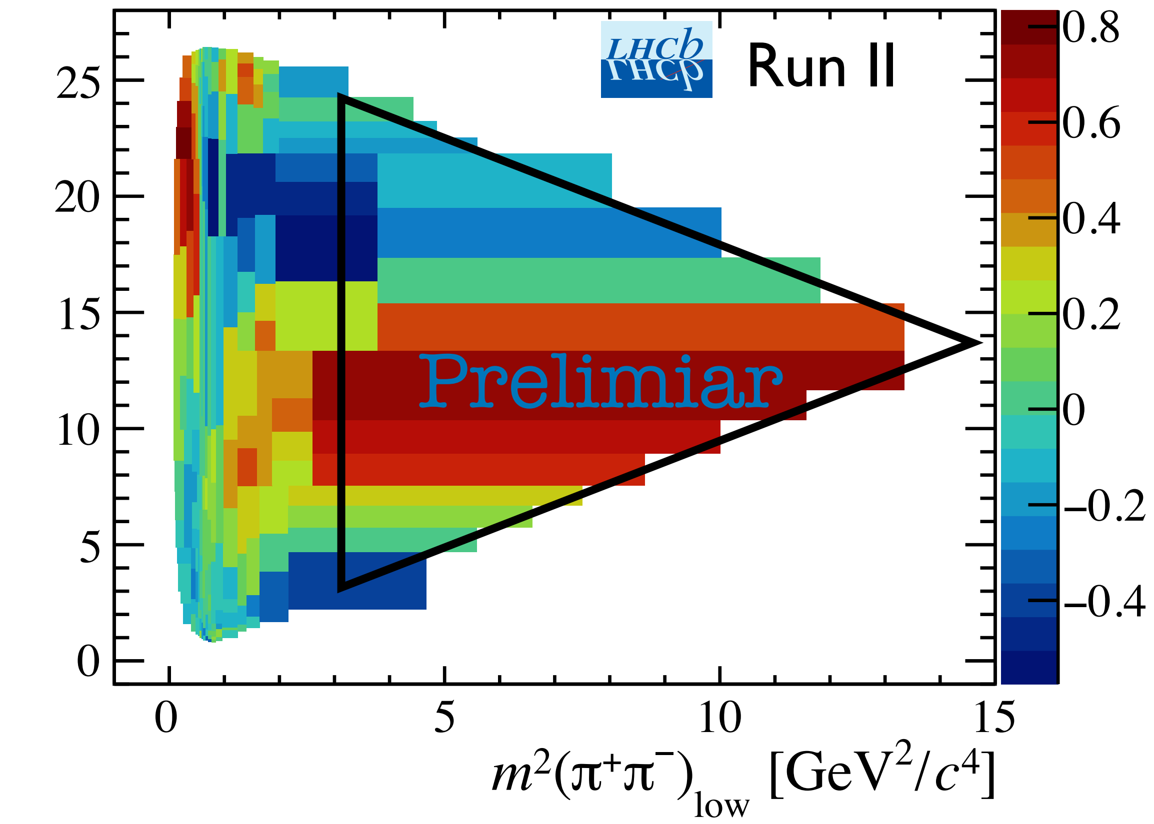


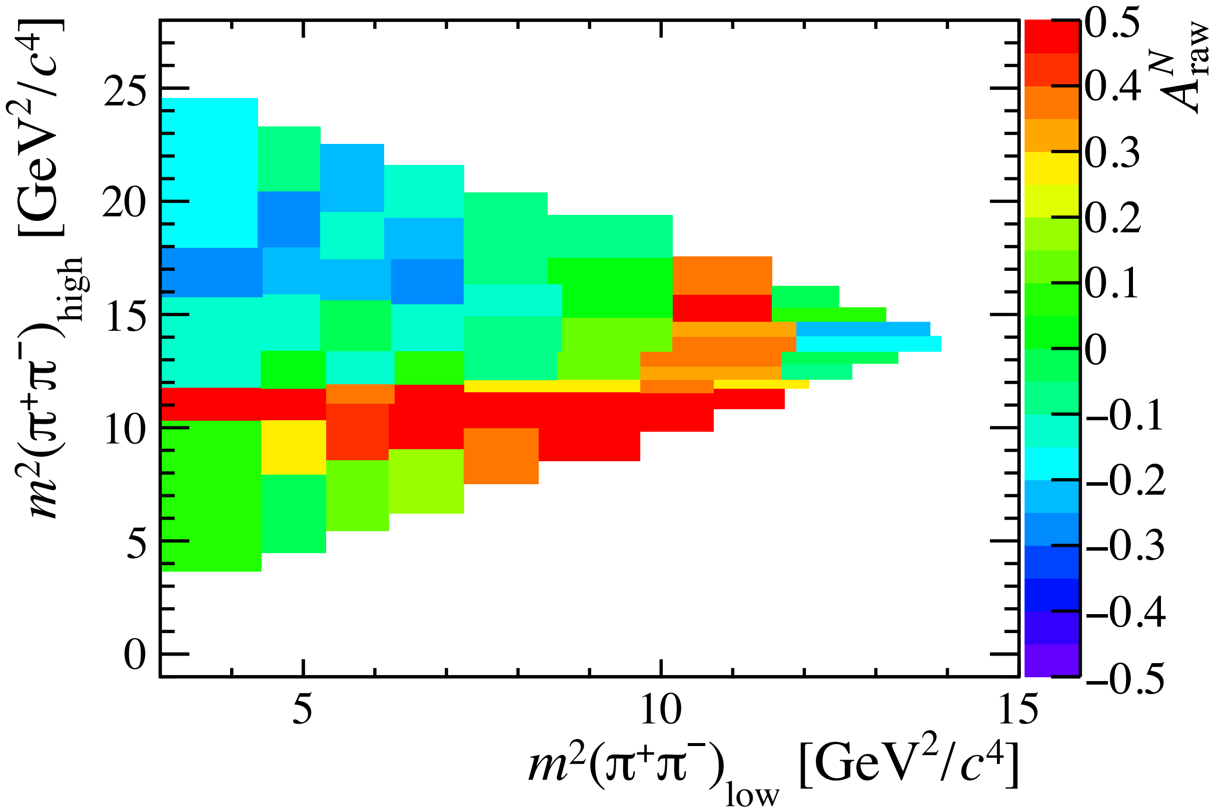


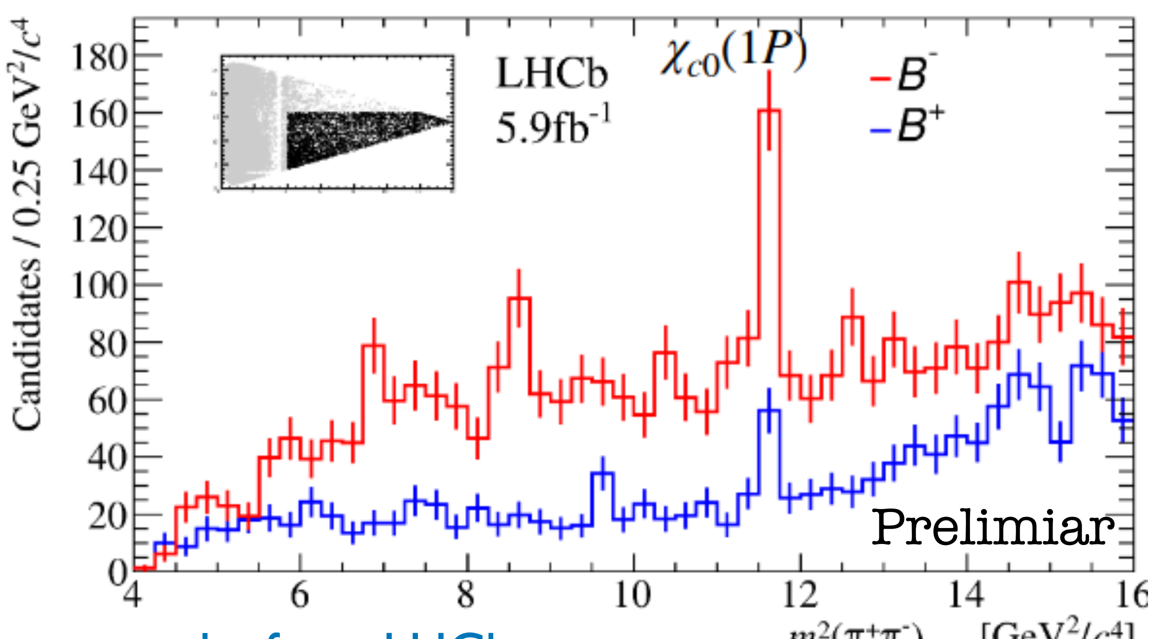
new results from LHCb



charm rescattering in $B^{\pm} \to \pi^{\pm}\pi^{-}\pi^{+}$







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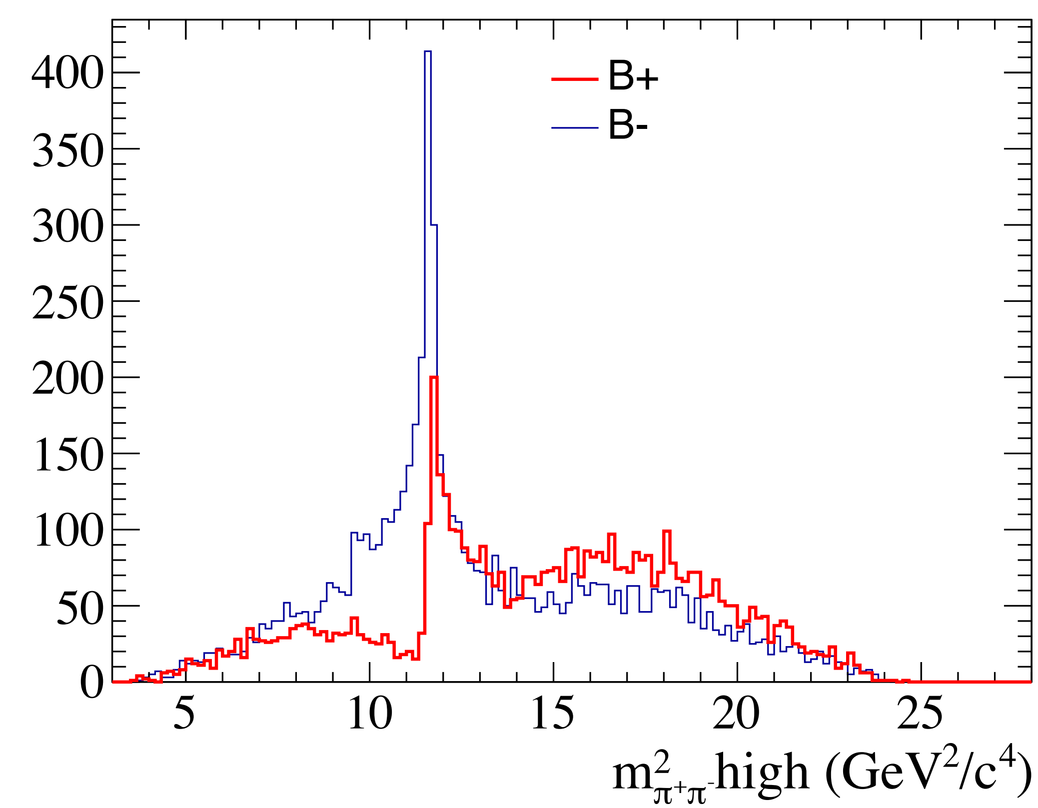


→ implementing this in Run II amplitude analysis!

$B^\pm \to h^\pm(V \to h^- h^+)$ CP Violation directly from data

Bediaga, Frederico, PCM
PRD 94 (2016) 054028

- Proposed a method to extract the type of CPV in particular regions of the phase-space directly from data

$B^\pm \to h^\pm(V \to h^- h^+)$ CP Violation directly from data

Bediaga, Frederico, PCM
PRD 94 (2016) 054028

- Proposed a method to extract the type of CPV in particular regions of the phase-space directly from data

- Amplitudes contain only one vector resonance and NR background

$$\mathcal{M}_+ = a_+^V e^{i\delta_+^V} F_V^{\rm BW} \cos\theta(s_\perp, s_\parallel) + a_+^{\rm NR} e^{i\delta_+^{\rm NR}} F^{\rm NR}$$
$$\mathcal{M}_- = a_-^V e^{i\delta_-^V} F_V^{\rm BW} \cos\theta(s_\perp, s_\parallel) + a_-^{\rm NR} e^{i\delta_-^{\rm NR}} F^{\rm NR}$$

$S_{||} \equiv (p_{h^+} + p_{h^-})^2$
$S_\perp \equiv (p_{h_b} + p_{h^\pm})^2$
$\theta \equiv$ helicity angle

- Asymmetry ∝ to square modulus of amplitude difference:

$$|\mathcal{M}_+|^2 \mp |\mathcal{M}_-|^2 = \left[\left(a_+^V\right)^2 \mp \left(a_-^V\right)^2\right] \left|F_V^{\rm BW}\right|^2 \cos^2\theta\left(s_\perp, s_\parallel\right) + \left[\left(a_+^{\rm NR}\right)^2 \mp \left(a_-^{\rm NR}\right)^2\right] \left|F^{\rm NR}\right|^2$$
$$+ 2\cos\theta\left(s_\perp, s_\parallel\right) \left|F_V^{\rm BW}\right|^2 \left|F^{\rm NR}\right|^2 \times$$
$$\left\{\left(m_V^2 - s_\parallel\right)\left[a_+^V a_+^{\rm NR} \cos\left(\delta_+^V - \delta_+^{\rm NR}\right) \mp a_-^V a_-^{\rm NR} \cos\left(\delta_-^V - \delta_-^{\rm NR}\right)\right]\right.$$
$$\left. - m_V \Gamma_V \left[a_+^V a_+^{\rm NR} \sin\left(\delta_+^V - \delta_+^{\rm NR}\right) \mp a_-^V a_-^{\rm NR} \sin\left(\delta_-^V - \delta_-^{\rm NR}\right)\right]\right\}$$

direct vector A_{CP} | direct NR A_{CP} | NR and vector interference

$B^{\pm} \to h^{\pm}(V \to h^{-}h^{+})$ CP Violation directly from data

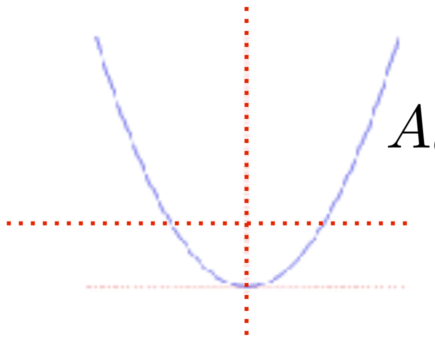
Bediaga, Frederico, PCM
PRD 94 (2016) 054028

- we select a small region around the resonance in $s_{\parallel}$ and look for the distribution $\Delta|\mathcal{M}^2|$ on $s_{\perp}$
  - $s_{\parallel} \approx m_V^2$ → cosθ ($s_{\perp}$)
  - can parametrize $\Delta|\mathcal{M}|^2 = a(x-c_0)^2 + b(x-c_0) + c$
    for $\cos\theta = x - c_0$

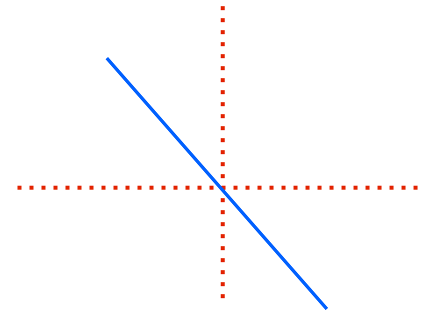
a $\Rightarrow$ $\boxed{\text{direct vector } A_{CP}}$

b $\Rightarrow$ $\boxed{\text{interference}}$

c $\Rightarrow$ $\boxed{\text{direct NR } A_{CP}}$



$$A_{CP} = \frac{a^+ - a^-}{a^+ + a^-}$$



constant

$B^\pm \to h^\pm(V \to h^-h^+)$ CP Violation directly from data

Bediaga, Frederico, PCM
PRD 94 (2016) 054028

- we select a small region around the resonance in s‖ and look for the distribution $\Delta|\mathcal{M}^2|$ on s⊥
  - $s_\parallel \approx m_V^2$ → cosθ (s⊥)
  - can parametrize $$\Delta|\mathcal{M}|^2 = a(x-c_0)^2 + b(x-c_0) + c$$ for $\cos\theta = x - c_0$

a ⇒ $\boxed{\text{direct vector } A_{CP}}$

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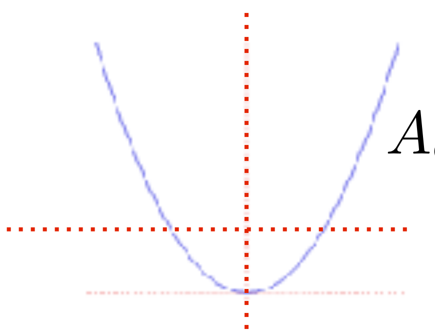

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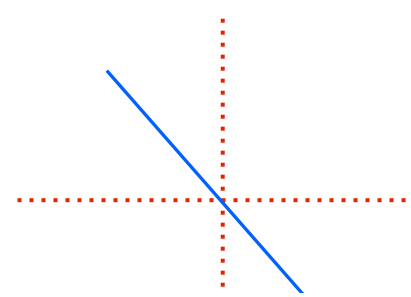


constant

- Applied to LHCb runII data !

  Prelimiar

  - (2+1) and huge $f_0(980)$

Decay channel	Vector Resonance	$\mathcal{A}_{CP}^V \pm\sigma_{\rm stat} \pm \sigma_{\rm syst}$	
$B^\pm \to \pi^\pm\pi^+\pi^-$	$\rho(770)^0 \to \pi^+\pi^-$	-0.004 ± 0.017 ± 0.007	(0.2σ)
$B^\pm \to K^\pm\pi^+\pi^-$	$\rho(770)^0 \to \pi^+\pi^-$	+0.150 ± 0.019 ± 0.008	(7.2σ)
	$K^*(892)^0 \to K^\pm\pi^\mp$	-0.015 ± 0.021 ± 0.007	(0.7σ)
$B^\pm \to \pi^\pm K^+K^-$	$K^*(892)^0 \to K^\pm\pi^\mp$	+0.007 ± 0.054 ± 0.028	(0.1σ)
$B^\pm \to K^\pm K^+K^-$	$\phi(1020) \to K^+K^-$	+0.004 ± 0.010 ± 0.006	(0.2σ)

Global CP Violation

Bediaga, Frederico, PCM, Torres Machado
PLB 824 (2022) 136824

- understand global asymmetries in LHCb data

Decay channel	$\Delta\Gamma_{CP}(10^6\,\mathrm{s}^{-1})$
$B^\pm \to K^\pm\pi^+\pi^-$	$+0.84 \pm 0.25$
$B^\pm \to K^\pm K^+ K^-$	-0.68 ± 0.17
$B^\pm \to \pi^\pm\pi^+\pi^-$	$+0.53 \pm 0.13$
$B^\pm \to \pi^\pm K^+ K^-$	-0.39 ± 0.07

U-spin: $$\frac{\Delta\Gamma_{CP}(\pi^\pm K^+K^-)}{\Delta\Gamma_{CP}(K^\pm\pi^+\pi^-)} = -0.46 \pm 0.16 \text{ and } \frac{\Delta\Gamma_{CP}(\pi^\pm\pi^+\pi^-)}{\Delta\Gamma_{CP}(K^\pm K^+K^-)} = -0.77 \pm 0.27$$

quark (s, d) form a dublet

U-spin symmetry: Bhattacharya, Gronau, Rosner, PLB 726 (2013) 337

$$\boxed{\begin{aligned} \Delta\Gamma_{CP}(K^\pm\pi^+\pi^-) &= -\Delta\Gamma_{CP}(\pi^\pm K^+K^-)\,, \\ \Delta\Gamma_{CP}(\pi^\pm\pi^+\pi^-) &= -\Delta\Gamma_{CP}(K^\pm K^+K^-)\,. \end{aligned}}$$

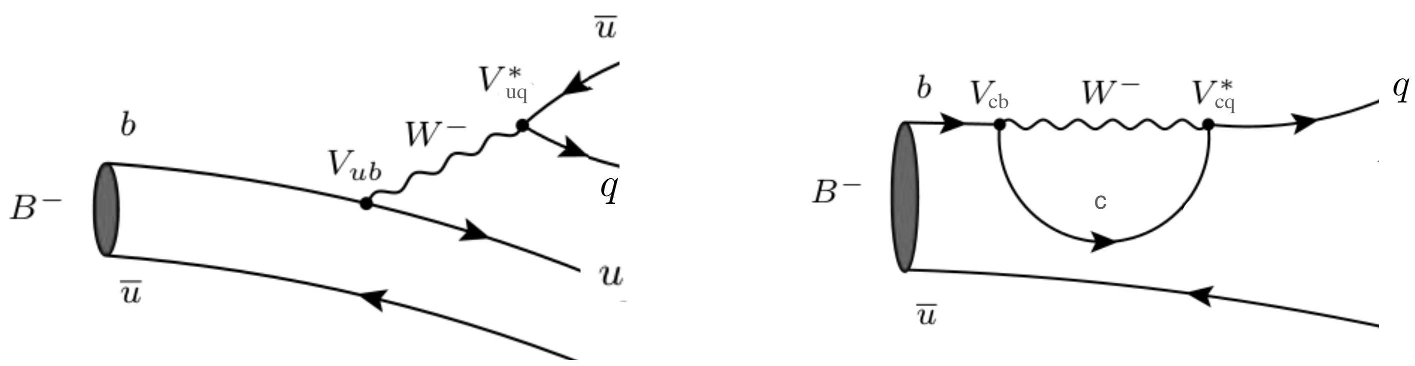
U-spin & FSI ? $$\frac{\Delta\Gamma_{CP}(K^\pm\pi^+\pi^-)}{\Delta\Gamma_{CP}(\pi^\pm\pi^+\pi^-)} = 1.59 \pm 0.62 \text{ and } \frac{\Delta\Gamma_{CP}(K^\pm K^+K^-)}{\Delta\Gamma_{CP}(\pi^\pm K^+K^-)} = 1.77 \pm 0.55$$

only U-spin don't work

Global CP Violation

Bediaga, Frederico, PCM, Torres Machado
PLB 824 (2022) 136824

- $$\Delta\Gamma_{CP}(h_1^{\pm}h_2^{+}h_3^{-}) = \Gamma(B^- \to h_1^- h_2^+ h_3^-) - \Gamma(B^+ \to h_1^+ h_2^- h_3^+)$$
$$= A_{CP}(B^{\pm} \to h_1^{\pm}h_2^{+}h_3^{-})\mathcal{B}(B^+ \to h_1^+ h_2^+ h_3^-)/\tau(B^+)$$



$q = d, s$

$$\boxed{\begin{aligned} A(B^u \to f^q) &= \langle f^q_{out}|\mathcal{H}_{\rm w}|B^u\rangle = V_{ub}V^*_{uq}\langle f^q_{out}|U^q|B^u\rangle + V_{cb}V^*_{cq}\langle f^q_{out}|C^q|B^u\rangle \\ A(\bar{B}^u \to \bar{f}^q) &= \langle \bar{f}^q_{out}|\mathcal{H}_{\rm w}|\bar{B}^u\rangle = V^*_{ub}V_{uq}\langle \bar{f}^q_{out}|\bar{U}^q|\bar{B}^u\rangle + V^*_{cb}V_{cq}\langle \bar{f}^q_{out}|\bar{C}^q|\bar{B}^u\rangle \end{aligned}}$$

$$\mathcal{U}_{f^q} = \langle f^q_{out}|U^q|B^u\rangle \quad \mathcal{C}_{f^q} = \langle f^q_{out}|C^q|B^u\rangle$$

- $$\Delta\Gamma_{CP}(q_i) = 4\,\mathrm{Im}[V^*_{ub}V_{uq}V_{cb}V^*_{cq}]\sum_{j,k}\mathrm{Im}\Big[S_{j,i}S^*_{k,i}\,\mathcal{U}^*_{q_j}\mathcal{C}_{q_k}\Big]$$

- S-matrix unitarity and CPT invariance applied to 2-coupled-channel $\pi\pi \leftrightarrow KK$

$$\sum \Delta\Gamma_{CP} = 0 \rightarrow \Delta\Gamma(q_{\pi\pi}) = -\Delta\Gamma(q_{KK})$$

- $$\frac{\Delta\Gamma_{CP}(\pi^{\pm}K^{+}K^{-})}{\Delta\Gamma_{CP}(\pi^{\pm}\pi^{+}\pi^{-})} = -0.73 \pm 0.23 \qquad \frac{\Delta\Gamma_{CP}(K^{\pm}K^{+}K^{-})}{\Delta\Gamma_{CP}(K^{\pm}\pi^{+}\pi^{-})} = -0.81 \pm 0.32$$

Global CP Violation

- From LHCb run II (preliminar results)

	(stat)	(syst)	($J/\psi K^\pm$)	
$A_{CP}(B^\pm \to K^\pm\pi^+\pi^-) = +0.011$	± 0.002	± 0.003	± 0.003	(2.4σ)
$A_{CP}(B^\pm \to K^\pm K^+K^-) = -0.037$	± 0.002	± 0.002	± 0.003	(8.5σ)
$A_{CP}(B^\pm \to \pi^\pm\pi^+\pi^-) = +0.080$	± 0.004	± 0.003	± 0.003	(14.1σ)
$A_{CP}(B^\pm \to \pi^\pm K^+K^-) = -0.114$	± 0.007	± 0.003	± 0.003	(13.6σ)

- $$\frac{\Delta\Gamma(B^\pm \to \pi^\pm K^+K^-)}{\Delta\Gamma(B^\pm \to K^\pm\pi^+\pi^-)} = \frac{A_{CP}(B^\pm \to \pi^\pm K^+K^-)\mathscr{B}(B^+ \to \pi^+K^+K^-)}{A_{CP}(B^\pm \to K^\pm\pi^+\pi^-)\mathscr{B}(B^+ \to K^+\pi^+\pi^-)} = -0.92 \pm 0.18$$
  $$\frac{\Delta\Gamma(B^\pm \to \pi^\pm\pi^+\pi^-)}{\Delta\Gamma(B^\pm \to K^\pm K^+K^-)} = \frac{A_{CP}(B^\pm \to \pi^\pm\pi^+\pi^-)\mathscr{B}(B^+ \to \pi^\pm\pi^+\pi^-)}{A_{CP}(B^\pm \to K^\pm K^+K^-)\mathscr{B}(B^+ \to K^+K^+K^-)} = -1.06 \pm 0.08$$

U-spin!

- $$\frac{A_{CP}(B^\pm \to \pi^\pm K^+K^-)\mathcal{B}(B^\pm \to \pi^\pm K^+K^-)}{A_{CP}(B^\pm \to K^\pm K^+K^-)\mathcal{B}(B^\pm \to K^\pm K^+K^-)} = 0.47 \pm 0.04\,,$$
  $$\frac{A_{CP}(B^\pm \to K^\pm\pi^+\pi^-)\mathcal{B}(B^\pm \to K^\pm\pi^+\pi^-)}{A_{CP}(B^\pm \to \pi^\pm\pi^+\pi^-)\mathcal{B}(B^\pm \to \pi^\pm\pi^+\pi^-)} = 0.48 \pm 0.09\,.$$

U-spin and FSI!

https://journals.aps.org/prd/pdf/10.1103/PhysRevD.102.112010

↪ the sign is correct, maybe symmetry issues

Final remarks

- FSI play an important role in B hadronic decays

- can be a mechanism to generate CPV at low and high mass regions

↳ $\pi\pi \to KK$ rescattering dominates the global A_{CP} in $B \to hhh$

↳ included in Amplitude analysis!

↳ Charm rescattering triangles is an important mechanism

↳ interference produce similar CPV data signature

↳ under investigation in run II Amplitude analysis

↳ developed a technique to identify the type of CPV directly from data

↳ method is good but (2+1) - CPV in $B \to K(\rho^0 \to \pi\pi)$

↳ strong $f_0(980)$ near by

- implementing phenomenological models in LHCb Run II amplitude analysis

Final remarks

- Where phenomenology have to improve?
  - models need to connect the weak and strong description

    → QCDF and FSI

  - models have to merge low and high FSI

Banksy

Final remarks

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    → QCDF and FSI

  - models have to merge low and high FSI

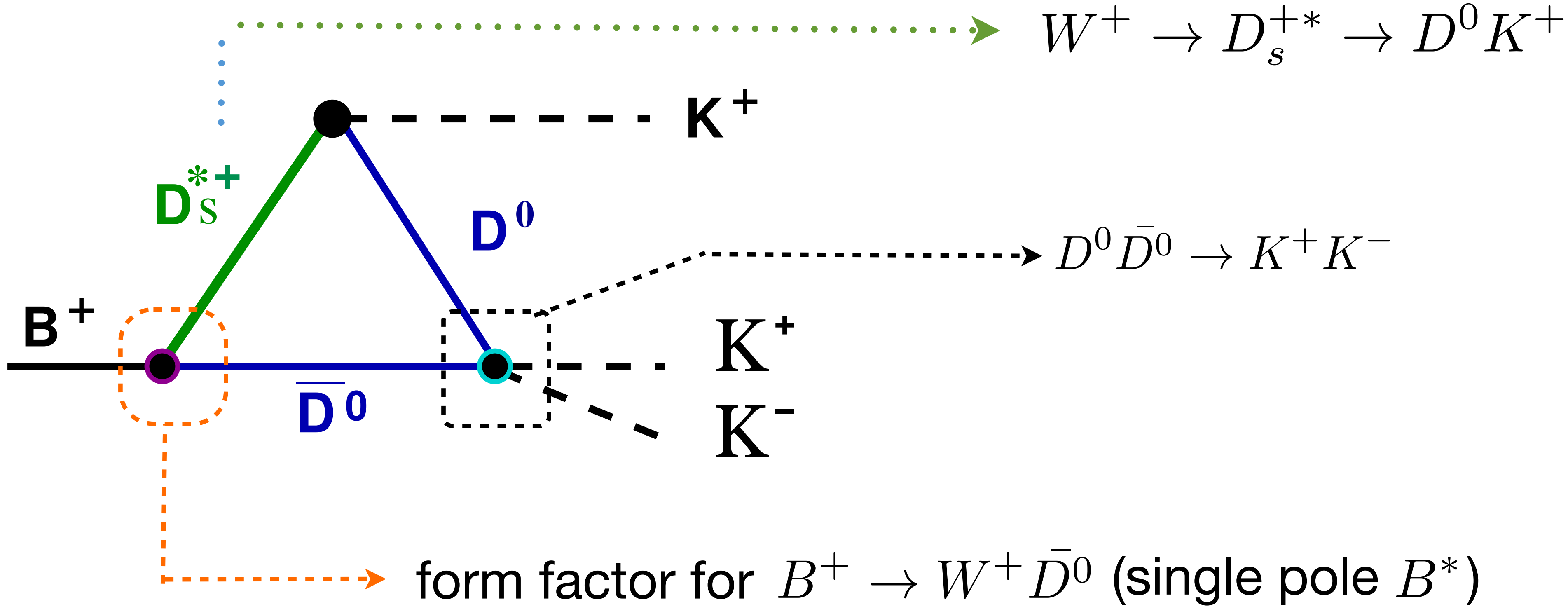
obrigada!!

#staysafe

Banksy

Backup slides

hadronic loop



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

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

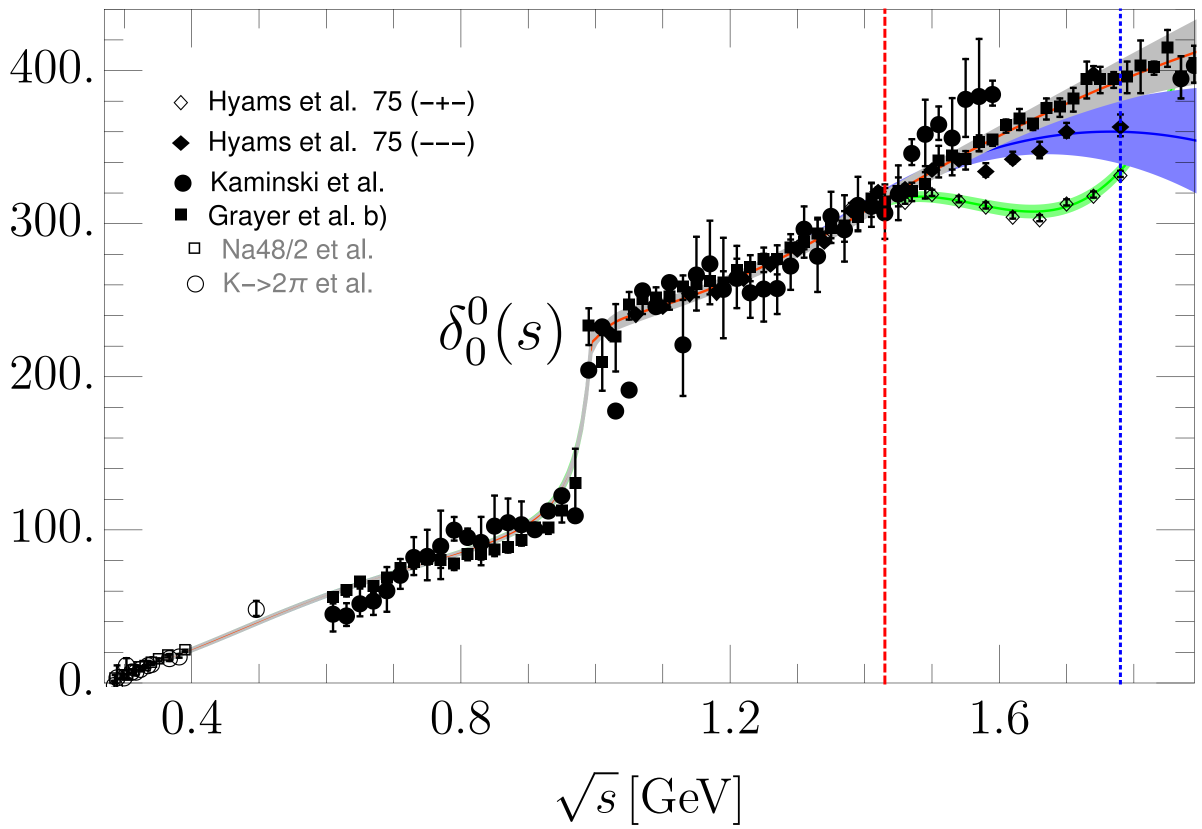
→ solved by Feynman technique

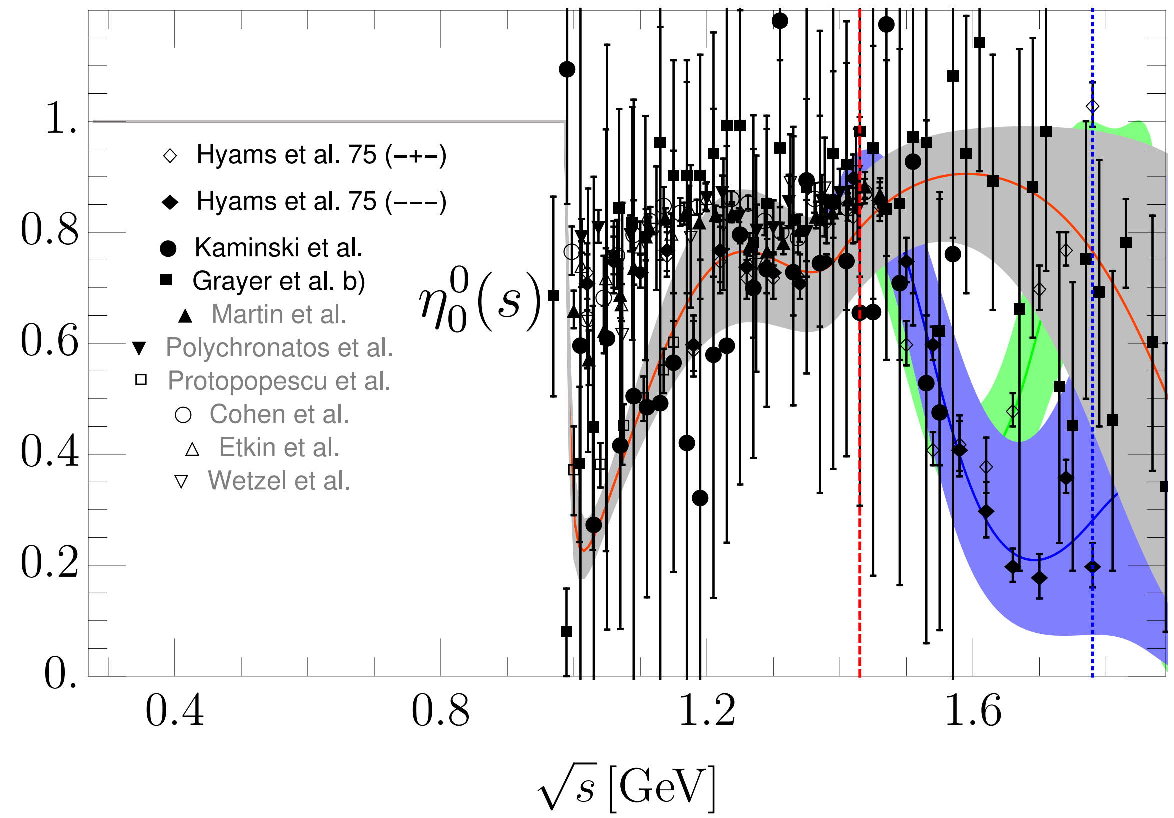
- strong phases $\delta_{\pi\pi}$, δ_{KK} and $\delta_{\pi\pi\to KK}$ are the same independent of the initial process

→ we can use CERN-Munich data from 80's

Longacre et al., Phys. Lett. B 177, 223 (1986)
Hyams et al., Nucl. Phys. B 100, 205 (1975)
Ochs, J. Phys. G 40, 043001 (2013)

- $\pi\pi \to \pi\pi$





Pelaez, Rodas, Elvira *Eur.Phys.J.C* 79 (2019) 12, 1008

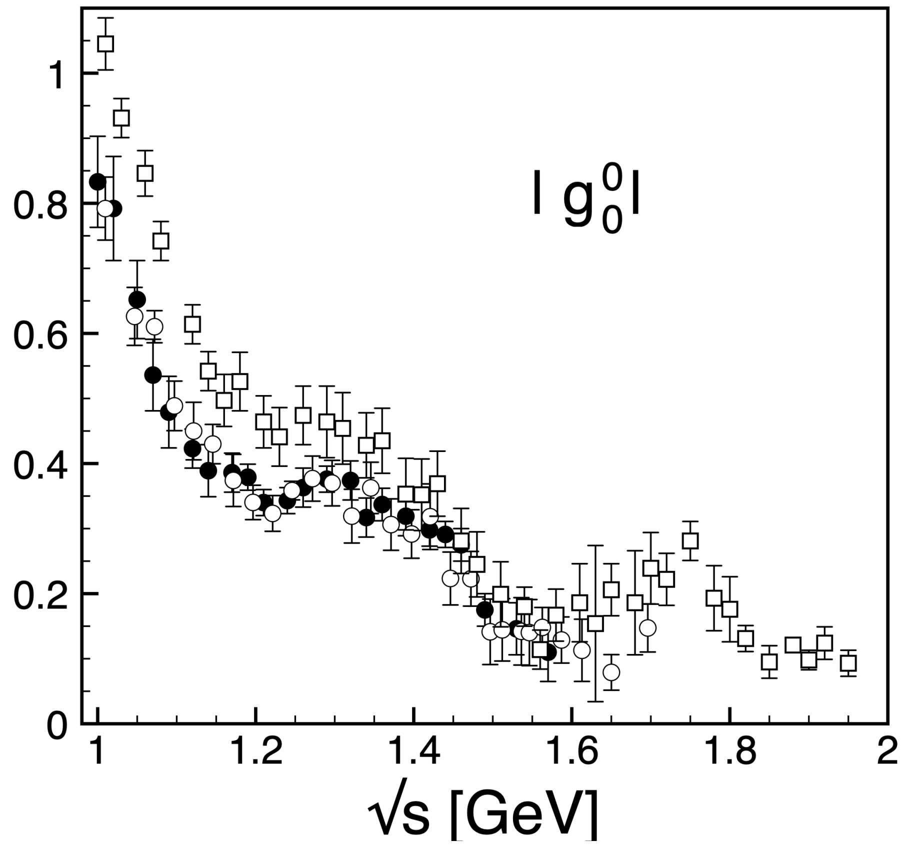
amplitude $\hat{f}_l(s) = \left[\dfrac{\eta_l e^{2i\delta_l} - 1}{2i}\right].$

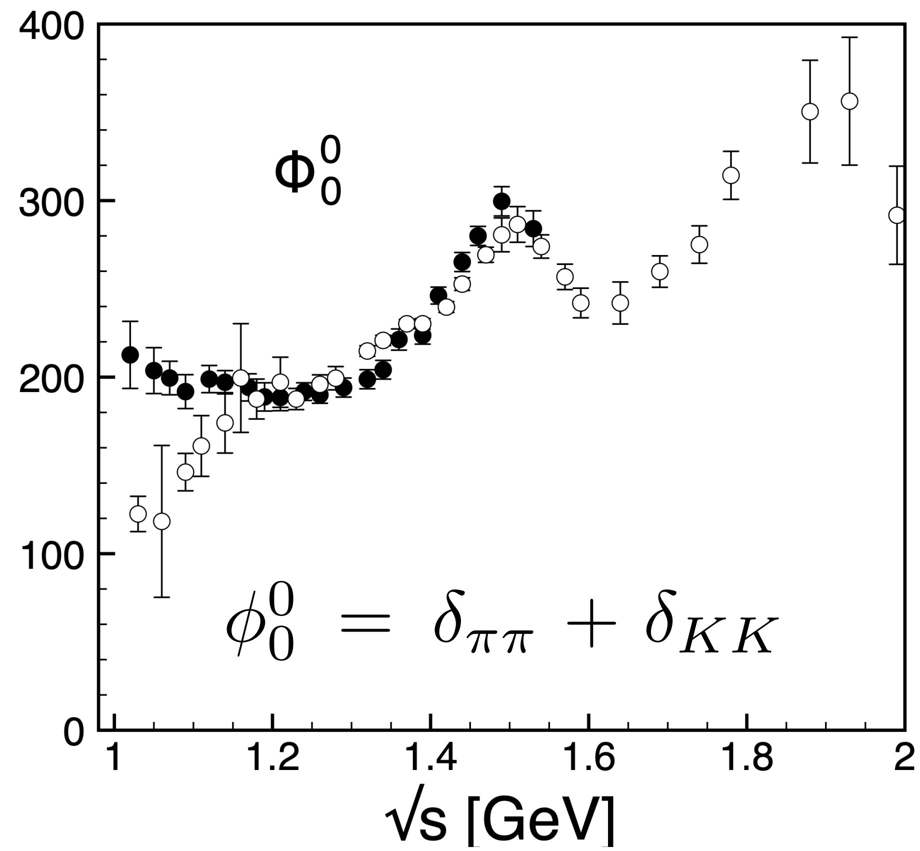
→ elasticity drops dramatically near $K\bar{K}$ → strongly couple

- $\pi\pi \to KK$

$$\rightarrow \quad S_{\pi\pi,KK}(s) = \imath\sqrt{1-\eta^2}\, e^{\imath(\delta_{\pi\pi}+\delta_{KK})} = i\,4\sqrt{\frac{q_\pi q_K}{s}}\,|g_0^0(s)|\, e^{i\phi_0^0(s)}\,\Theta(s-4m_K^2)$$

Pelaez and Rodas, Eur. Phys. J. C 78, 897 (2018)





Cohen et al., Phys. Rev. D 22, 2595 (1980)
Etkin et al., Phys. Rev. D 25, 1786 (1982)

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 — Anisovich PLB 653(2007)

  - rescattering $\pi\pi \to KK$ contribution in LHCb $\begin{cases} B^\pm \to \pi^+\pi^-\pi^\pm & \text{PRD101 (2020) 012006; PRL 124 (2020) 031801} \\ B^\pm \to K^-K^+\pi^\pm & \text{PRL 123 (2019) 231802} \end{cases}$

    Pelaez, Yndurain PRD71(2005) 074016

    ↳ new parametrization Pelaez, Rodas, Elvira *Eur.Phys.J.C* 79 (2019) 12, 1008

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    ↳ new parametrization Pelaez, Rodas, Elvira *Eur.Phys.J.C* 79 (2019) 12, 1008

→ still not enough to fully described data

- from theory: list of scalar and vector form factors

$<\pi\pi|0>$ Moussallam EPJ C 14, 111 (2000); Daub, Hanhart, and B. Kubis JHEP 02 (2016) 009. Hanhart, PL B715, 170 (2012). Dumm and Roig EPJ C 73, 2528 (2013).

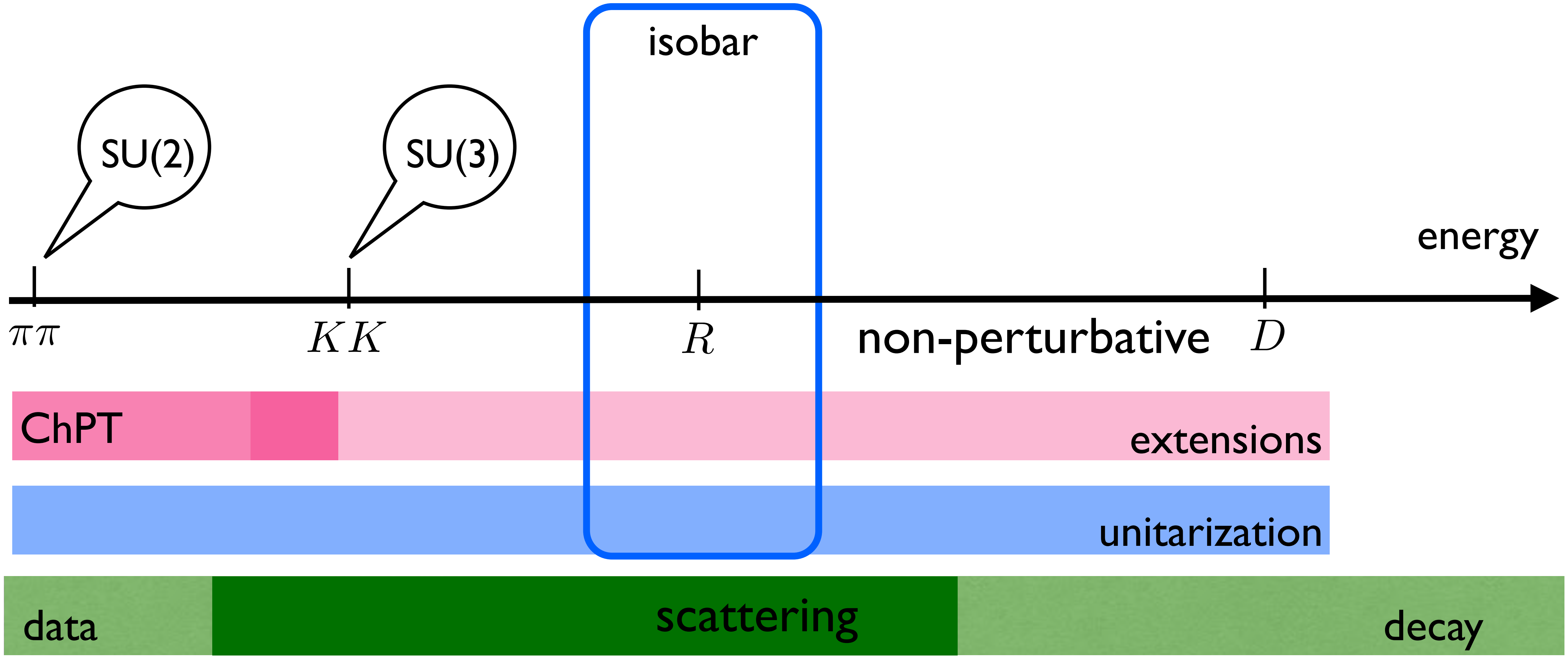
$<K\pi|0>$ Moussallam EPJ C 53, 401 (2008) Jamin, Oller and Pich, PRD 74, 074009 (2006) Boito, Escribano, and Jamin EPJ C 59, 821 (2009).

$<KK|0>$ Fit from 3-body data PCM, Robilotta + LHCb JHEP 1904 (2019) 063

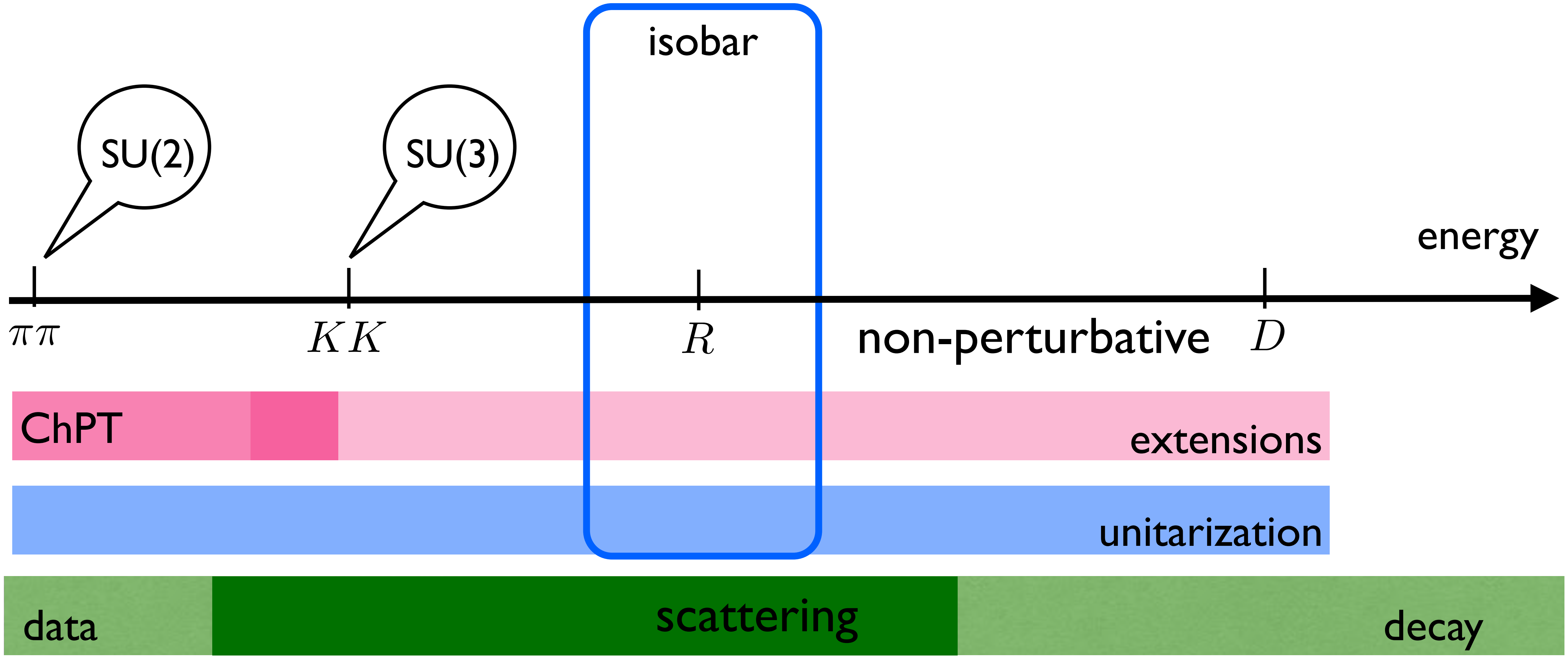
no data extrapolate from unitarity model Albaladejo and Moussallam EPJ C 75, 488 (2015).

quark model with isospin symmetry Bruch, Khodjamirian, and Kühn , EPJ C 39, 41 (2005)

scale issue


isobar
SU(2)
SU(3)
energy
$\pi\pi$
KK
R
non-perturbative
D
ChPT
extensions
unitarization
data
scattering
decay

scale issue



- we need non-perturbative meson-meson interactions up to…. 3 GeV
- extend 2-body amplitude theory validity

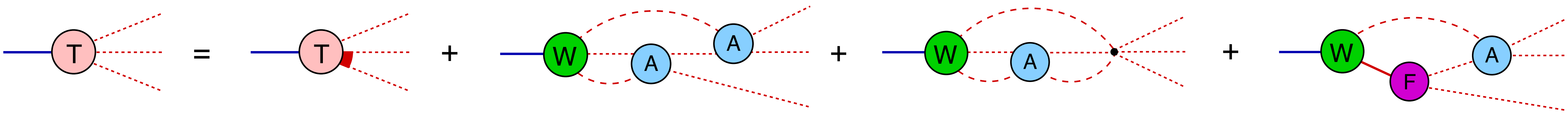
Ropertz, Kubis, Hanhart
EPJ Web Conf. 202 (2019) 06002

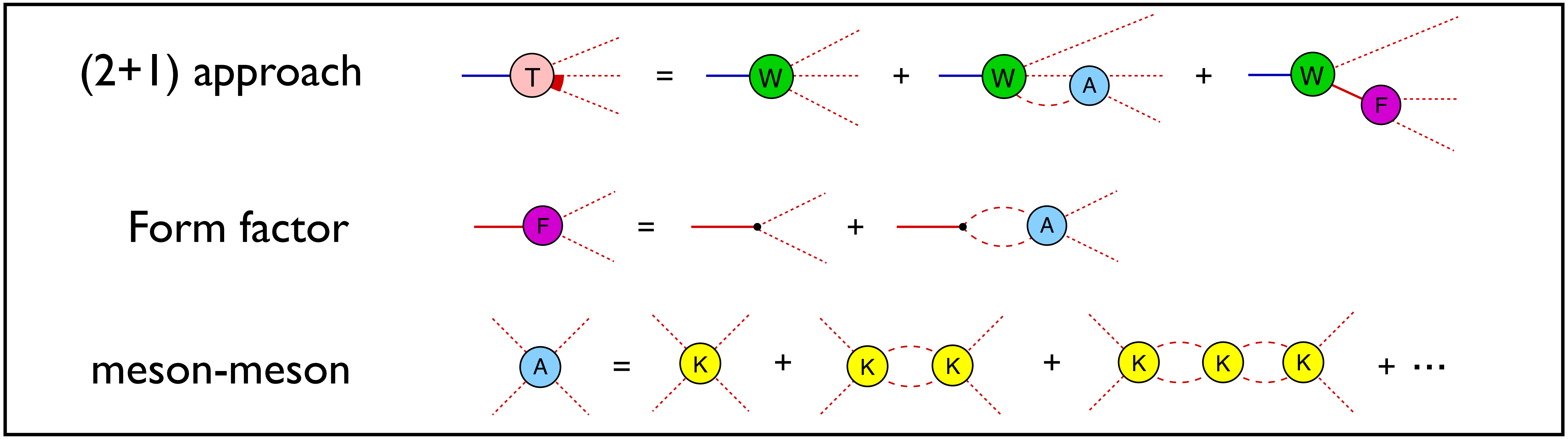
PCM, A.dos Reis, Robilotta
PRD 102, 076012 (2020)

Tool kit for meson-meson interactions in 3-body decay

- Any 3-body decay amplitude

MAGALHAES, A.dos Reis, Robilotta
PRD 102, 076012 (2020)





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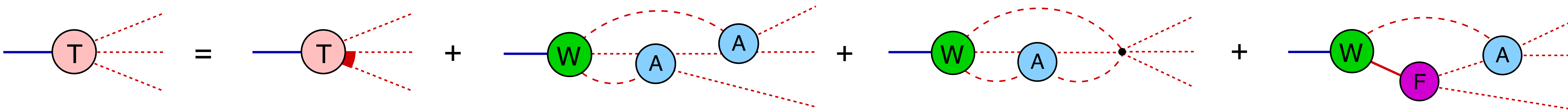
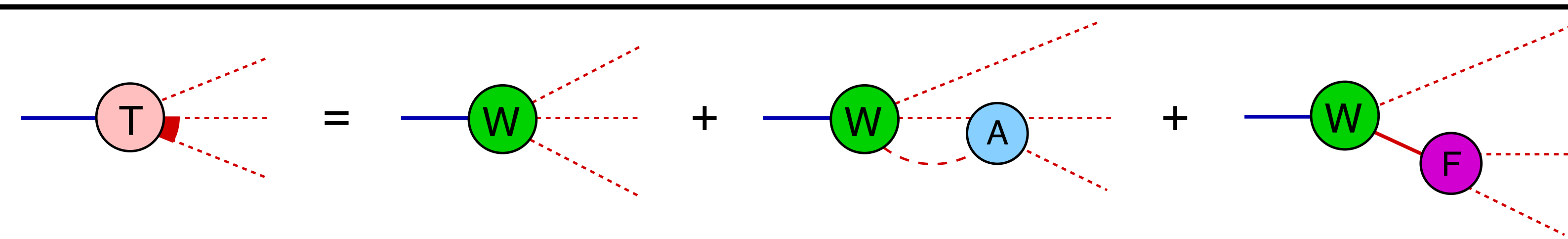
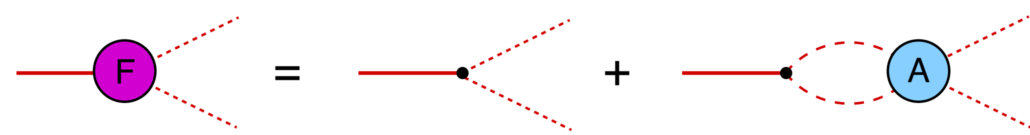


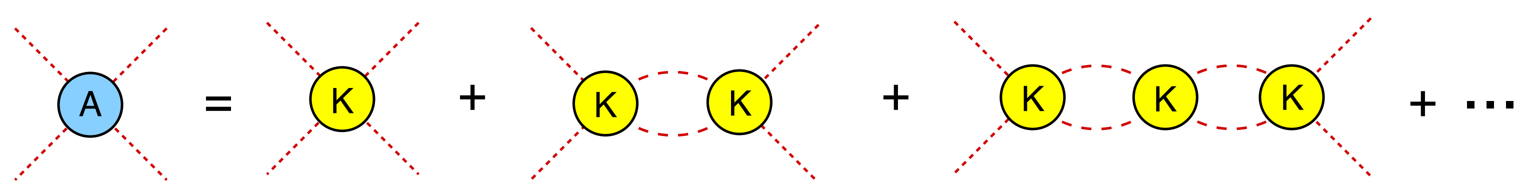
(2+1) approach

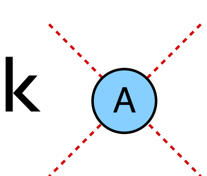


Form factor



meson-meson



↳ provide the building block 

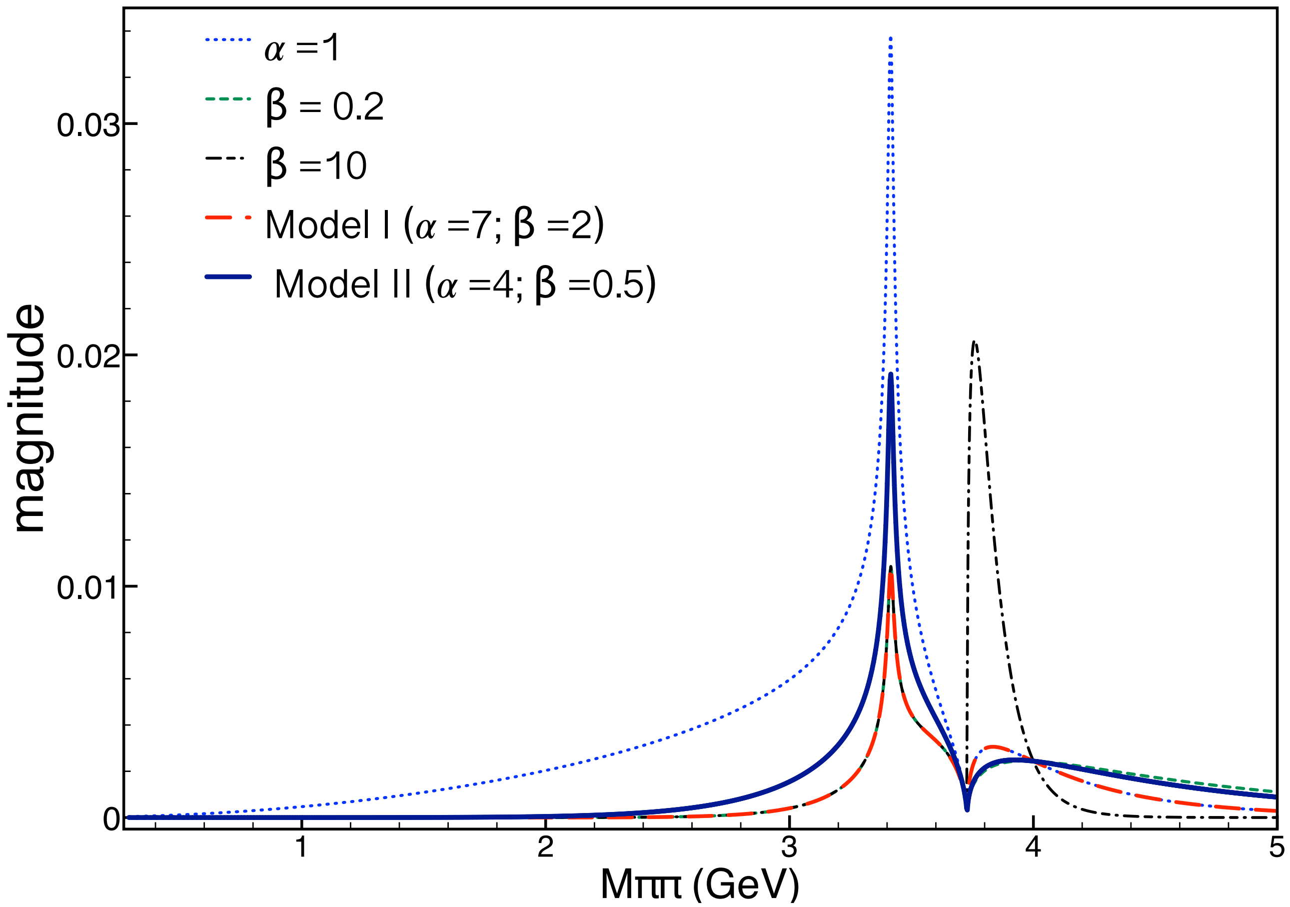
- includes multiple resonances in the same channel (as many as wanted)
- free parameter (massas and couplings) to be fitted to data.

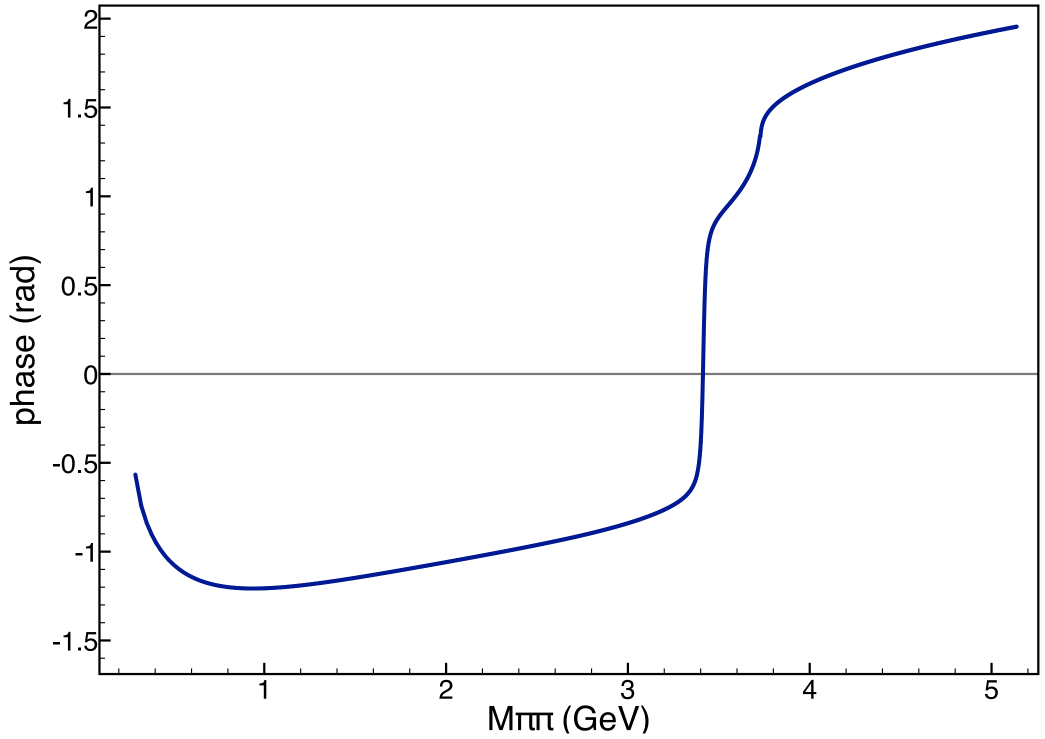
⟶ Available to be implement in data analysis!!

- unitary coupled-channel S-matrix $= \begin{pmatrix} \eta\, e^{2i\delta_1} & \boxed{i\sqrt{1-\eta^2}\, e^{i(\delta_1+\delta_2)}} \\ i\sqrt{1-\eta^2}\, e^{i(\delta_1+\delta_2)} & \eta\, e^{2i\delta_2} \end{pmatrix}$

  → χ_{c0} (3414) : a pole bellow $D\bar{D}$ threshold in δ_2

- amplitude features:
  - χ_{c0} peak superposed to a wide bump below threshold;
  - zero at $D\bar{D}$ threshold
  - phase jump at $D\bar{D}$ threshold

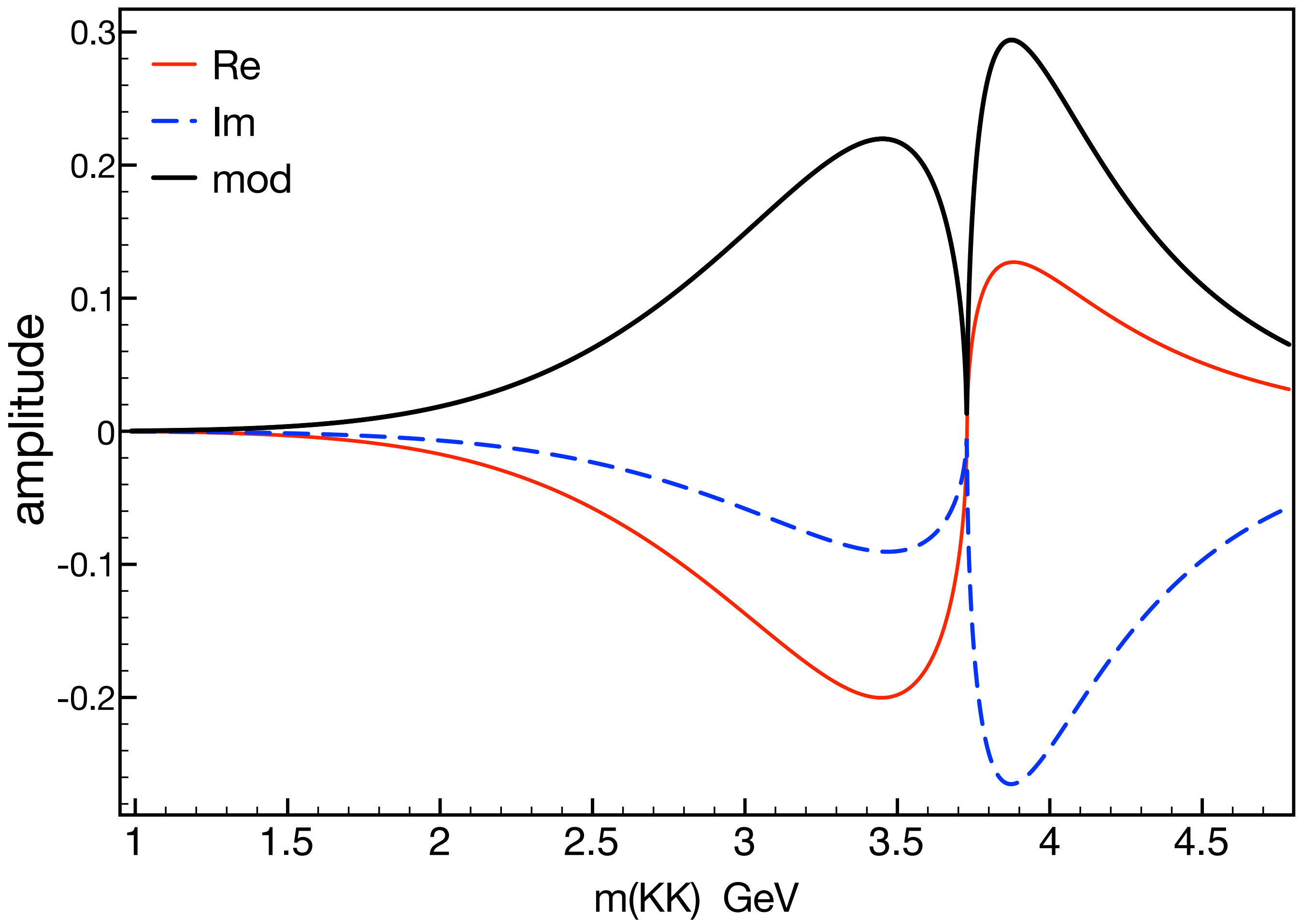




→ parameters should should be fitted

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

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



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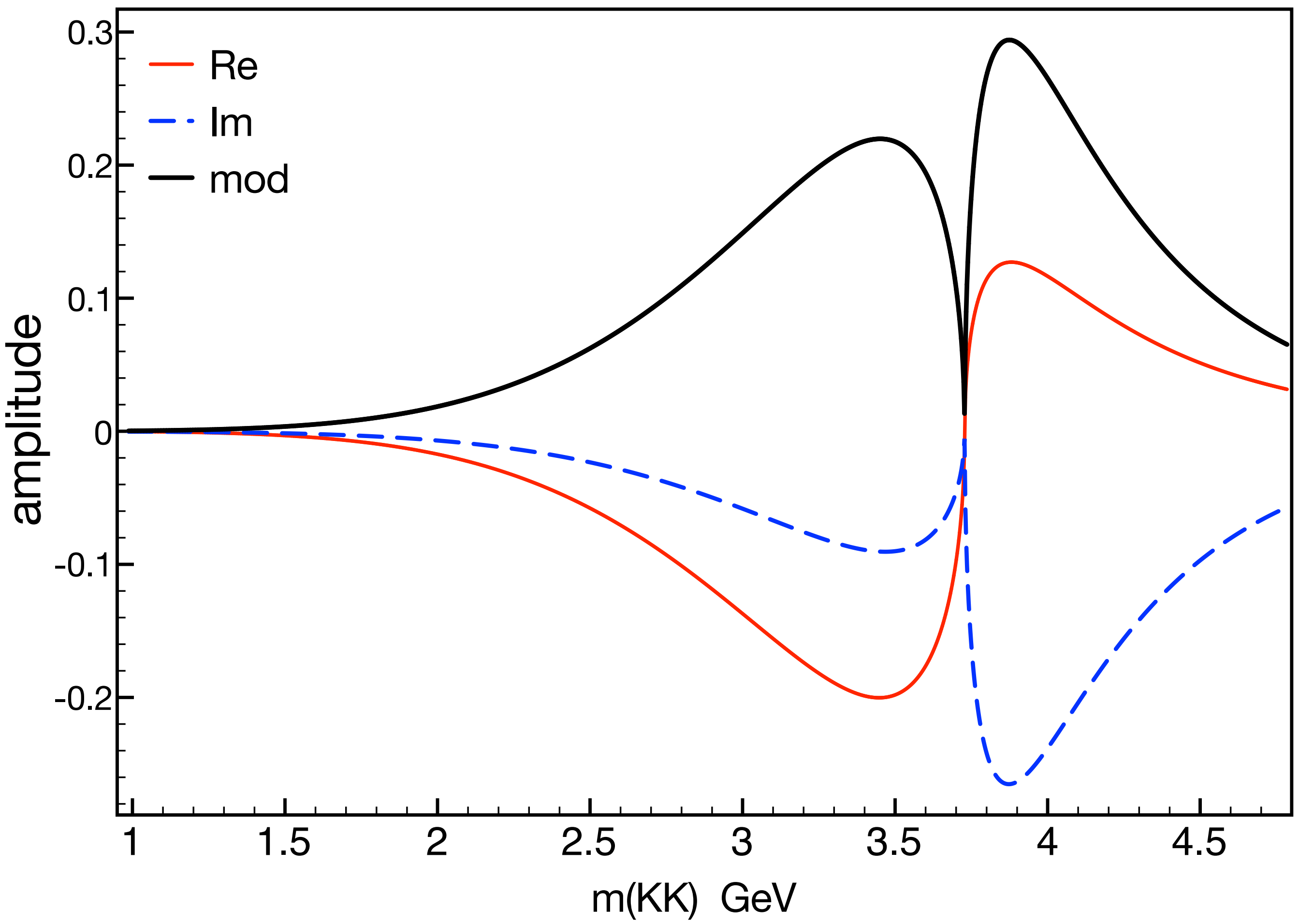
  $$= -i\,\frac{2\,k_2}{\sqrt{s_{th\,D\bar{D}}}}\left(\frac{s_{th\,D\bar{D}}}{s+s_{QCD}}\right)^{\xi}\left(\frac{m_0}{s-m_0}\right)^{\beta}\left[\left(\frac{c+bk_1^2-ik_1}{c+bk_1^2+ik_1}\right)\left(\frac{\frac{1}{a}-ik_2}{\frac{1}{a}+ik_2}\right)\right]^{\frac{1}{2}},\ s \geq s_{th\,D\bar{D}}$$

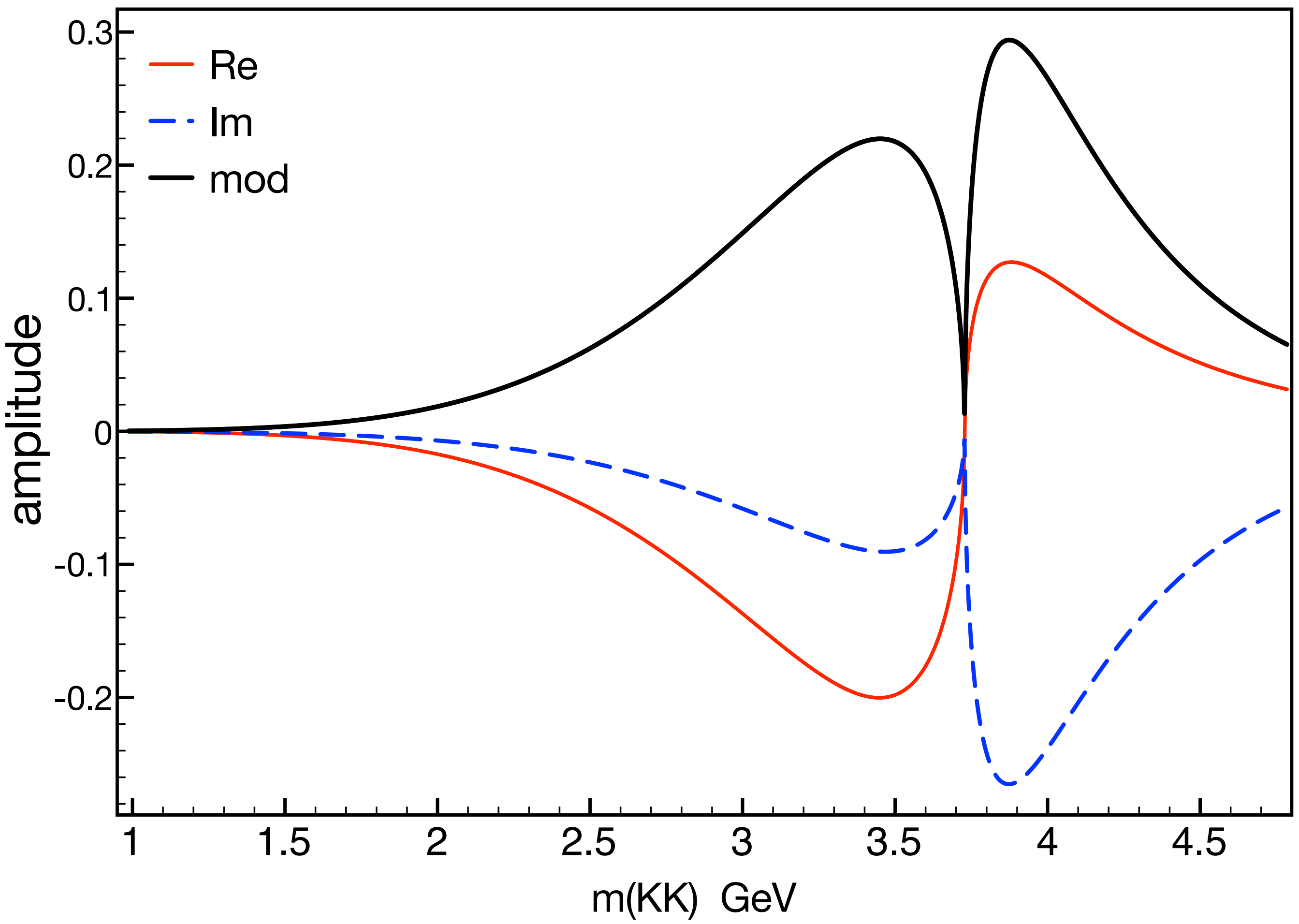
→ parameters fix by data!



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

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

parameters fix by data!

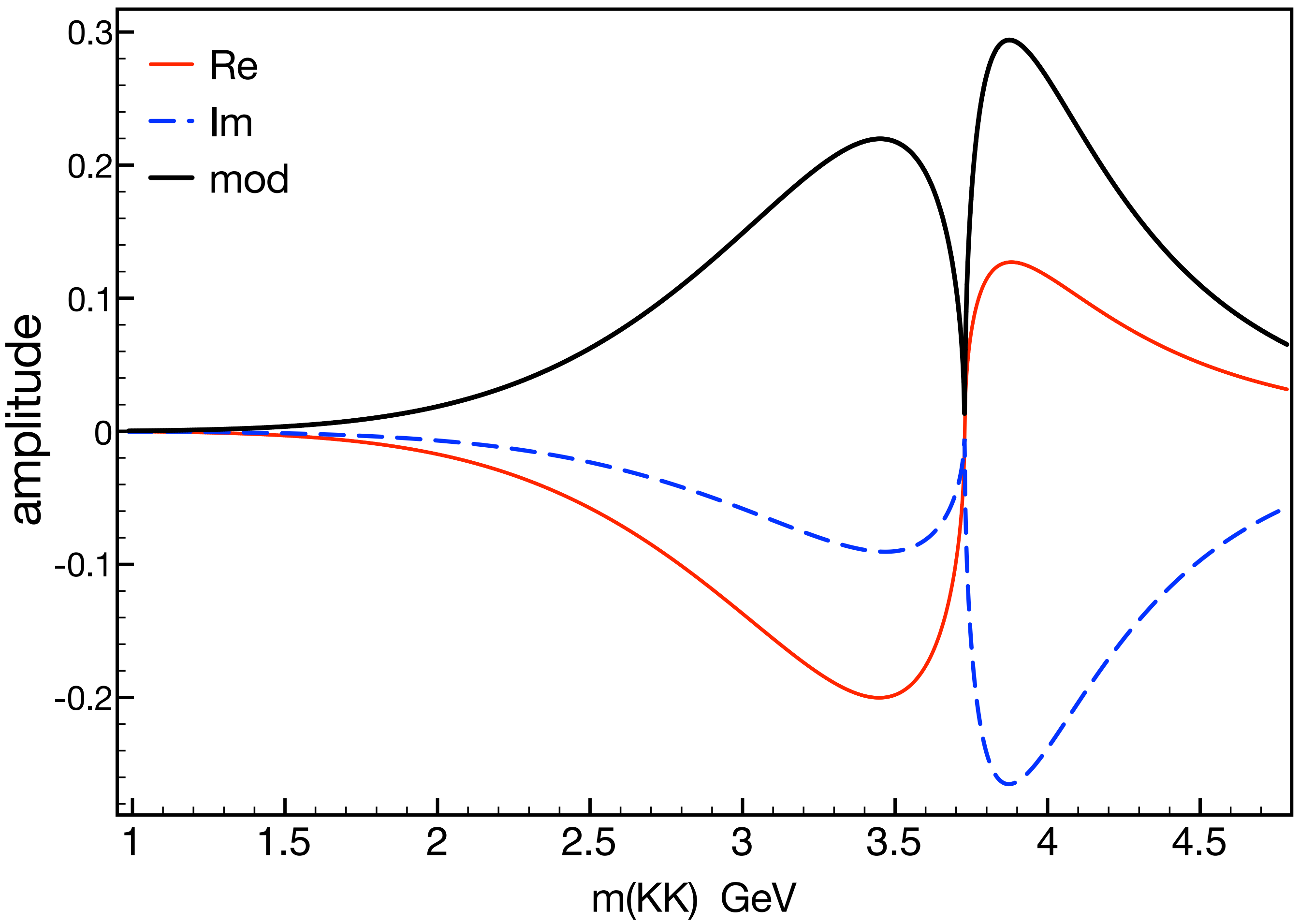


zero at threshold

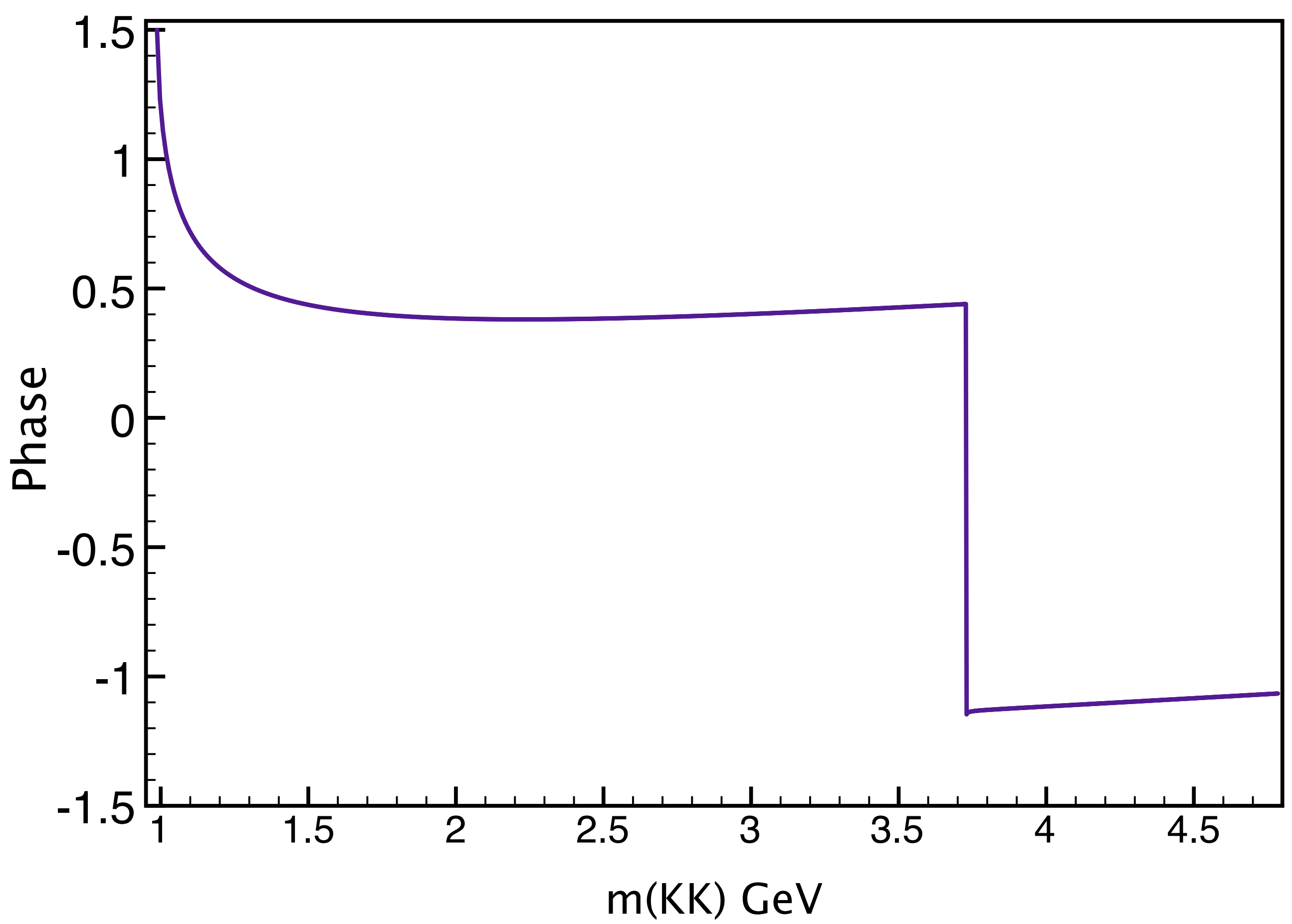
$D^0 \bar{D}^0 \to K^+ K^-$ scattering amplitude

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

→ parameters fix by data!



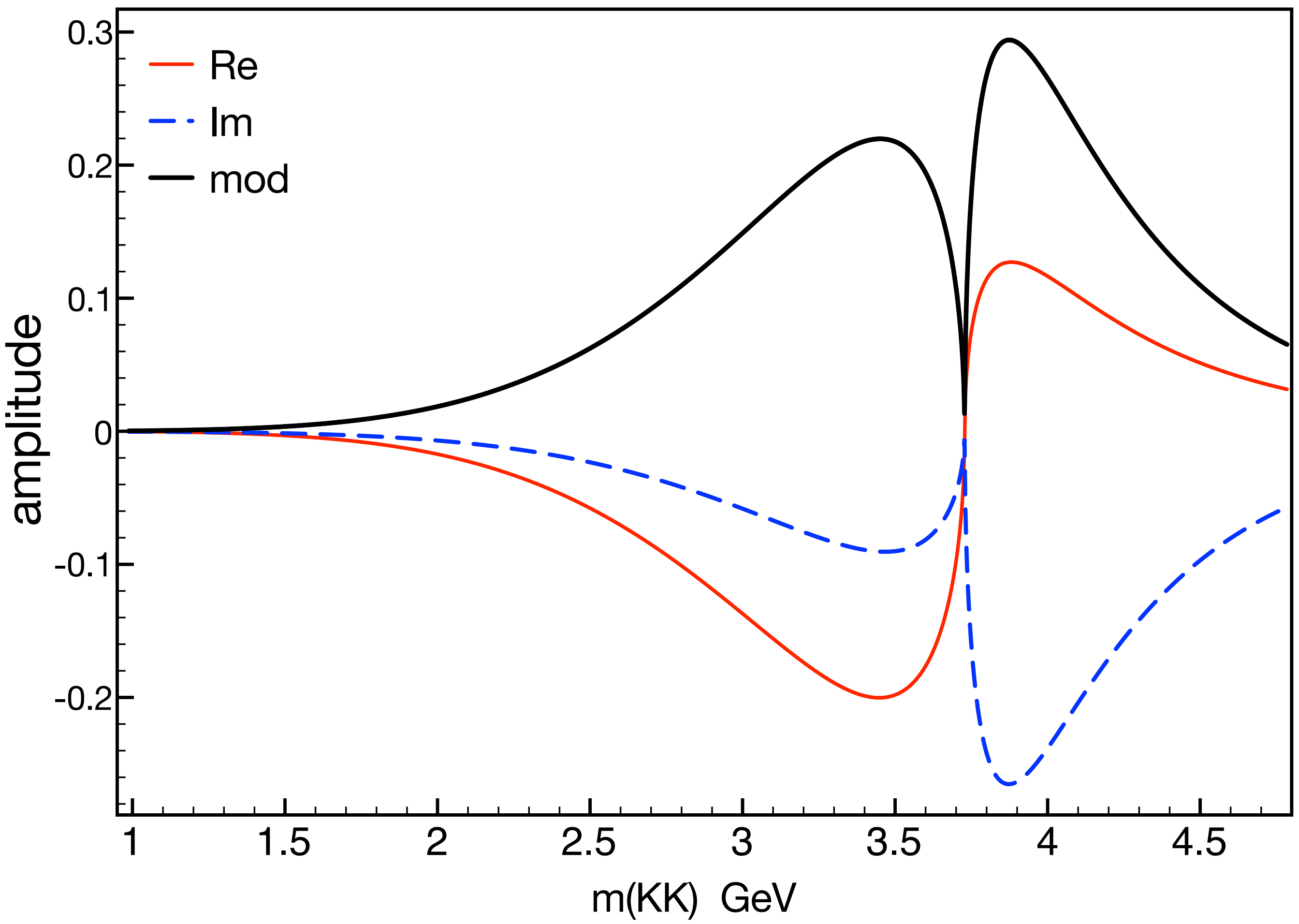
→ zero at threshold



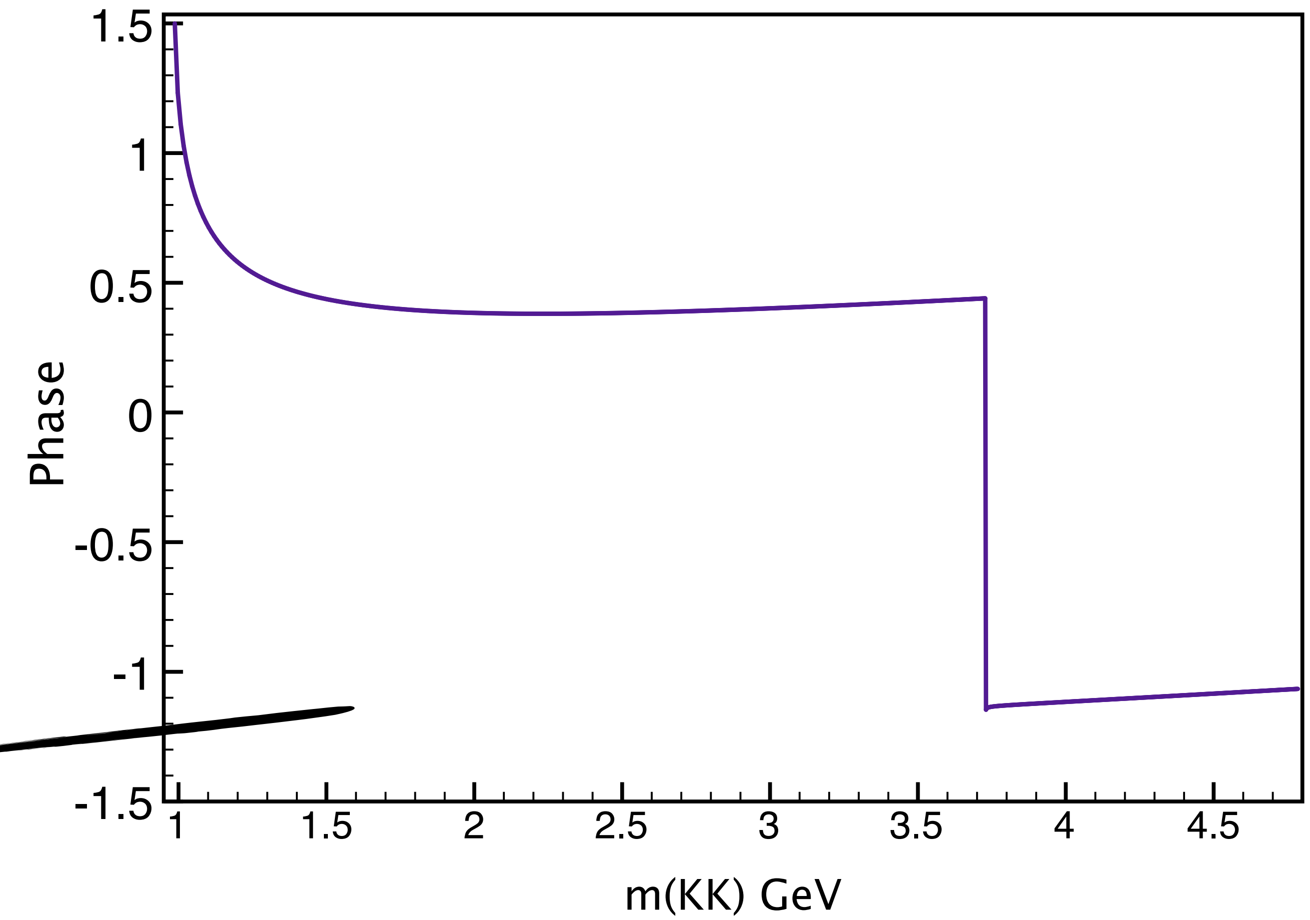
$D^0\bar{D}^0 \to K^+K^-$ scattering amplitude

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

→ parameters fix by data!



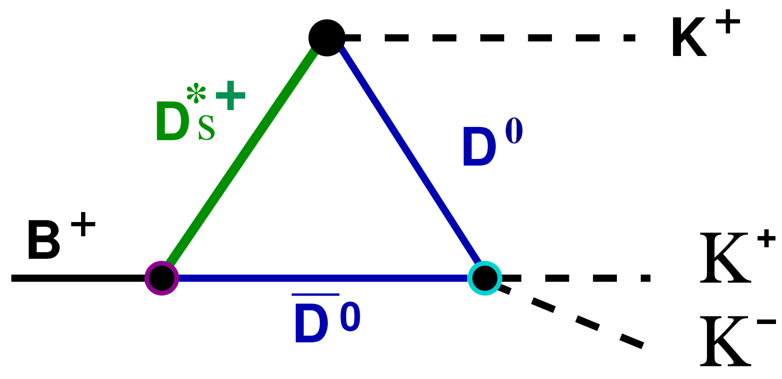
→ zero at threshold

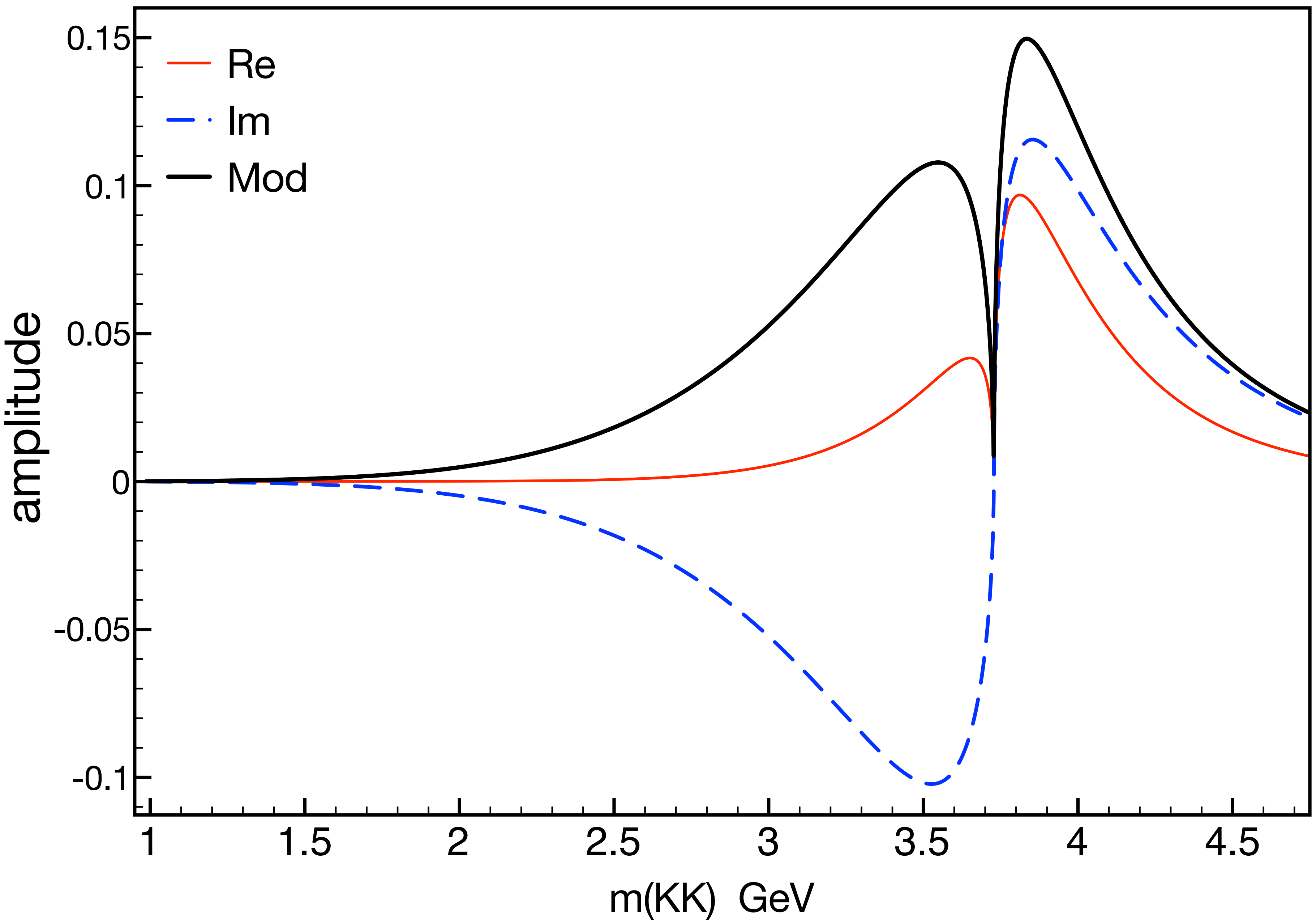


discontinuity at threshold ←

Final Amplitude

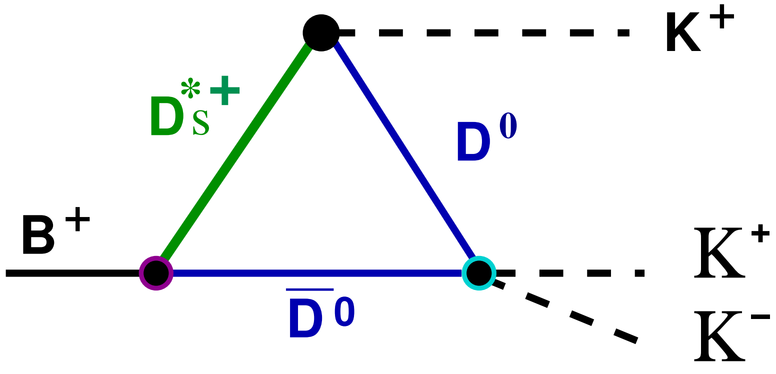
- $$A = iC\ m_a^2 \int \frac{d^4\ell}{(2\pi)^4}\ \frac{T_{\bar{D}^0 D^0 \to KK}(s_{23})\,[-2\,p_3' \cdot (p_2' - p_1)]}{\Delta_{D^{+*}}\,\Delta_{D^0}\,\Delta_{\bar{D}^0}\,\Delta_a}\ ,$$

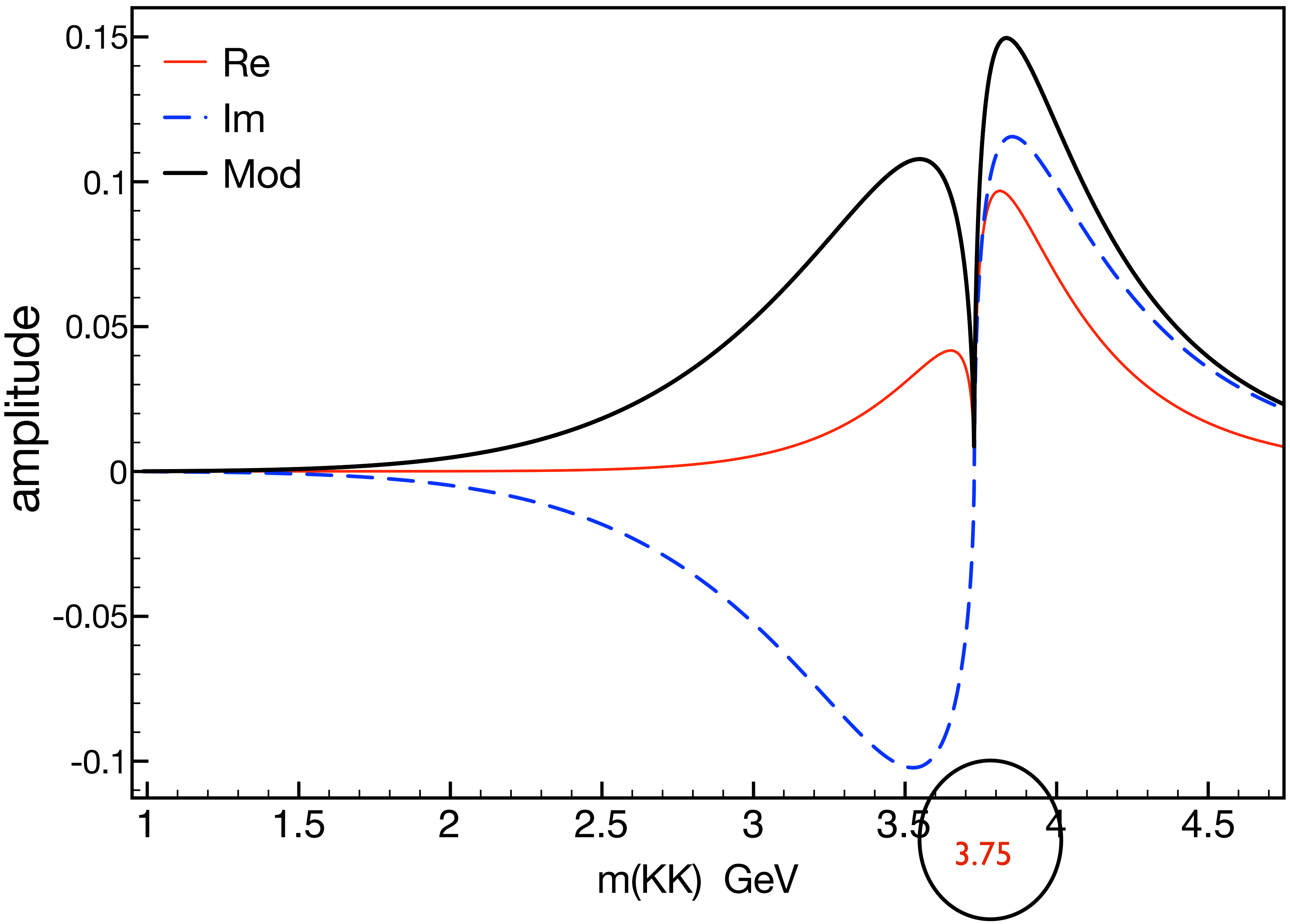




Final Amplitude

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

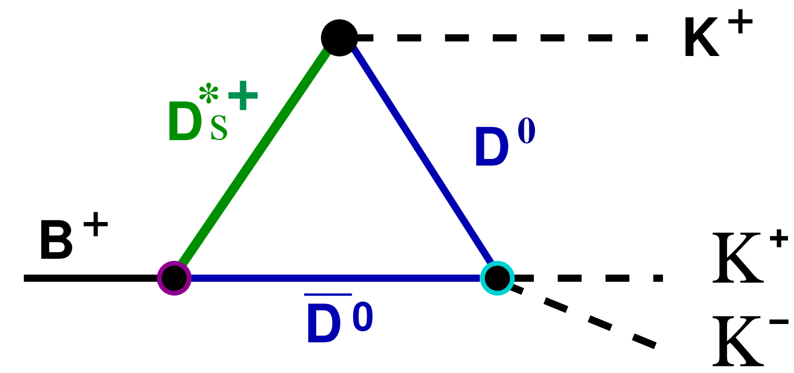


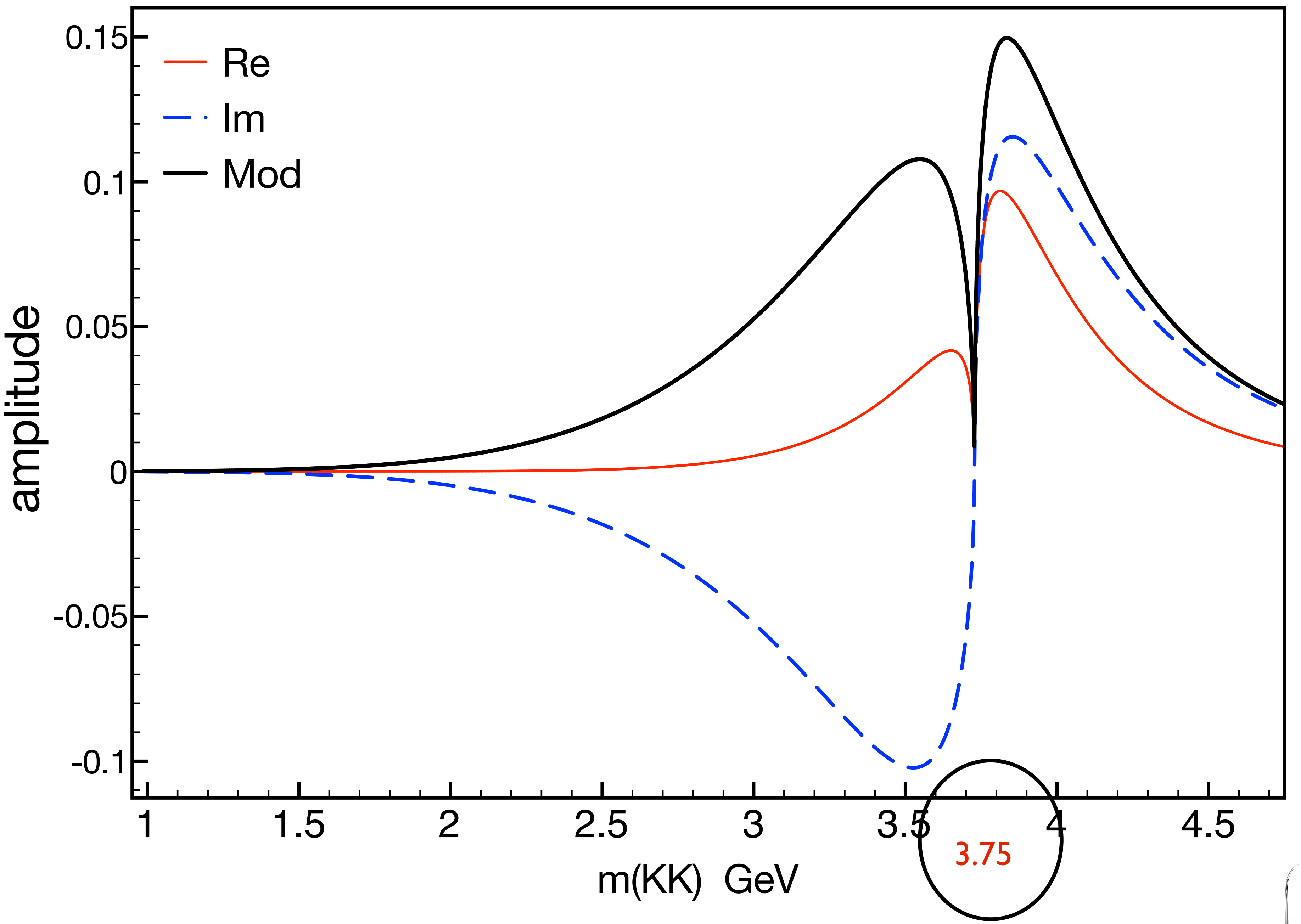


→ zero in between two bumps

Final Amplitude

- $$A = iC\ m_a^2 \int \frac{d^4\ell}{(2\pi)^4}\ \frac{T_{\bar{D}^0 D^0 \to KK}(s_{23})\,[-2\,p'_3\ \cdot (p'_2 - p_1)]}{\Delta_{D^{+*}}\,\Delta_{D^0}\,\Delta_{\bar{D}^0}\,\Delta_a}\ ,$$

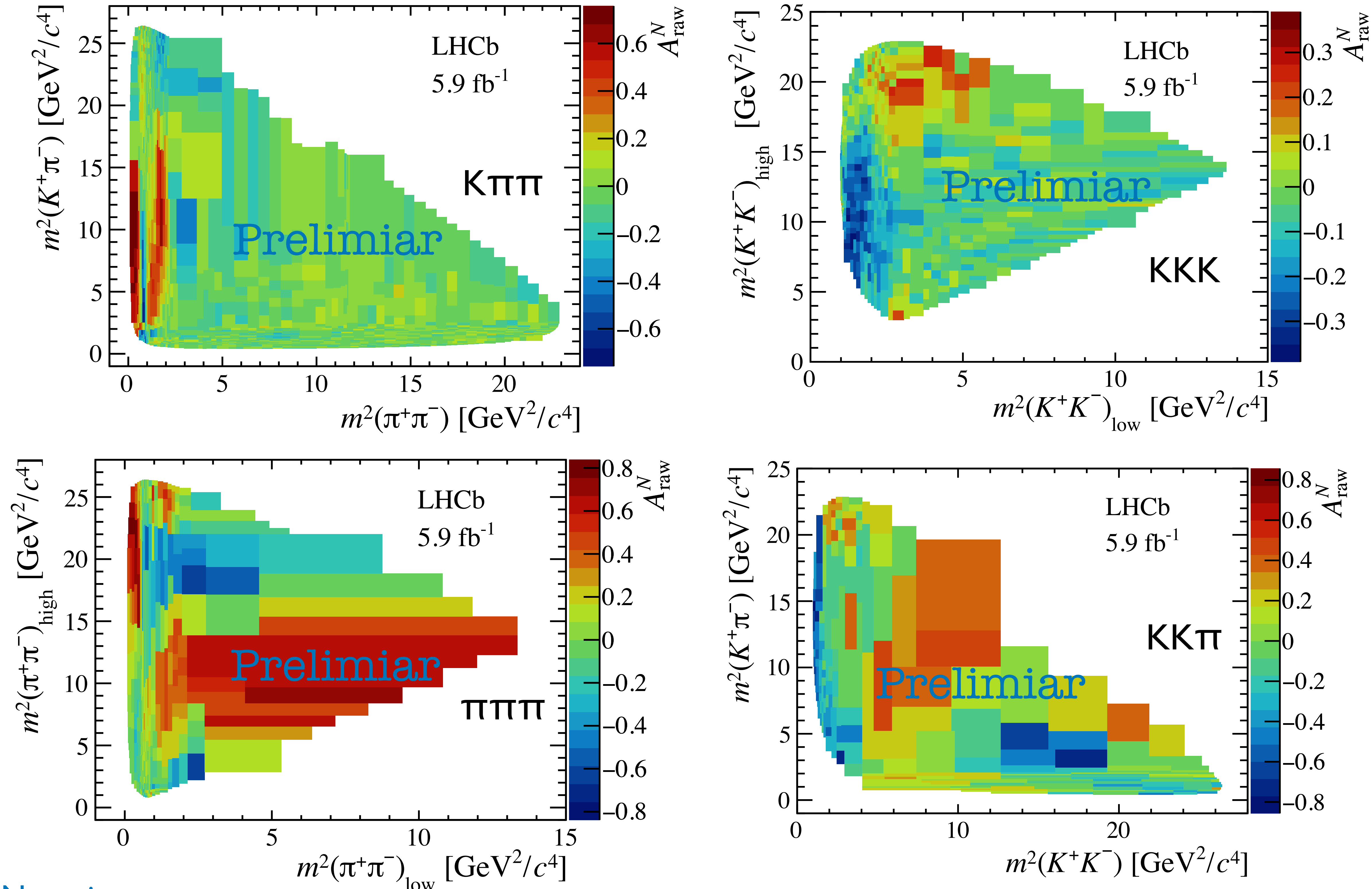




zero in between two bumps

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

- $B^{\pm} \to h^{\pm}h^{-}h^{+}$ LHCb Run II



Run II/Run I
pipipi: 4.1
Kpipi: 2.8
KKpi: 5.3
KKK: 3.3

link to CERN seminar

- $B^{\pm} \to h^{\pm}h^{-}h^{+}$ Run II

Run II/Run I
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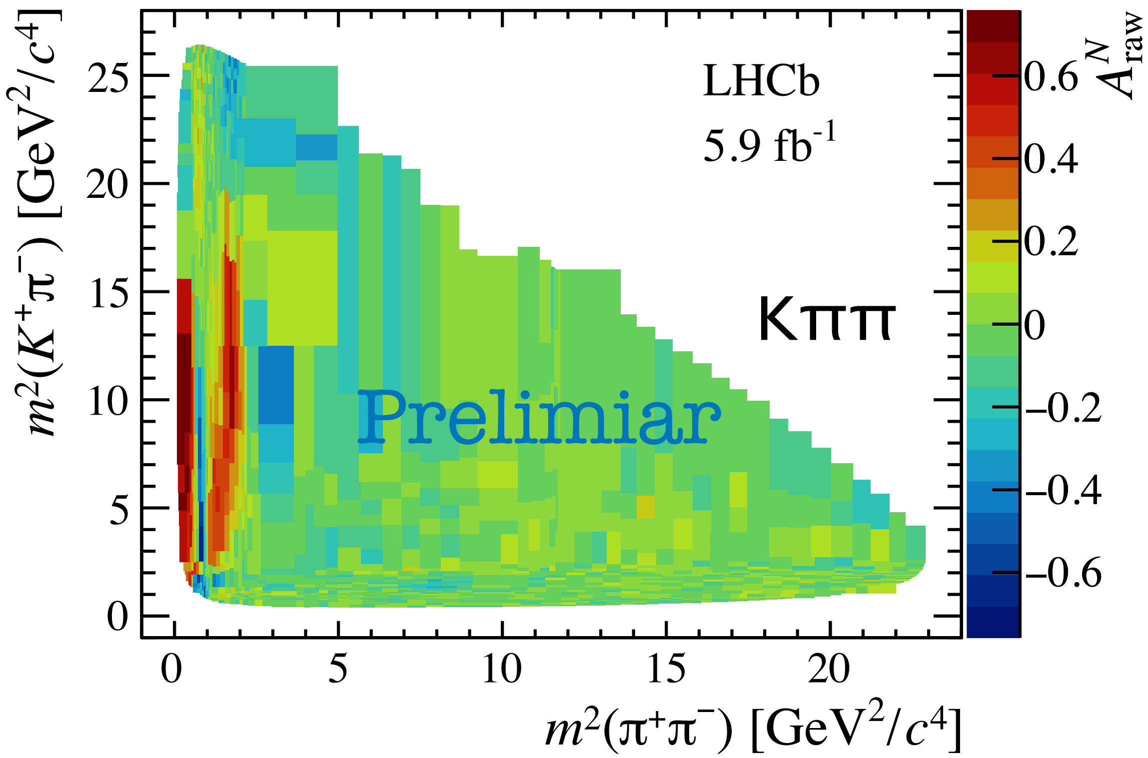

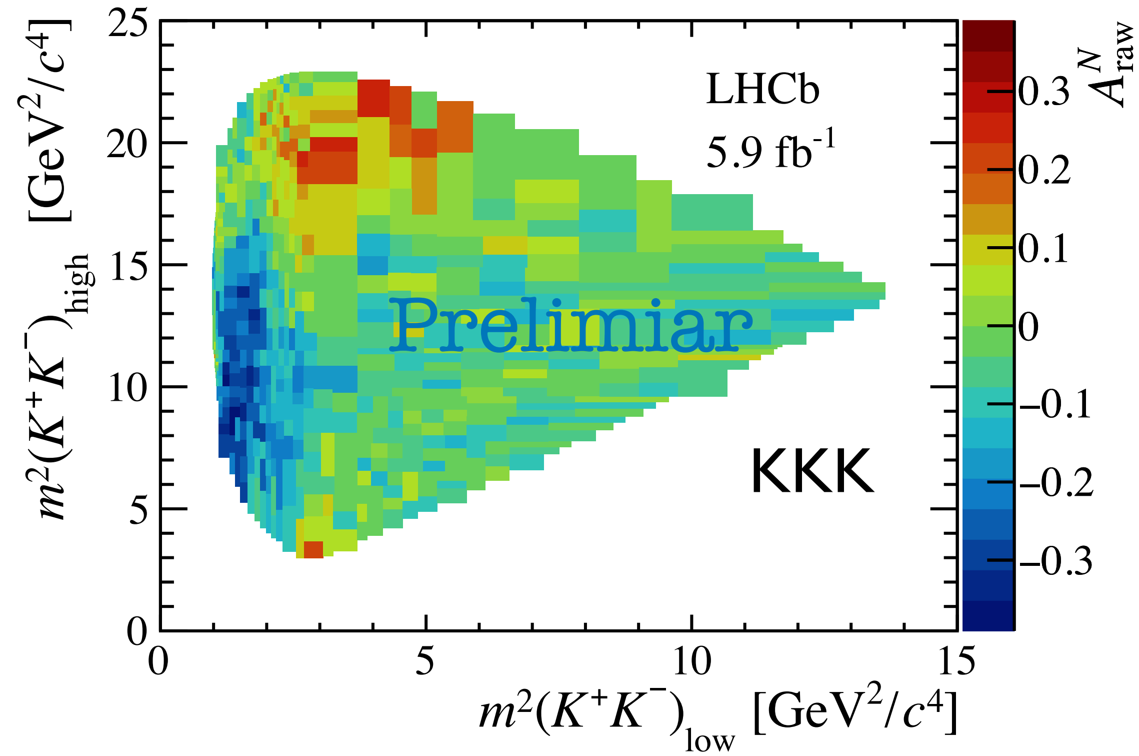

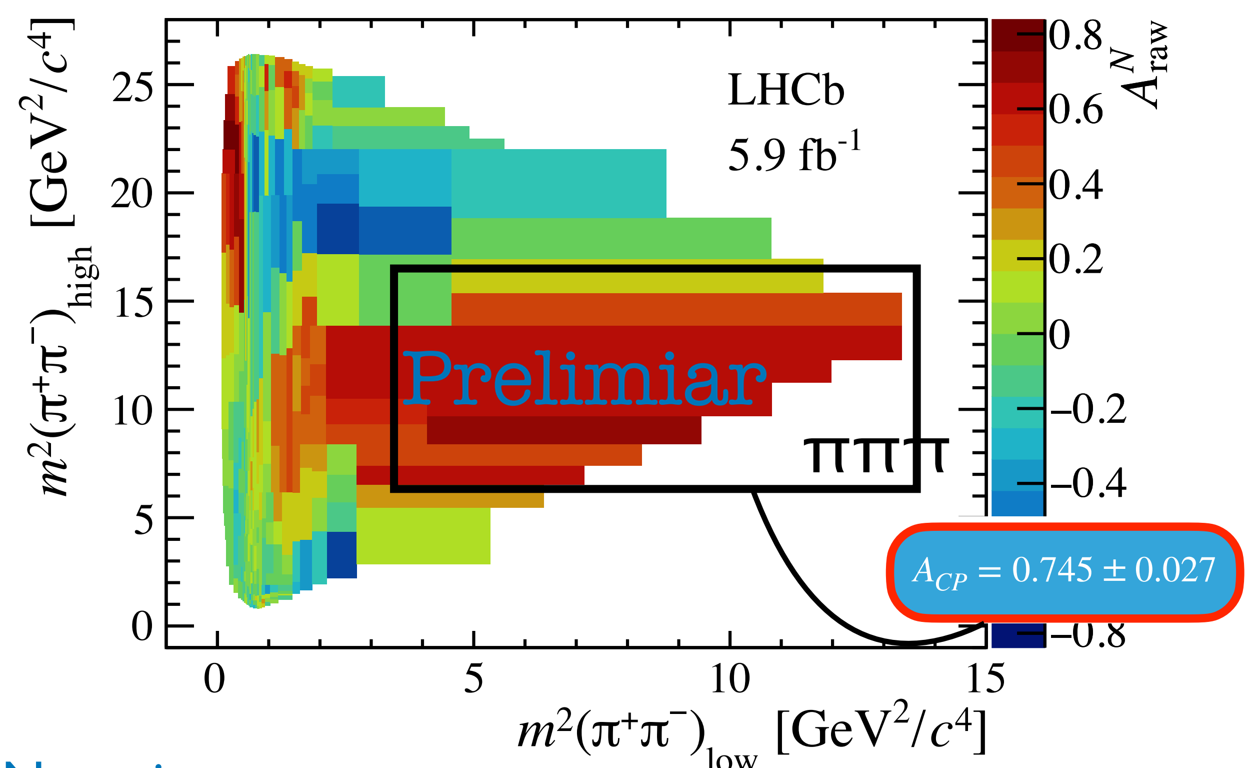

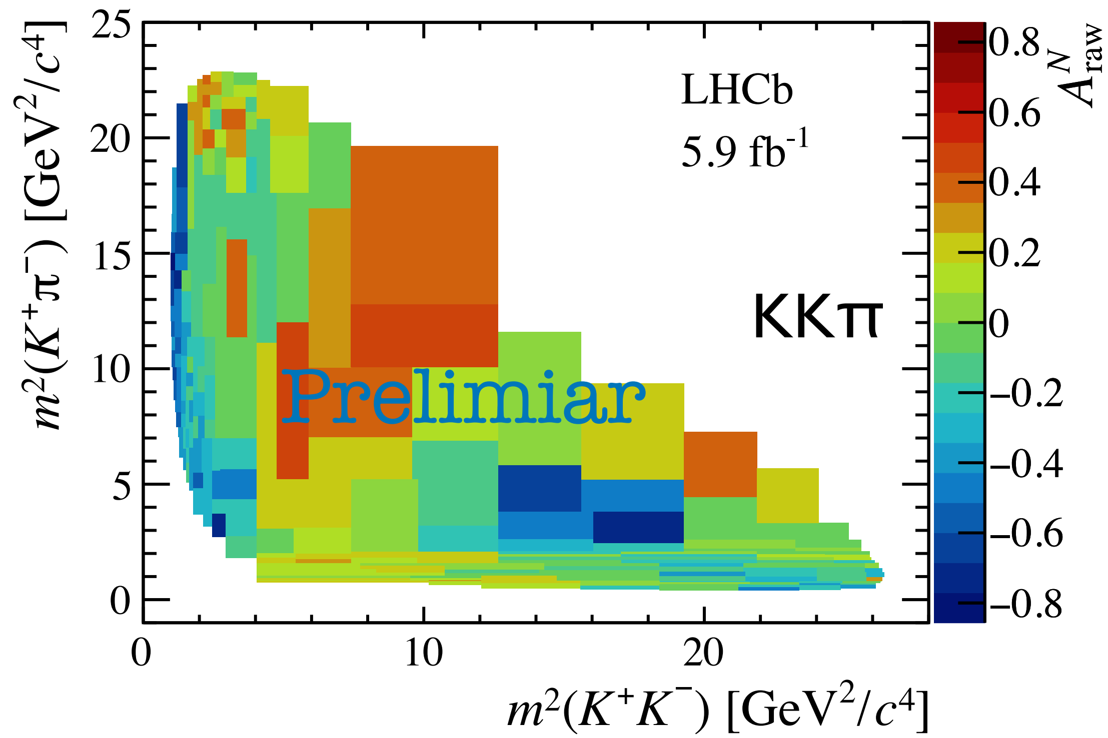

link to CERN seminar