Charmless B decays at LHCb

R. Cardinale on behalf of the LHCb Collaboration

University of Genova and INFN Genova

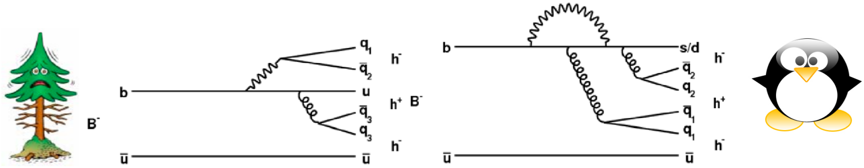
LHCP 2014 - New York - 2-7 June 2014

Outline

- Why charmless B decays?
- The LHCb detector
- Search for $\Lambda_b^0(\Xi_b^0) \to K_s^0 p h^-$ [JHEP04 (2014) 087]
- Effective lifetime measurements of the $B_s^0 \to K^+K$, $B^0 \to K^+\pi^-$ and $B_s^0 \to \pi^+K^-$ decays - PRELIMINARY [LHCb-PAPER-2014-011]
- Measurement of CP violation in the phase space of $B^\pm \to K^+K^-\pi^\pm$ and $B^\pm \to \pi^+\pi^-\pi^\pm$ [PRL 112, 011801 (2014)]
- Measurement of polarization amplitudes and CP asymmetries in $B^0 \to \phi K^{*0}$ decays [arXiv:1403.2888]

Why charmless B decays?

Charmless decays have many great features:

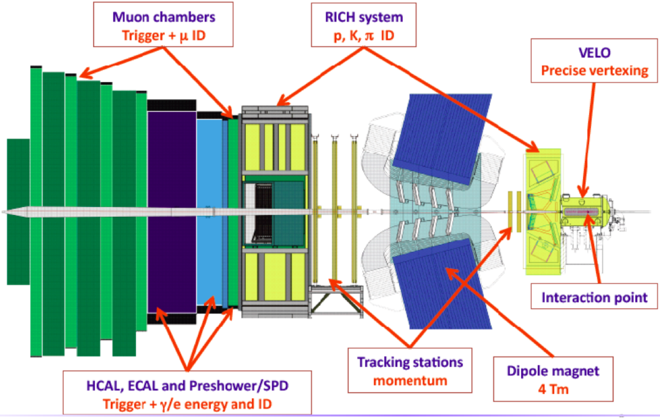


- Contributions from tree and penguin diagrams
- Potential for direct CP violation
- Sensitive to CKM angles
- Possible contributions from new physics particles in the loop
- Can search for signs of new physics such as enhanced branching fractions, anomalous CP asymmetries or polarizations

LHCb Detector

LHCb is an excellent place to look for charmless B decays:

- Efficient hadron trigger
- Precise vertexing
- Excellent particle identification



Search for $\Lambda_b^0(\Xi_b^0) \to K_s^0 p h^-$

JHEP04 (2014) 087

$1\,\mathrm{fb}^{-1}$

Search for $\Lambda_b^0(\Xi_b^0) \to K_s^0 p h^-$

- Study of b-baryons is almost an unexplored field: growing interest in baryonic modes
- b-baryon not yet observed decaying to charmless three-body final states
- Possibility to search for CP violation

Objectives

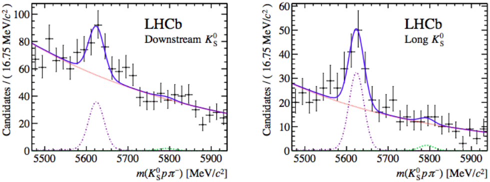
- Search for the unobserved decays $\Lambda_b(\Xi_b) \to K_s p\pi$ and $K_s pK$ decays (and intermediate charm states)
- Measure the BF (set upper limits) using $B^0 \to K_s\pi^+\pi^-$ as normalisation channel
- Extract $\mathcal{A}_{\rm CP}$

$\Lambda_b^0 \to \bar{K}^0 p\pi^-$ observed for the first time [significance level of 8.6σ]

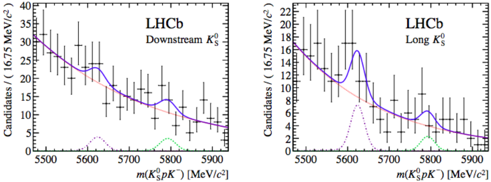
$$\mathcal{B}(\Lambda_b^0 \to \bar{K}^0 p\pi^-) = (1.57 \pm 0.21 \pm 0.08 \pm 0.42 \pm 0.06) \times 10^{-5}$$

uncertainties are statistical, systematics, from $f_{\Lambda_b^0}/f_d$ and from the $\mathcal{B}(B^0 \to K_s^0\pi^+\pi^-)$

$\Lambda_b^0, \Xi_b^0 \to K_s^0 p\pi^-$



$\Lambda_b^0, \Xi_b^0 \to K_s^0 pK^-$



No observation of other considered modes, estimate of ULs

$f_{\Xi_b^0}/f_d \times \mathcal{B}(\Xi_b^0 \to \bar{K}^0 p\pi^-) <$ $1.6(1.8) \times 10^{-6}$ @ $90\%(95\%)$ CL

$\mathcal{B}(\Lambda_b^0 \to K^0 pK^- < 3.5(4.0) \times 10^{-6}$ @ $90\%(95\%)$ CL

$f_{\Xi_b^0}/f_d \times \mathcal{B}(\Xi_b^0 \to \bar{K}^0 pK^-) <$ $1.1(1.2) \times 10^{-6}$ @ $90\%(95\%)$ CL

First measurement of phase-space integrated CP asymmetry:

$$\mathcal{A}^{\rm CP}(\Lambda_b^0 \to \bar{K}_s^0 p\pi^-) = (0.22 \pm 0.13 \pm 0.03)$$

Effective lifetime measurements of the $B_s^0 \to K^+K^-$, $B^0 \to K^+\pi^-$ and $B_s^0 \to \pi^+K^-$ decays

PRELIMINARY

LHCb-PAPER-2014-011

$1\,\mathrm{fb}^{-1}$

$B_s^0 \to h^+h'^-$ lifetime

- Special behaviour for $B_s^0 \to K^+K^-$ decay time: the decay consists almost entirely of the light mass eigenstate (CP even final state)
- Ignoring high order of $\Delta\Gamma_s/\Gamma_s$:

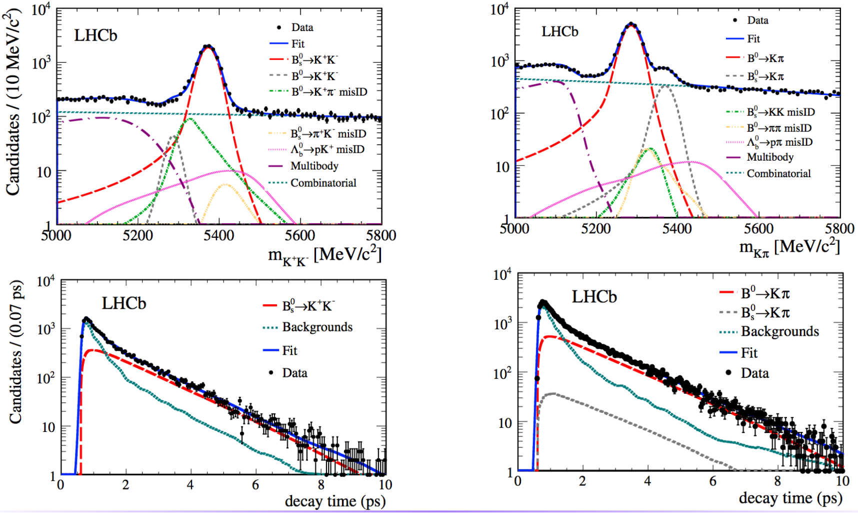
$$\tau_{K^+K^-} \sim \tau_{B_s^0}(1 + \frac{A_{\Delta\Gamma_s}\Delta\Gamma_s}{2\Gamma_s})$$

- Measure the $B_s^0 \to K^+K^-$ effective lifetime: useful to constrain the B_s mixing phase and the CP violating parameter $A_{\Delta\Gamma_s}$
- Put constraints on contributions from new physical phenomena to the B_s^0 system
- With SM predictions: $A_{\Delta\Gamma}(B_s^0 \to K^+K^-) = \frac{-2Re(\lambda)}{(1+|\lambda|^2)} = -0.97^{+0.014}_{-0.009}$ and $\Delta\Gamma_s/\Gamma_s = 0.123 \pm 0.017$ [arXiv: 1207.1158]

$$(\frac{\tau_{K^+K^-}}{\tau_{B_s}})_{\mathrm{SM}} = 0.940 \pm 0.008$$

- In addition measurement of the $B^0 \to K^+\pi^-$ and $B_s^0 \to K^+\pi^-$ lifetimes: contributes to the world average of $\tau(B^0)$ and $\tau(B_s^0)$.

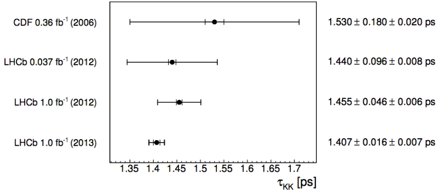
- Data driven method to determine the decay time acceptance function per event: move primary vertices along the B momentum direction and re-run the selection for all the hypothetical lifetimes (Swimming technique)
- Factorised fit: mass and lifetime assumed uncorrelated

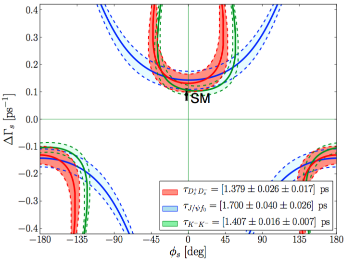


Results [PRELIMINARY]

$B_s^0 \to K^+K^-$: Best measurement! [PRELIMINARY]

$$\tau_{B_s^0 \to K^+K^-} = 1.407 \pm 0.016(stat) \pm 0.007(syst)\ \text{ps}$$





Previous 2012 LHCb result used a prescaled trigger in order to avoid bias in the lifetime [PLB 716 (2012) 393]

$B^0 \to K^+\pi^-$ and $B_s^0 \to K^+\pi^-$: contribute to the average $\tau(B^0)$ and $\tau(B_s^0)$

$$\tau_{B^0 \to K^+\pi^-} = 1.524 \pm 0.011(stat) \pm 0.004(syst)\ \text{ps}$$ [PRELIMINARY]

$$\tau_{B_s^0 \to \pi^+K^-} = 1.56 \pm 0.006(stat) \pm 0.01(syst)\ \text{ps}$$ [PRELIMINARY]

Measurement of CP violation in the phase space of $B^{\pm} \to K^{+}K^{-}\pi^{\pm}$ and $B^{\pm} \to \pi^{+}\pi^{-}\pi^{\pm}$

PRL 112, 011801 (2014)

$1\,\mathrm{fb}^{-1}$

CP violation in the phase-space of $B^+ \to K^+K^-\pi^+$ and $B^+ \to \pi^+\pi^-\pi^+$

- Motivated by large CP violation observed in two-body charmless decays
- Two possible sources of CPV:
  - Interference between resonant and non-resonant contributions (large strong phase differences)
  - $KK \leftrightarrow \pi\pi$ rescattering: introduction of additional strong phases which could increase CP asymmetry

Inclusive asymmetries

- Raw asymmetry extracted from unbinned maximum likelihood fit to the B mass

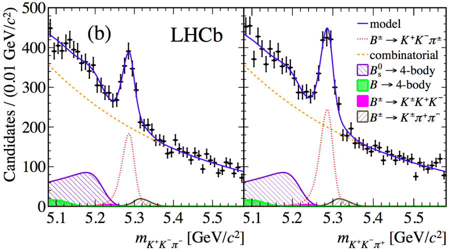
$$A_{\rm CP} = A_{\rm raw} - A_D(\pi^\pm) - A_P(B^+)$$

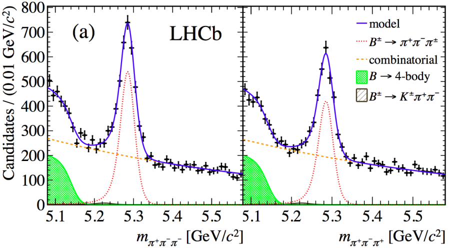
  - $A_D(\pi^\pm)$ is the $\pi^\pm$ detection asymmetry: calculated using the ratio of full to partially reconstructed $D^{*+} \to \pi^+ D^0$ decays [PLB 713 (2012) 186195]
  - $A_P(B^+)$ is the $B^\pm$ production asymmetry calculated using $B^+ \to J/\psi K^+$ as control channel

Inclusive asymmetry

$$B^+ \to K^+ K^- \pi^+$$
$$N = 1870 \pm 133$$

$$B^+ \to \pi^+ \pi^- \pi^+$$
$$N = 4904 \pm 148$$





$$A_{\rm CP}(B^+ \to K^+ K^- \pi^+) = -0.141 \pm 0.040(stat) \pm 0.018(syst) \pm 0.007(A_{\rm CP}(J/\psi K))$$

significance: 3.2σ

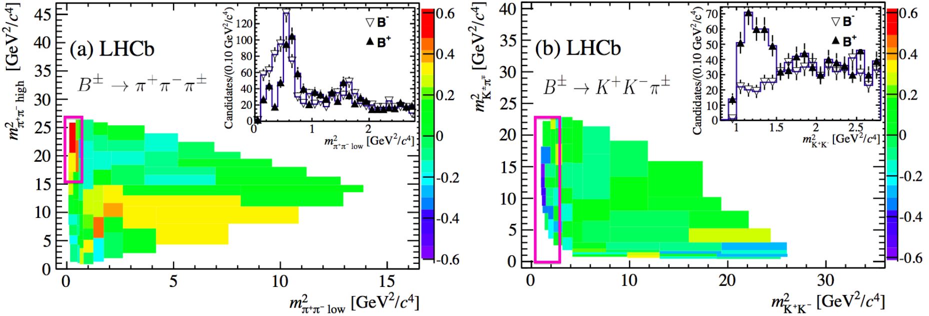
$$A_{\rm CP}(B^+ \to \pi^+ \pi^- \pi^+) = 0.117 \pm 0.021(stat) \pm 0.009(syst) \pm 0.007(A_{\rm CP}(J/\psi K))$$

significance: 4.9σ

CP asymmetry in Dalitz phase space

Large local asymmetries in certain areas of the phase space:

- $m^2_{\pi^+\pi^-\,high} > 15\,\mathrm{GeV}^2/c^2$ and $m^2_{\pi^+\pi^-\,low} > 0.4\,\mathrm{GeV}^2/c^2$
- $m^2_{K^+K^-} < 1.5\,\mathrm{GeV}^2/c^2$



Regional asymmetry: not associated to resonances

$$A_{CP}(B^+ \to K^+K^-\pi^+) = -0.648 \pm 0.070(stat) \pm 0.013(syst) \pm 0.007(A_{CP}(J/\psi K))$$
$$A_{CP}(B^+ \to \pi^+\pi^-\pi^+) = -0.584 \pm 0.082(stat) \pm 0.027(syst) \pm 0.007(A_{CP}(J/\psi K))$$

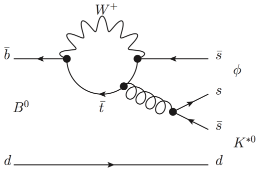
Measurement of polarization amplitudes and CP asymmetries in $B^0 \to \phi K^{*0}$ decays

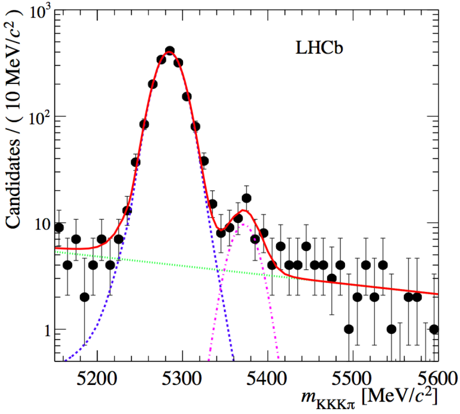
arXiv:1403.2888

$1\,\mathrm{fb}^{-1}$

Motivation for $B^0 \to \phi K^*$

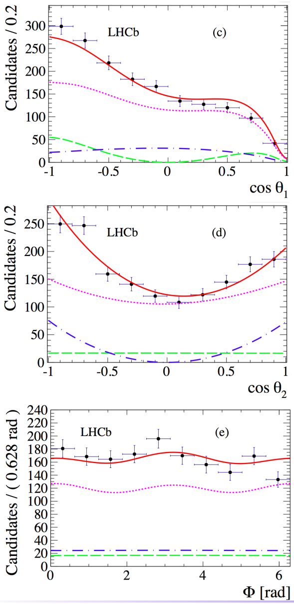
- FCNC process: proceeds via gluonic penguin diagram
- New physics can enter in the loop
- Longitudinal polarisation $f_L \simeq 1$. Measured $f_L \sim 0.5$ [BaBar PRD 78(2008), 092008; Belle PRD88(2013)072004]

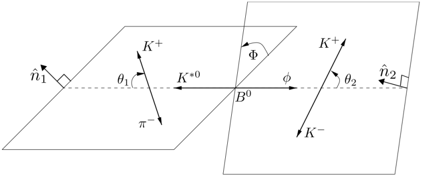




- $N(B^0) = 1655 \pm 42$
- Measurement of the time-integrated polarisation amplitudes and strong phase differences
- From the angular analysis triple-product asymmetries have been extracted
- Measurement of the direct CP asymmetry

Angular Analysis





- $P \to VV$ decay needs angular analysis to disentangle helicity structure
  - Three P-wave contributions: f_L, $f_\perp$, $f_\parallel$ + strong phases $\delta_\perp$, $\delta_\parallel$
  - Two S-wave contributions from $B^0 \to \phi K^+\pi^-$ and $B^0 \to K^*(892)^0 K^+K^-$ which give two additional amplitudes $A_s^{K\pi}$ and A_s^{KK} and phases $\delta_s^{K\pi}$ and δ_s^{KK}
  - Unbinned maximum likelihood fit to angles and K^+K^- and $K^+\pi^-$ masses

$B^0 \to \phi K^*$ results

$$f_{\rm L} = 0.497 \pm 0.019(stat) \pm 0.015(sys)$$

$$f_{\perp} = 0.221 \pm 0.016(stat) \pm 0.013(sys)$$

$$f_s(K\pi) = 0.143 \pm 0.013(stat) \pm 0.012(sys)$$

$$f_s(KK) = 0.122 \pm 0.013(stat) \pm 0.008(sys)$$

$$\delta_{\perp} = 2.633 \pm 0.062(stat) \pm 0.037(sys)$$

$$\delta_{\parallel} = 2.562 \pm 0.069(stat) \pm 0.040(sys)$$

$$A_0^{\rm CP} = -0.003 \pm 0.038(stat) \pm 0.005(sys)$$

$$A_{\perp}^{\rm CP} = +0.047 \pm 0.072(stat) \pm 0.0059(sys)$$

$$\delta_{\perp}^{\rm CP} = +0.062 \pm 0.062(stat) \pm 0.006(sys)$$

$$\delta_{\parallel}^{\rm CP} = +0.045 \pm 0.068(stat) \pm 0.015(sys)$$

- Results in agreement with BaBar (PRD 78(2008) 092008) and Belle (PRD 88(2013) 072004) and a factor ~ 2 more precise
- No dominant longitudinal component
- Significant S-wave contributions
- CP asymmetries in amplitudes and phases compatible with zero
- Largest uncertainty from the understanding of the detector acceptance

Direct CP Asymmetry using reference channel $B^0 \to J/\psi K^{*0}$

$$A_{\rm CP}(B^0 \to \phi K^*) = (1.5 \pm 3.2 \pm 0.5)\%$$

No CPV observed

Triple Product Asymmetry

- Triple product asymmetry can be evaluated using combination of the polarisation amplitudes and phases extracted from the angular analysis
- Non zero triple-product asymmetries:
  - T-violation ("True")
  - Final state interactions ("Fake")

$$A^i_{T(true)} = \frac{1}{2}(A^i_{T(B)} + A^i_{T(\bar{B})})$$

$$A^i_{T(fake)} = \frac{1}{2}(A^i_{T(B)} - A^i_{T(\bar{B})})$$

- $A^i_{T(true)}$ predicted to be zero in the SM

$$\begin{aligned}
A^1_{T(true)} &= -0.007 \pm 0.012\,(\text{stat}) \pm 0.002\,(\text{syst}) \\
A^2_{T(true)} &= +0.004 \pm 0.014\,(\text{stat}) \pm 0.002\,(\text{syst}) \\
A^3_{T(true)} &= +0.004 \pm 0.006\,(\text{stat}) \pm 0.001\,(\text{syst}) \\
A^4_{T(true)} &= +0.002 \pm 0.006\,(\text{stat}) \pm 0.001\,(\text{syst}) \\
A^1_{T(fake)} &= -0.105 \pm 0.012\,(\text{stat}) \pm 0.005\,(\text{syst}) \\
A^2_{T(fake)} &= -0.017 \pm 0.014\,(\text{stat}) \pm 0.003\,(\text{syst}) \\
A^3_{T(fake)} &= -0.063 \pm 0.006\,(\text{stat}) \pm 0.005\,(\text{syst}) \\
A^4_{T(fake)} &= -0.019 \pm 0.006\,(\text{stat}) \pm 0.007\,(\text{syst})
\end{aligned}$$

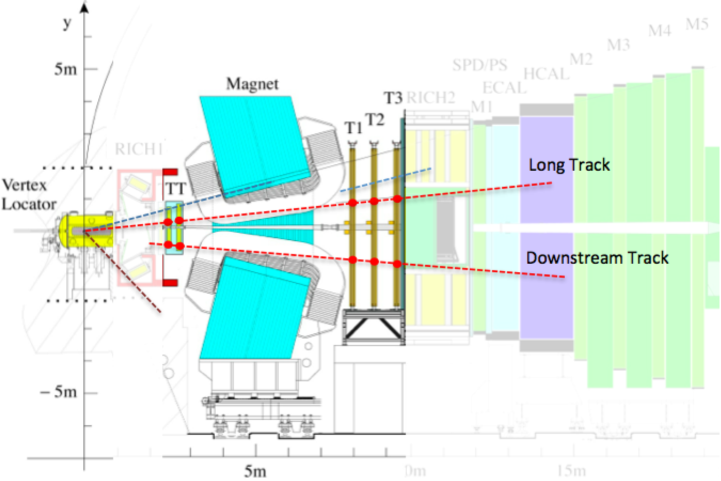
- True asymmetries compatible with zero: no evidence of CP violation
- Non zero fake asymmetries: presence of final state interactions

Conclusions

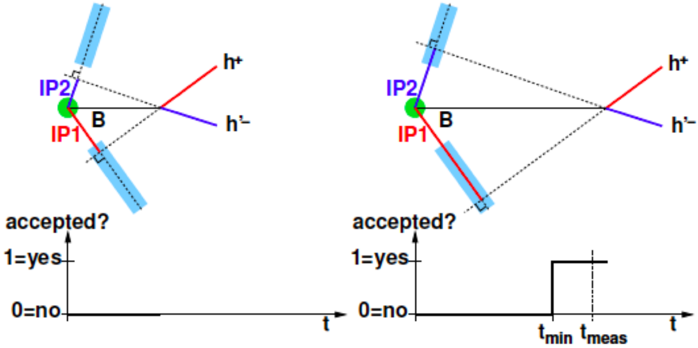
- Charmless b-hadron decays are good probe to test the SM and search for new physics
- Several new results from LHCb:
  - Observation of new modes including baryon decays: $\Lambda_b^0 \to K_s^0 p \pi^-$
  - Lifetime measurements: $B_s^0 \to h^+ h^{'-}$
  - Measurement of global and local CP asymmetries: $B^0 \to \phi K^{*0}$, $B^+ \to K^+ K^- \pi^+$ and $B^+ \to \pi^+ \pi^- \pi^+$
- Many other analysis on-going
- Plenty of charmless channels still to explore
- $\sim 2\,\mathrm{fb}^{-1}$ of data on tape to analyse and larger data sample $\sim 9\,\mathrm{fb}^{-1}$ expected by 2018

Spare Slides

Downstream and long tracks



Swimming Method



Full Fit Model for $B^0 \to \phi K^*(892)^0$

$$\frac{d^5\Gamma}{d\cos\theta_1 d\cos\theta_2 d\Phi dm_{KK} dm_{K\pi}} = \frac{9}{8\pi}\sum_{i=1}^{15} K_i\ f_i(\theta_1,\theta_2,\Phi)\ \mathcal{M}_i(m_{K\pi}, m_{KK}) d\Phi_4(K,K,K,\pi)$$

K_i: polarisation amplitudes, f_i: angle dependent term, M_i: mass dependent term and $d\phi_4$: phase space

i	A	$f_i\ (\theta_1,\theta_2,\Phi)$	$\mathcal{M}_i(m_{K\pi}, m_{KK})$
1	$\lvert A_0\rvert^2$	$\cos\theta_1^2 \cos\theta_2^2$	$M_1(K\pi)^2 M_1^*(KK)^2$
2	$\lvert A_\parallel\rvert^2$	$\frac{1}{4}\sin\theta_1^2 \sin\theta_2^2(1+\cos(2\Phi))$	$M_1(K\pi)^2 M_1^*(KK)^2$
3	$\lvert A_\perp\rvert^2$	$\frac{1}{4}\sin\theta_1^2 \sin\theta_2^2(1-\cos(2\Phi))$	$M_1(K\pi)^2 M_1^*(KK)^2$
4	$A_\perp A_\parallel^*$	$-\frac{1}{2}\sin\theta_1^2 \sin\theta_2^2 \sin(2\Phi)$	$M_1(K\pi)^2 M_1^*(KK)^2$
5	$A_\parallel A_0^*$	$\sqrt{2}\cos\theta_1 \sin\theta_1 \cos\theta_2 \sin\theta_2 \cos\Phi$	$M_1(K\pi)^2 M_1^*(KK)^2$
6	$A_\perp A_0^*$	$-\sqrt{2}\cos\theta_1 \sin\theta_1 \cos\theta_2 \sin\theta_2 \sin\Phi$	$M_1(K\pi)^2 M_1^*(KK)^2$
7	$\lvert A_s^{K\pi}\rvert^2$	$\frac{1}{3}\cos\theta_2^2$	$M_0(K\pi)^2 M_1^*(KK)^2$
8	$A_\parallel A_s^{K\pi*}$	$\frac{\sqrt{6}}{3}\sin\theta_1 \cos\theta_2 \sin\theta_2 \cos\Phi$	$M_1(KK)^2 M_0^*(K\pi)$
9	$A_\perp A_s^{K\pi*}$	$-\frac{\sqrt{6}}{3}\sin\theta_1 \cos\theta_2 \sin\theta_2 \sin\Phi$	$M_1(KK)^2 M_0^*(K\pi)$
10	$A_0 A_s^{K\pi*}$	$\frac{2}{\sqrt{3}}\cos\theta_1 \cos\theta_2^2$	$M_1(KK)^2 M_0^*(K\pi)$
11	$\lvert A_s^{KK}\rvert^2$	$\frac{1}{3}\cos\theta_1^2$	$M_0^2(KK) M_1^*(K\pi)^2$
12	$A_\parallel A_s^{KK*}$	$\frac{\sqrt{6}}{3}\sin\theta_1 \cos\theta_1 \sin\theta_2 \cos\Phi$	$M_1(K\pi)^2 M_0^*(KK)$
13	$A_\perp A_s^{KK*}$	$-\frac{\sqrt{6}}{3}\sin\theta_1 \cos\theta_1 \sin\theta_2 \sin\Phi$	$M_1(K\pi)^2 M_0^*(KK)$
14	$A_0 A_s^{KK*}$	$\frac{2}{\sqrt{3}}\cos\theta_1^2 \cos\theta_2$	$M_1(K\pi)^2 M_0^*(KK)$
15	$A_s^{K\pi} A_s^{KK*}$	$\frac{2}{3}\cos\theta_1 \cos\theta_2$	$M_0(K\pi) M_0^*(KK)$

Triple Product Definition

$$A_T^1 = -\frac{4}{\pi}\mathcal{I}m(A_\perp A_0^*)$$

$$A_T^2 = -\frac{2\sqrt{2}}{\pi}\mathcal{I}m(A_\perp A_\parallel^*)$$

$$A_T^3 = \frac{\Gamma(s_{\theta_1}\sin\Phi > 0) - \Gamma(s_{\theta_1}\sin\Phi < 0)}{\Gamma(s_{\theta_1}\sin\Phi > 0) + \Gamma(s_{\theta_1}\sin\Phi < 0)}$$
$$= -\sqrt{\frac{3}{2}}\int |M_1^{KK}(m_{KK})|^2\mathcal{I}m(A_\perp A_{\mathrm{S}}^{*K\pi} M_1^{K\pi}(m_{K\pi})M_0^{*K\pi}(m_{K\pi}))dm_{KK}dm_{K\pi}$$

$$A_T^4 = \frac{\Gamma(s_{\theta_2}\sin\Phi > 0) - \Gamma(s_{\theta_2}\sin\Phi < 0)}{\Gamma(s_{\theta_2}\sin\Phi > 0) + \Gamma(s_{\theta_2}\sin\Phi < 0)}$$
$$= -\sqrt{\frac{3}{2}}\int |M_1^{K\pi}(m_{K\pi})|^2\mathcal{I}m(A_\perp A_{\mathrm{S}}^{*KK} M_1^{KK}(m_{KK})M_0^{*KK}(m_{KK}))dm_{KK}dm_{K\pi}$$