Exploring an alternative model of the long-distance contributions to $\bar{B}^0 \to \bar{K}^{0*}\mu^+\mu^-$ transitions 1709.03921.

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- Present an empirical model of the long-distance contributions to $\bar{B}^0 \to \bar{K}^{0*}\mu^+\mu^-$ transitions.
- Simple approach that allows to extract short-distance components while capturing resonant structures across the full dimuon mass spectrum.
    - Our model of long-distance effects is not meant as a formal prediction for various hadronic contributions.
- Interference between short- and long-distance amplitudes could mimic New Physics.

Modeling short- and long-distance contributions

- The differential decay rate of $\bar{B}^0 \to \bar{K}^{0*}(892)\mu^+\mu^-$ transitions depends on 6 complex amplitudes, $A_0^{L,R}, A_\parallel^{L,R}, A_\perp^{L,R}$.

$$\mathcal{A}_0^{\mathrm{L,R}}(q^2) = -8N\frac{m_B m_{K^*}}{\sqrt{q^2}}\left\{(C_{9\,0}^{\mathrm{eff}} \mp C_{10})A_{12}(q^2) + \frac{m_b}{m_B + m_{K^*}}C_7 T_{23}(q^2)\right\},$$

$$\mathcal{A}_\parallel^{\mathrm{L,R}}(q^2) = -N\sqrt{2}(m_B^2 - m_{K^*}^2)\left\{(C_{9\,\parallel}^{\mathrm{eff}} \mp C_{10})\frac{A_1(q^2)}{m_B - m_{K^*}} + \frac{2m_b}{q^2}C_7 T_2(q^2)\right\},$$

$$\mathcal{A}_\perp^{\mathrm{L,R}}(q^2) = N\sqrt{2\lambda}\left\{(C_{9\,\perp}^{\mathrm{eff}} \mp C_{10})\frac{V(q^2)}{m_B + m_{K^*}} + \frac{2m_b}{q^2}C_7 T_1(q^2)\right\},$$

Wilson Coefficients Form Factors

- Form Factors are taken from a combination of Light Cone Sum Rules (LCSM) and Lattice QCD (LQCD) results given in, Straub et al, JHEP08(2016)098.

Long distance contributions

- Empirical model using relativistic Breit-Wigners to model resonant contributions (a similar approach as $B \to K^+\mu^+\mu^-$, PAPER-2016-045).
- Incorporate many hadronic contributions: $J/\psi, \psi(2S), \rho(770), \phi(1020), \psi(3770), \psi(4040), \psi(4160)$.
- We group the resonant contributions into the Wilson Coefficient C_9

$$\Delta C_{9\,\lambda}^{\rm had}(q^2) = \sum_j \boxed{\eta_j^\lambda} e^{i\boxed{\theta_j^\lambda}} \boxed{A_j^{\rm res}(q^2)},$$

Breit-Wigner

Magnitude and phase
of each resonant amplitude relative to C_9

$$\Delta C_{9\,\lambda}^{\rm had}(q^2) = \sum_j \boxed{\eta_j^\lambda} e^{i\boxed{\theta_j^\lambda}} \boxed{A_j^{\rm res}(q^2)},$$

Breit-Wigner

Magnitude and phase
of each resonant amplitude relative to C_9

- Analyses of $B \to VK^*$ decays from LHCb, Belle and BaBar constrain the overall sizes of the magnitudes $\eta_{0,\perp,\parallel}$ and phases $\theta_\parallel, \theta_\perp$.
- The phase, θ_0 is an unknown parameter for each resonance.
- No analyses exist for the $\psi(3770)$,$\psi(4040)$ and $\psi(4160)$.
  - Estimate from $B \to K^* J/\psi$ results and scaling of measurements from $B^+ \to VK^+$.

$$\Delta C_{7\,0}^{\rm had}(q^2) = \frac{m_b}{m_B + m_{K^{*0}}} \frac{T_{23}(q^2)}{A_{12}(q^2)} \boxed{\zeta^0 e^{i\omega^0}},$$

$$\Delta C_{7\,\parallel}^{\rm had}(q^2) = 2\frac{m_b}{q^2}(m_B - m_{K^{*0}}) \frac{T_2(q^2)}{A_1(q^2)} \boxed{\zeta^\parallel e^{i\omega^\parallel}},$$

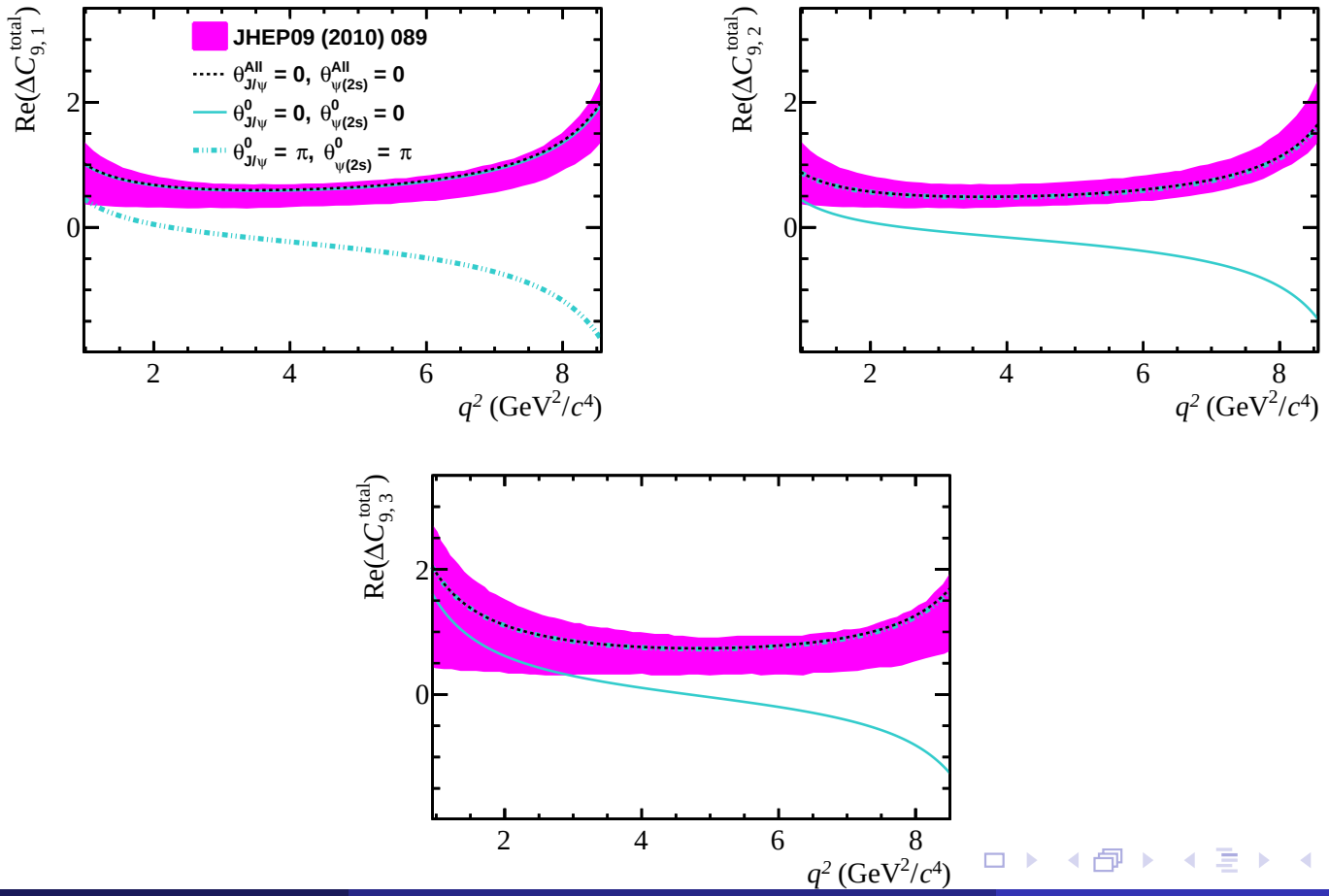
$$\Delta C_{7\,\perp}^{\rm had}(q^2) = 2\frac{m_b}{q^2}(m_B + m_{K^{*0}}) \frac{T_1(q^2)}{V(q^2)} \boxed{\zeta^\perp e^{i\omega^\perp}},$$

Parameters to be determined from experimental measurements

- Include long-distance contributions entering $\Delta C_{7\lambda}^{\rm had}$. Parameters $\zeta_{0,\perp,\parallel}$ and $\omega_{0,\perp,\parallel}$ need to be determined from fit to $B^0 \to K^{*0}\mu^+\mu^-$ data
- Total long distance contribution $= \Delta C_{9\lambda}^{\rm had} + \Delta C_{7\lambda}^{\rm had}$.

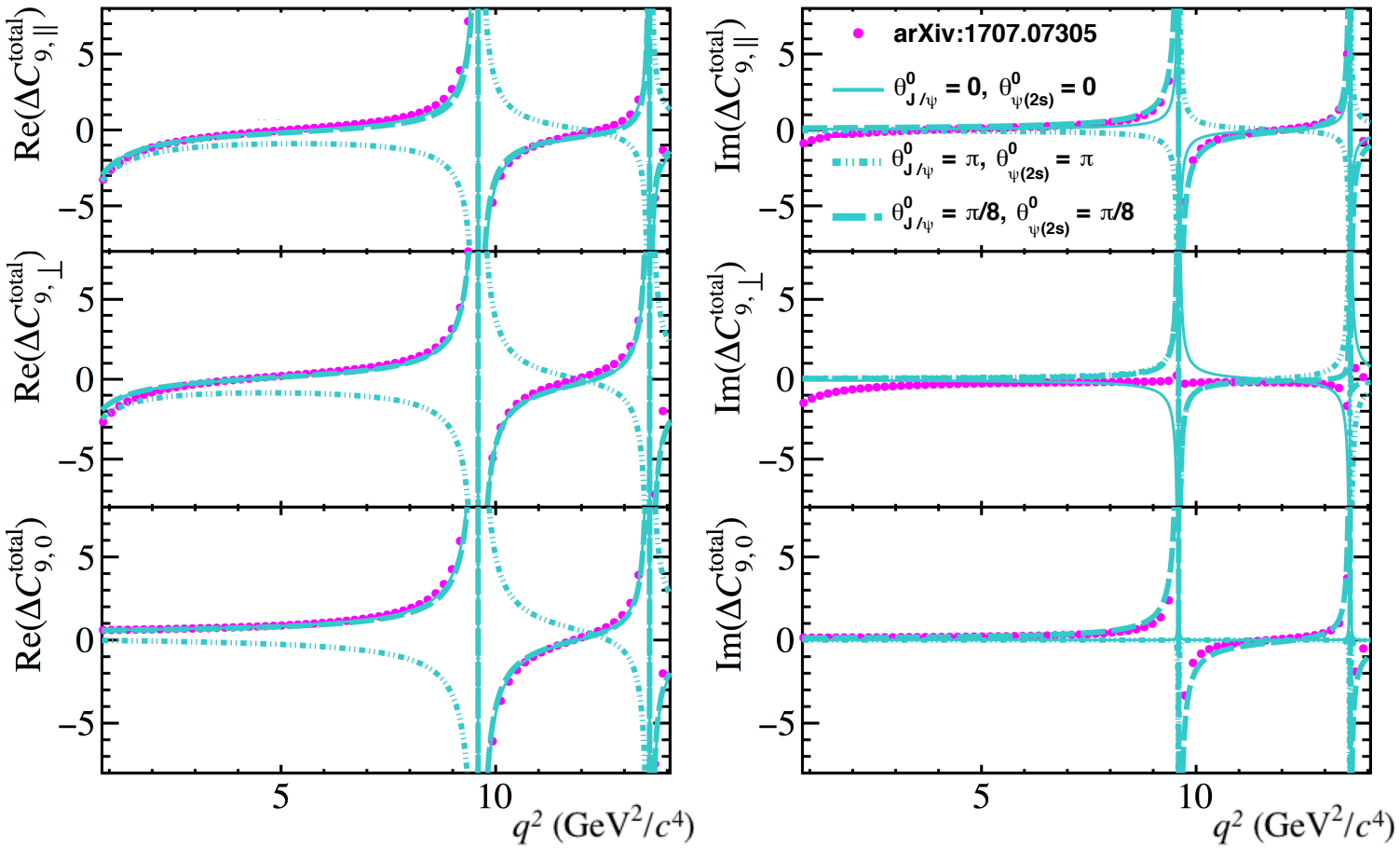
Model 1:

- Compare to model by A. Khodjamirian et al, JHEP09(2010)089.
- The model does not account for strong phases.
- Ignoring all phases gives a good agreement. But when we introduce the measured relative phases, no value of θ_0 can describe the amplitudes simultaneously .



Model 2

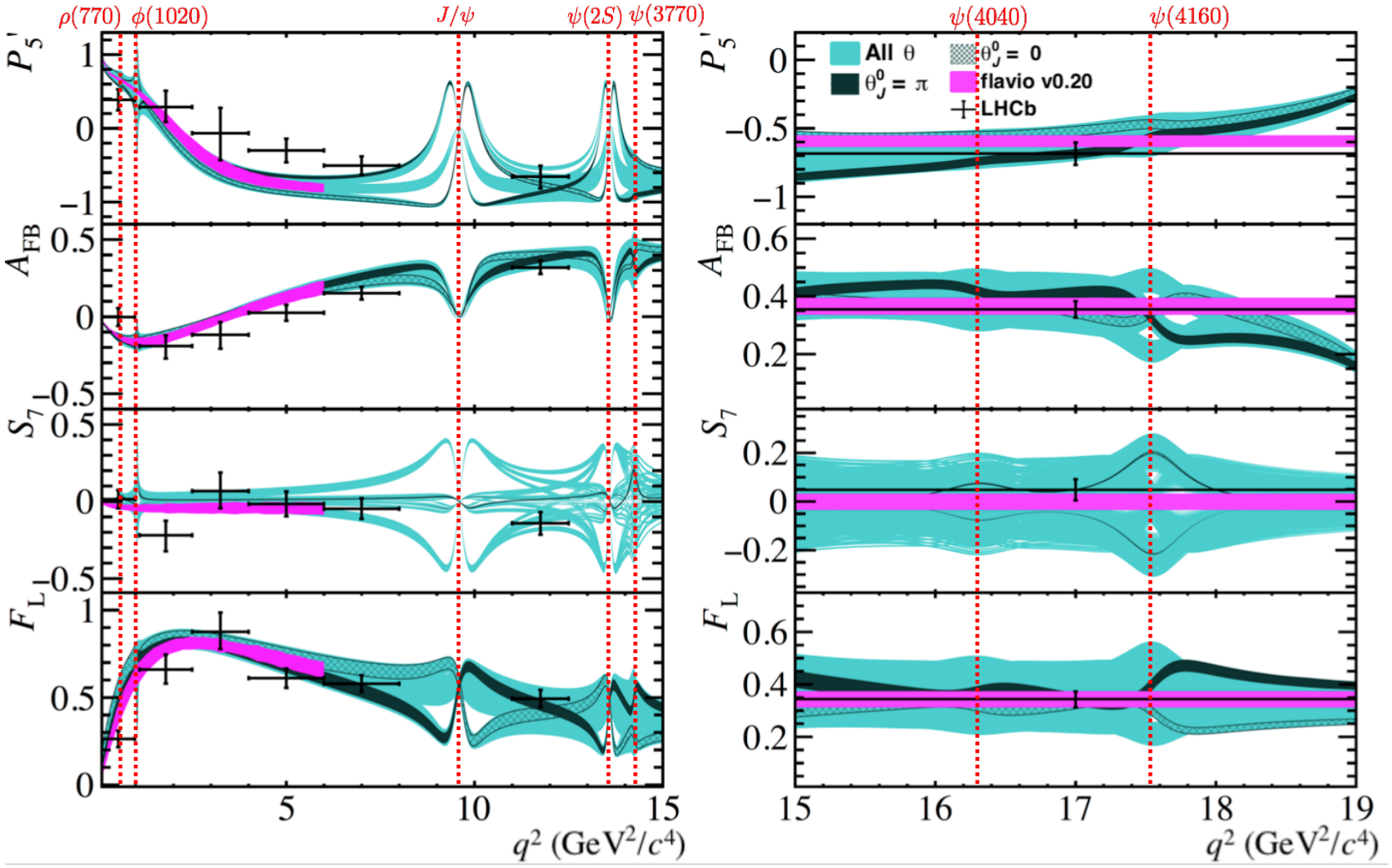
- Compare to model by D. van Dyk et al,1707.07305 as presented earlier .
- For a given choice of phase, there is nice agreement.
- Discrepancy for the imaginary part is understood and comes setting $\omega_\lambda = \pi$. A complex value of ΔC_7^{had} provides a better agreement.



$\bar{B}^0 \to \bar{K}^{0*}\mu^+\mu^-$ angular observables

$CP-$averaged observables

- Our model for $\Delta C_9^{\text{total}}$ can be used to provide predictions for $\bar{B}^0 \to \bar{K}^{0*}\mu^+\mu^-$ angular observables in the SM.
- For each observable scan over all possible combinations of θ_0 for each of the resonances.
- Bands are formed for each phase combination, by the $B \to K^*$ form factor uncertainties which are from combining light cone sum rules and lattice QCD calculations.

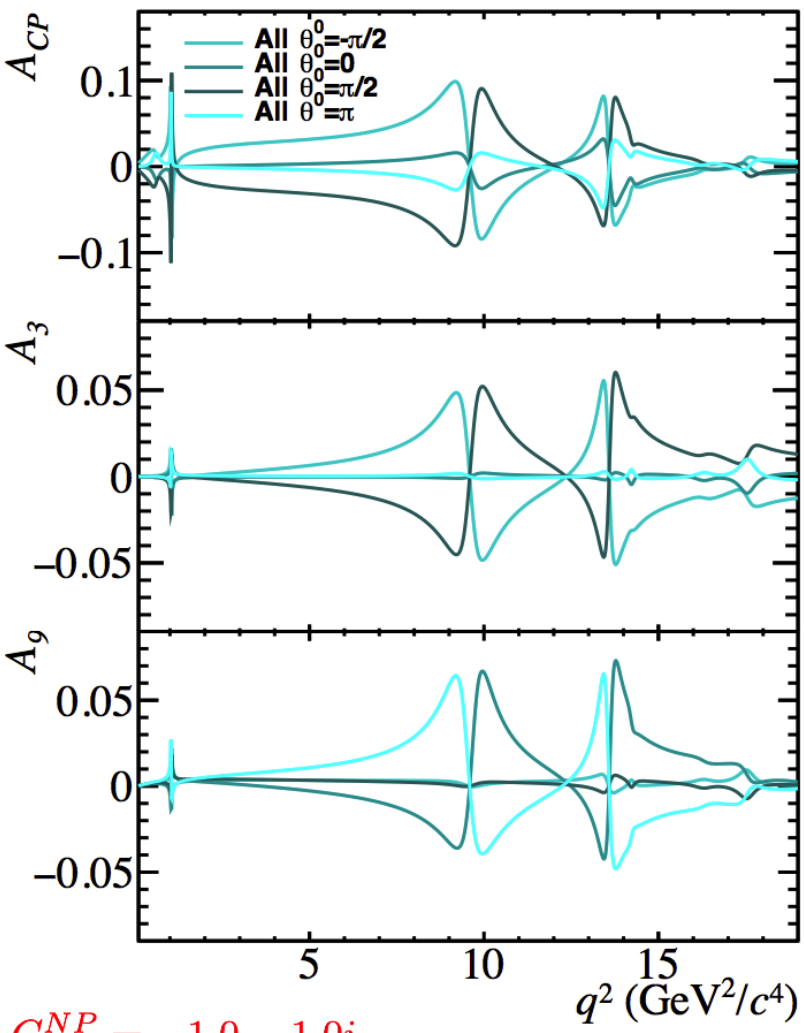


- Distributions of the angular observables as function of q^2, for different phases(cyan), above(right) and below(left) the open charm threshold for regions below.
- Observe S_7 being extremely sensitive to the choice of phases.

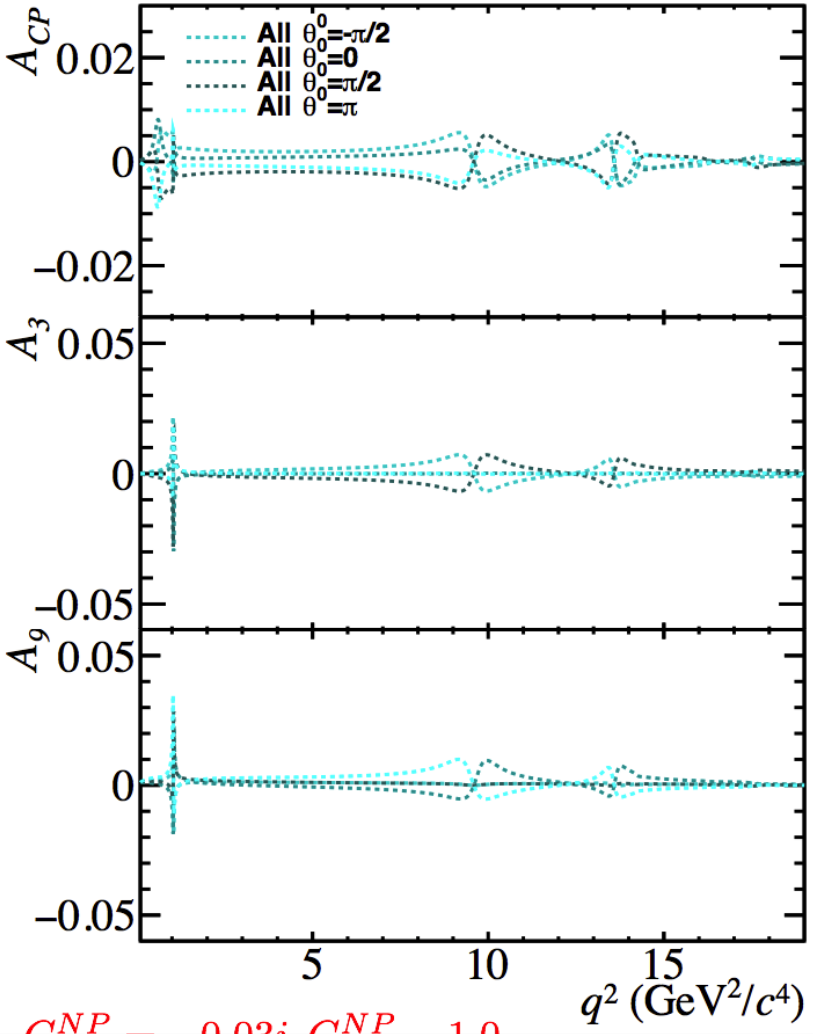
Exploring possible $CP-$violation

$CP-$odd observables

- Since we have a model for the strong phases, we can now explore the impact of CP violation by introducing weak phases.
- A similar method has been done in $D \to Pl^+l^-$ decays PhysRevD.87.054026.
- Determine subset of particularly sensitive $CP-$odd observables.
- Set the relative (strong) phase θ_j^0 for all long distant contributions to $\underline{-\frac{\pi}{2}, 0, \pi, \frac{\pi}{2}}$.
- Determine two scenarios given experimental constraints (Straub et al: JHEP04(2017)027, Kumar Alok et al: PhysRevD.96.015034)
  1. $C_9^{\mathrm{NP}} = -1.0 - 1.0\mathrm{i}$
  2. $C_7^{\mathrm{NP}} = -0.03\mathrm{i}$ and $C_9^{\mathrm{NP}} = -1$



$C_9^{NP} = -1.0 - 1.0i$

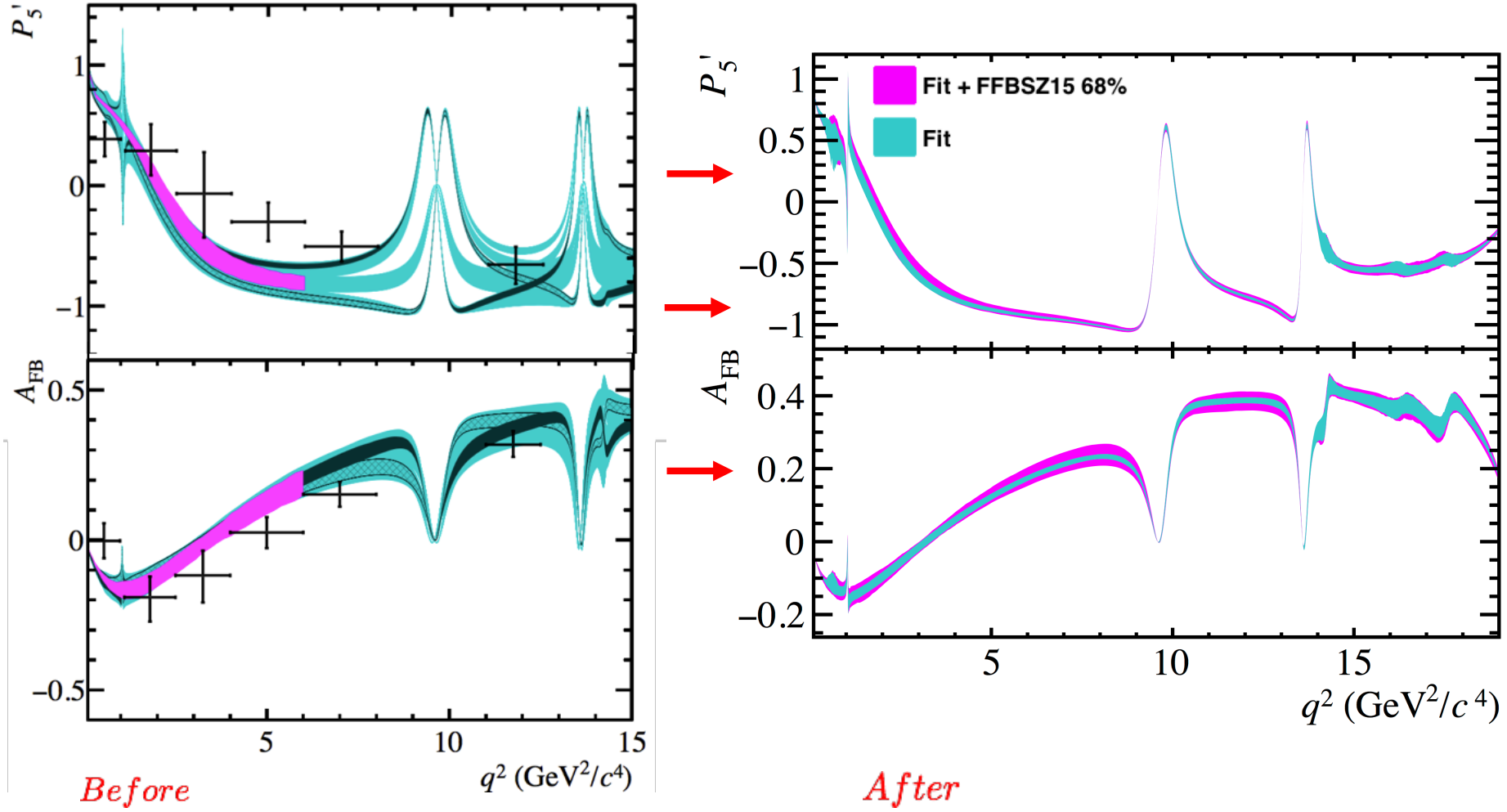


$C_7^{NP} = -0.03i, C_9^{NP} - 1.0$

- Depending on the free phase, θ_j^0, one can enhance CP violation.

Predicted experimental precision

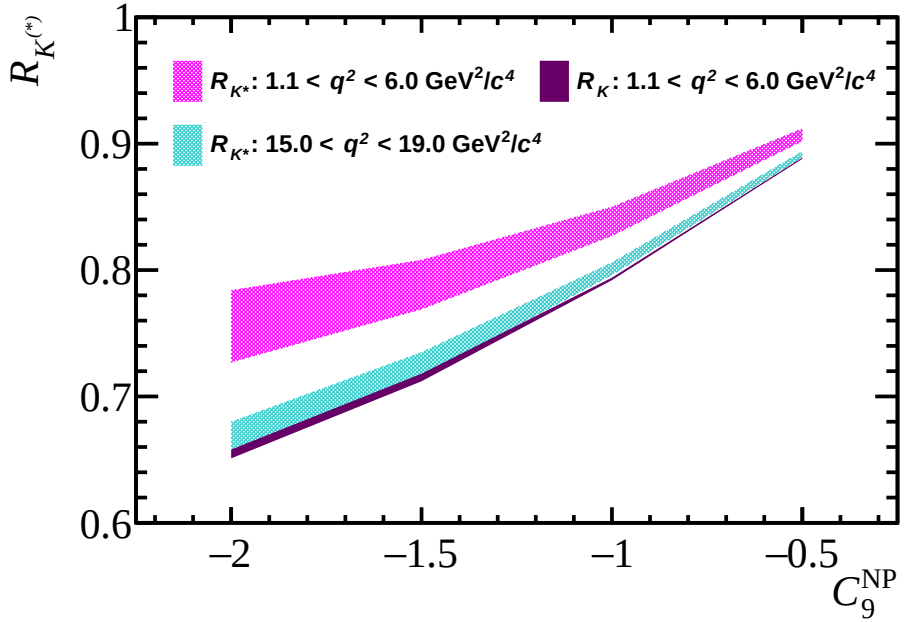
- Generate Monte Carlo equivalent to expected yields in Run 2.
- Include S-wave amplitudes for the J/ψ and $\psi(2S)$, others are minute and so ignored.
- As dealing with narrow hadronic contributions we include detector resolution effects in q^2, applied in both generating and fitting.
- Perform a 4-dimensional fit in $q^2, cos(\theta_L), cos(\theta_K)$ and ϕ.
- Float all resonant amplitudes including the Wilson Coefficients C_9, C_{10}.
- Form Factors fixed in the fit but introduced later as a systematic uncertainty.



- Predictions of the observables P_5' and A_{FB} using the resulting precision from a fit to the model introducing long-distance contributions to $\bar{B}^0 \to \bar{K}^{0*}\mu^+\mu^-$.
- LHCb data can help pin down the phases $\theta_{0,\parallel,\perp}$ for each resonance.

Long-distance effects in tests of lepton universality

- If C_9 is not universal, hadronic effects do not cancel and observables such as R_K and R_K^* cannot be calculated precisely in the SM.
- Predictions for R_K uses long-distance model and has been measured by PAPER-2016-045.
- Consider full variation of θ_0 for each resonance to assess residual dependence of R_K^* on hadronic effects.
- Effect on R_K^* is small but dominates over residual form factor uncertainties (cf Form Factor choice from Capdevila et al:1704.05340).



Conclusions

- Our model will allow a simultaneous measurement of Wilson Coefficients and of multiple strong phases across the whole q^2 region.
- Knowledge of strong phases enables an optimised measurement of CP violating effects.
- The residual dependence of R_K and R_K^* on hadronic effects in the presence of NP was found to be small.

Backup

Wilson Coefficients

Values of the Wilson Coefficients used.

	Value
C_9	4.27
$C_9^{'}$	0
C_{10}	-4.166
$C_{10}^{'}$	0
C_7	-0.304
$C_7^{'}$	-0.006