New Physics at Belle II – Feb 23-25th 2015

Phenomenology of $B \to K\pi\pi$ modes and Prospects with LHCb and Belle-II data

Alejandro Pérez Pérez
IPHC – CNRS Strasbourg

On behalf of the CKMfitter Group

Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

Outline

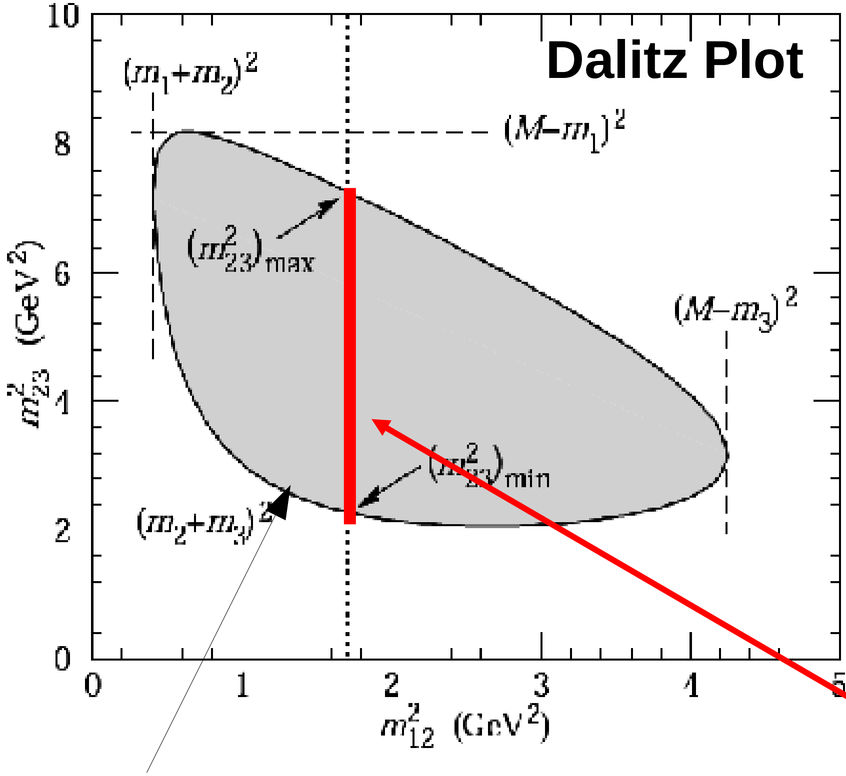
- **Amplitude analyses**
- **The phenomenological framework**
- **Some theoretical scenarios for constraining CKM**
- **Constraints on hadronic amplitudes using the latest $B\to K^*\pi$ measurements**
- **Prospects for future LHCb and Belle-II data**
- **Summary and outlook**

Amplitude Analyses

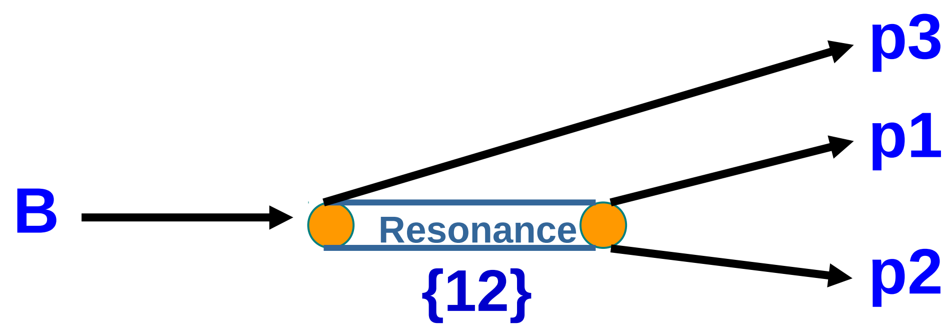
Dalitz Plot (DP)

Three body decays described by two parameters

Mandelstam variables $m_{ij}^2 = (p_i + p_j)^2$



Kinematic boundary



$$P \rightarrow P_{res} + p_3$$

$$P_{res} \rightarrow p_1 + p_2$$

(Distribution around resonance mass)

Amplitude Analyses: Parametrization

Parametrizing Decay amplitude using Isobar Model:

Dalitz Plot Isobar Model

$$\begin{cases} A(DP) = \sum a_j F_j(DP) \\ \overline{A}(DP) = \sum \overline{a}_j \overline{F}_j(DP) \end{cases}$$

Amplitude Analyses: Parametrization

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Shapes of intermediate states over DP

Isobar amplitudes:

Weak phases information

Amplitude Analyses: Parametrization

Parametrizing Decay amplitude using Isobar Model:

Dalitz Plot Isobar Model

$$\begin{cases} A(DP) = \sum a_j \boxed{F_j(DP)} \\ \overline{A}(DP) = \sum \overline{a}_j \boxed{\overline{F}_j(DP)} \end{cases}$$

Shapes of intermediate states over DP

$$\boxed{F_j^L(DP) = R_j(m) \times X_L(|\vec{p}^\star|r) \times X_L(|\vec{q}|r) \times T_j(L,\vec{p},\vec{q})}$$

Line-shape

Kinematic part

For B→Kππ

Relativistic Breit-Wigner:	K*(892)π
Flatté:	f_0(980)K
Gounaris-Sakurai:	ρ(770)K
S-wave Kπ:	LASS
Non-resonant:	Different parameterizations
Other contributions:	

Amplitude Analyses: Parametrization

Parametrizing Decay amplitude using Isobar Model:

Dalitz Plot Isobar Model

$$\begin{cases} A(DP) = \sum a_j F_j(DP) \\ \overline{A}(DP) = \sum \overline{a}_j \overline{F}_j(DP) \end{cases}$$

Time-dependent DP PDF **(|q/p| = 1)**

$$f(\Delta t, DP, q_{\rm tag}) \propto \left(|A|^2 + |\bar{A}|^2\right) \frac{e^{-|\Delta t|/\tau}}{4\tau}$$
$$\left(1 + q_{\rm tag} \underbrace{\frac{2\mathcal{I}m[(q/p)\bar{A}A^*]}{|A|^2 + |\bar{A}|^2}}_{\text{mixing and decay CPV}} \sin(\Delta m_d \Delta t) - q_{\rm tag} \underbrace{\frac{|A|^2 - |\bar{A}|^2}{|A|^2 + |\bar{A}|^2}}_{\text{Direct CPV}} \cos(\Delta m_d \Delta t)\right)$$

Only different from zero for final states accessible to both B^0 and $\overline{B}^0$

(e.g. $B^0 \to K^0_S \pi^+ \pi^-$)

Amplitude Analyses: Parametrization

Parametrizing Decay amplitude using Isobar Model:

Dalitz Plot Isobar Model

$$\begin{cases} A(DP) = \sum a_j F_j(DP) \\ \bar{A}(DP) = \sum \bar{a}_j \bar{F}_j(DP) \end{cases}$$

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$$f(\Delta t, DP, q_{\rm tag}) \propto (|A|^2 + |\bar{A}|^2)\frac{e^{-|\Delta t|/\tau}}{4\tau}$$
$$\left(1 + q_{\rm tag}\frac{2\mathcal{I}m[(q/p)\bar{A}A^*]}{|A|^2+|\bar{A}|^2}\sin(\Delta m_d \Delta t) - q_{\rm tag}\frac{|A|^2 - |\bar{A}|^2}{|A|^2+|\bar{A}|^2}\cos(\Delta m_d \Delta t)\right)$$

mixing and decay CPV

Direct CPV

Sensitivity to phase difference between amplitudes in the same DP plane (B or $\bar{\mathrm{B}}$)

Sensitivity to phase differences between a_j and $\bar{a}_j$ amplitudes
Includes q/p mixing phase

Amplitude Analyses: Parametrization

Parametrizing Decay amplitude using Isobar Model:

Dalitz Plot Isobar Model

$$\begin{cases} A(DP) = \sum a_j F_j(DP) \\ \overline{A}(DP) = \sum \overline{a}_j \overline{F}_j(DP) \end{cases}$$

Time-dependent DP PDF **(|q/p| = 1)**

$$f(\Delta t, DP, q_{\rm tag}) \propto \left(|A|^2 + |\bar{A}|^2\right) \frac{e^{-|\Delta t|/\tau}}{4\tau}$$

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Complex amplitudes a_j and $\bar{a}_j$ determine DP interference pattern.
Modules and phases can be directly fitted on data

Amplitude Analyses: What can be measured?

- **Any function of the isobar parameters which does not depend on conventions is a physical observable**

- **Examples**
  - Direct CP-asymmetries: $A^{j}_{CP} = \frac{|\bar{a}_j|^2 - |a_j|^2}{|\bar{a}_j|^2 + |a_j|^2}$
  - Branching Fractions: $B_j \propto \iint \left(|a_j|^2 + |\bar{a}_j|^2 \right) F_j(DP)\, dDP$
  - Phase differences in the same B or $\bar{B}$ DP: $\varphi_{ij} = arg\left(a_i / a_j\right)$ $\quad \bar{\varphi}_{ij} = arg\left(\bar{a}_i / \bar{a}_j\right)$
  - Phase differences between B and $\bar{B}$ DP: $\Delta\varphi_j = arg\left(\bar{a}_j / a_j\right)$

- **All amplitude analyses should provide the complete set of isobar parameters together with the full statistical and systematic covariance matrices**
- **This allows to properly use all the available experimental information and to correctly interpret the results**

Amplitude Analyses: the signal model

- Isobar model needs predefined list of components with their lineshapes: **signal model**
- No straightforward way of determining the signal model from theory
- The signal model is mainly determined from data
  - Use previous experimental results to come out with a smart guess of this predefined list $\Rightarrow$ Raw Signal Model (RSM)
  - Use the data to test for additional contributions which could eventually be added to RSM $\Rightarrow$ building of "Nominal Signal Model"
  - Minor contributions treated as systematics **$\Rightarrow$ Model uncertainties**
  - Additional model errors: uncertainties on line-shapes (e.g. non-resonant and $K\pi$ S-wave)
- SU(3) prediction: same components should contribute to SU(3) related final states
  - Final states with high efficiency and low background can be used to build the signal model
  - This model can then be used coherently among SU(3) related final states
  - This implies correlations of the model uncertainties of the SU(3) related final states which need to be evaluated **$\Rightarrow$ currently it is assumed no correlation**

- **We strongly recommend to analyst of all $B\rightarrow hhh$ ($h = \pi$, K) modes to work in coordination, ideally the same set of conventions should be used by all experiments**

Phenomenological Framework

$B \to K^{*}\pi$ System: Isospin relations

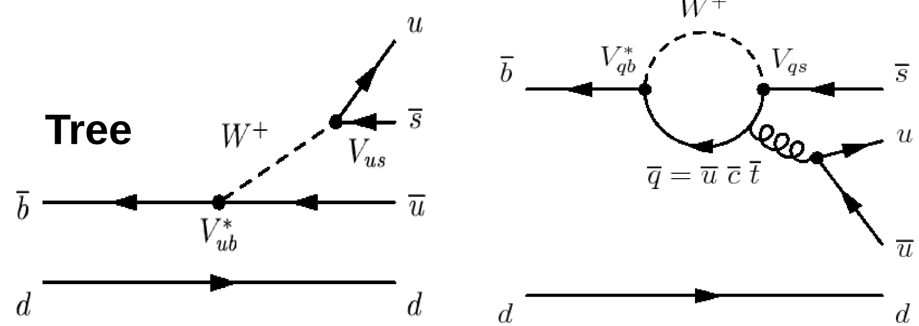
SU(2) Isospin relations:

$$A^{0+} + \sqrt{2}A^{+0} = \sqrt{2}A^{00} + A^{+-}$$

$$\overline{A}^{0+} + \sqrt{2}\overline{A}^{+0} = \sqrt{2}\overline{A}^{00} + \overline{A}^{+-}$$

$B^0 \to K^{*+}\pi^-$

Penguin



(S)

$$A(B^0 \to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P^{+-}$$

$$A(B^+ \to K^{*0}\pi^+) = V_{us}V^*_{ub}N^{0+} + V_{ts}V^*_{tb}(-P^{+-}+P^{C}_{EW})$$

$$\sqrt{2}A(B^+ \to K^{*+}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00}_{C}-N^{0+}) + V_{ts}V^*_{tb}(P^{+-}-P^{C}_{EW}+P_{EW})$$

$$\sqrt{2}A(B^0 \to K^{*0}\pi^0) = V_{us}V^*_{ub}T^{00}_{C} + V_{ts}V^*_{tb}(-P^{+-}+P_{EW})$$

- Due to CKM unitarity the hadronic amplitudes receive contributions of different topologies. In the above convention they are referred by the main contributions
  - T^{+-} and P^{+-}: colour allowed three and penguin
  - N^{0+}: annihilation contributions
  - T^{00}_{C}: colour suppressed tree
  - P_{EW} and P^{C}_{EW}: colour allowed and colour suppressed electroweak penguins

$B\to K^*\pi$ System: extraction of α (CPS/GPSZ)

$$A(B^0\to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} \quad + \quad V_{ts}V^*_{tb}P^{+-}$$

$$A(B^+\to K^{*0}\pi^+) = V_{us}V^*_{ub}N^{0+} \quad + \quad V_{ts}V^*_{tb}(-P^{+-}+P^C_{EW})$$

$$\sqrt{2}A(B^+\to K^{*+}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00}_C-N^{0+}) + V_{ts}V^*_{tb}(P^{+-}-P^C_{EW}+P_{EW})$$

$$\sqrt{2}A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}T^{00}_C \quad + \quad V_{ts}V^*_{tb}(-P^{+-}+P_{EW})$$

(S)

Neglecting P_{EW}, the amplitude combinations:

$$3A_{3/2} = A(B^0\to K^{*+}\pi^-) + \sqrt{2}.A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00})$$

$$\overline{3A}_{3/2} = \overline{A}(\overline{B^0}\to K^{*-}\pi^+) + \sqrt{2}.\overline{A}(\overline{B^0}\to \overline{K^{*0}}\pi^0) = V^*_{us}V_{ub}(T^{+-}+T^{00})$$

which gives: $R'_{3/2} = (3A_{3/2})/(\overline{3A}_{3/2}) = e^{-2i\gamma}$ → *CPS PRD74:051301* *GPSZ PRD75:014002*

The actually physical observable is

(invariant under phase redefinitions)

$$R_{3/2} = (q/p)(3A_{3/2})/(\overline{3A}_{3/2}) = e^{-2i\beta}e^{-2i\gamma} = e^{-2i\alpha}$$

$B \to K^{*}\pi$ System: unknowns and observables count

$$A(B^0 \to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} \quad + \quad V_{ts}V^*_{tb}P^{+-}$$

$$A(B^+ \to K^{*0}\pi^+) = V_{us}V^*_{ub}N^{0+} \quad + \quad V_{ts}V^*_{tb}(-P^{+-}+P^{C}_{EW})$$

$$\sqrt{2}A(B^+ \to K^{*+}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00}_{C}-N^{0+}) + V_{ts}V^*_{tb}(P^{+-}-P^{C}_{EW}+P_{EW})$$

$$\sqrt{2}A(B^0 \to K^{*0}\pi^0) = V_{us}V^*_{ub}T^{00}_{C} \quad + \quad V_{ts}V^*_{tb}(-P^{+-}+P_{EW})$$

11 QCD and 2 CKM = 13 unknowns

(S)

Observables:

- 4 BFs and 4 A_{CP} from DP and Q2B analyses.
- 5 phase differences:
  - $\Delta\phi = \arg((q/p)\overline{A}(\overline{B}^0 \to K^{*-}\pi^+)A^*(B^0 \to K^{*+}\pi^-))$: $B^0 \to K^0_S\pi^+\pi^-$
  - $\phi = \arg(A(B^0 \to K^{*0}\pi^0)A^*(B^0 \to K^{*+}\pi^-))$ and
    $\overline{\phi} = \arg(\overline{A}(\overline{B}^0 \to \overline{K}^{*0}\pi^0)\overline{A}^*(\overline{B}^0 \to K^{*-}\pi^+))$ from $B^0 \to K^+\pi^-\pi^0$
  - $\phi = \arg(A(B^+ \to K^{*0}\pi^+)A^*(B^+ \to K^{*+}\pi^0))$ and
    $\overline{\phi} = \arg(\overline{A}(B^- \to \overline{K}^{*0}\pi^-)\overline{A}^*(B^- \to K^{*-}\pi^0))$ from $B^+ \to K^0\pi^+\pi^0$

A total of 13 observables

Event if N(unknowns) = N(obs), reparametrization invariance prevents the simultaneous extraction of all CKM and hadronic parameters without additional information

PRD71:094008 (2005)

$B \to K^* \pi$ System: two strategies

Scenario 1: set some constraints on hadronic parameters:

- If Had $\to$ Had + δHad gives CKM $\to$ CKM + δCKM ☺

  Ex.: α from $B \to \pi\pi$

- If Had $\to$ Had + δHad gives CKM $\to$ CKM + ΔCKM ☹

Goal: test CPS/GPSZ method

Scenario 2: CKM from external input (global fit) and fit hadronic parameters:

- Uncontroversial: only assumes CKM unitarity
- inputs:
  - Fix CKM parameters from global fit
  - $B \to K\pi\pi$ experimental measurements
- output:
  - Prediction of unavailable observables
  - Exploration of hadronic amplitudes $\Rightarrow$ test of QCD predictions

$B \to K^* \pi$ System: CPS/GPSZ theoretical prediction

CPS PRD74:051301
GPSZ PRD75:014002

GPS/CPSZ: relation between the P_{EW} and $T_{3/2} = T^{+-} + T^{00}_{C}$

- $B \to \pi\pi$: $P_{EW} = RT_{3/2}$, $R = 1.35\%$ and real. (SU(2) and Wilson coeff. $|c_{8,9}|$ small).
  P and T CKM of same order $\to$ P_{EW} negligible

- $B \to K\pi$: $P_{EW} = RT_{3/2}$ (same as $\pi\pi$ and SU(3))
  P amplified CKM wrt. T ($|V_{ts}V^*_{tb}/V_{us}V^*_{ub}| \sim 55$) $\to$ P_{EW} non-negligible

- $B \to K^*\pi$: $P_{EW} = R_{eff} T_{3/2}$
  - $R_{eff} = R(1-r_{VP})/(1+r_{VP})$
  - r_{VP} complex $\to$ vector-pseudoscalar phase space
  - GPSZ estimation $|r_{VP}| < 5\%$

$B \to K^*\pi$ System: proposed parametrization of observables

$B^0 \to K^0_S \pi^+\pi^-$

$B(B^0 \to K^{*+}\pi^-)$

$A_{CP}(B^0 \to K^{*+}\pi)$

$\Delta\phi(B^0 \to K^{*+}\pi^-)$

$Re(A(K^{*-}\pi^+)/A(K^{*+}\pi^-))$

$Im(A(K^{*-}\pi^+)/A(K^{*+}\pi^-))$

$B(B^0 \to K^{*+}\pi^-)$

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

$B(B^0 \to K^{*+}\pi^-)$

$A_{CP}(B^0 \to K^{*+}\pi^-)$

$B(B^0 \to K^{*0}\pi^0)$

$A_{CP}(B^0 \to K^{*0}\pi^0)$

$\phi(K^{*0}\pi^0/K^{*+}\pi^-)$

$\phi(\overline{K^{*0}}\pi^0/K^{*-}\pi^+)$

$|\overline{A}(K^{*-}\pi^+)/A(K^{*+}\pi^-)|$

$Re(A(K^{*0}\pi^0)/A(K^{*+}\pi^-))$

$Im(A(K^{*0}\pi^0)/A(K^{*+}\pi^-))$

$Re(A(\overline{K^{*0}}\pi^0)/A(K^{*-}\pi^+))$

$Im(A(\overline{K^{*0}}\pi^0)/A(K^{*-}\pi^+))$

$B(B^0 \to K^{*0}\pi^0)$

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

$B(B^+ \to K^{*0}\pi^+)$

$A_{CP}(B^+ \to K^{*0}\pi^+)$

$|A(\overline{K^{*0}}\pi^-)/A(K^{*0}\pi^-)|$

$B(B^+ \to K^{*0}\pi^+)$

$B^+ \to K^0_S \pi^+\pi^0$

$B(B^+ \to K^{*0}\pi^+)$

$A_{CP}(B^+ \to K^{*0}\pi^+)$

$B(B^+ \to K^{*+}\pi^0)$

$A_{CP}(B^+ \to K^{*+}\pi^0)$

$\phi(K^{*+}\pi^0/K^{*0}\pi^+)$

$\phi(K^{*-}\pi^0/\overline{K^{*0}}\pi^-)$

$|A(K^{*-}\pi^0)/A(K^{*+}\pi^0)|$

$Re(A(K^{*+}\pi^0)/A(K^{*0}\pi^+))$

$Im(A(K^{*+}\pi^0)/A(K^{*0}\pi^+))$

$Re(A(K^{*-}\pi^0)/A(\overline{K^{*0}}\pi^-))$

$Im(A(K^{*-}\pi^0)/A(\overline{K^{*0}}\pi^-))$

$B(B^+ \to K^{*+}\pi^0)$

Scenarios to constrain CKM

Scenarios to constrain CKM: the strategy

Closure test

- Fix CKM parameters to current values
- Assing ad-hoc “true” values to Had. amplitudes
- Deduce corresponding values of physical observables
- Explore constraints on CKM parameters assuming very small uncertainties on observables
- Had. amplitudes constrained to follow naïve hierarchy pattern
  - $T^{+-} > T^{00} > N^{0+}$ and $P^{+-} > P_{EW} > P^{C}_{EW}$
- Furthermore, P_{EW} constrained to match CPS/GPSZ assumption
  - $|P_{EW}/(T^{+-} + T^{00})| = 0.0135$ and $\arg(P_{EW}) = \arg(T^{+-} + T^{00})$
- This ad-hoc choice of “true” values roughly reproduces current BF and A_{CP} (c.f. table)

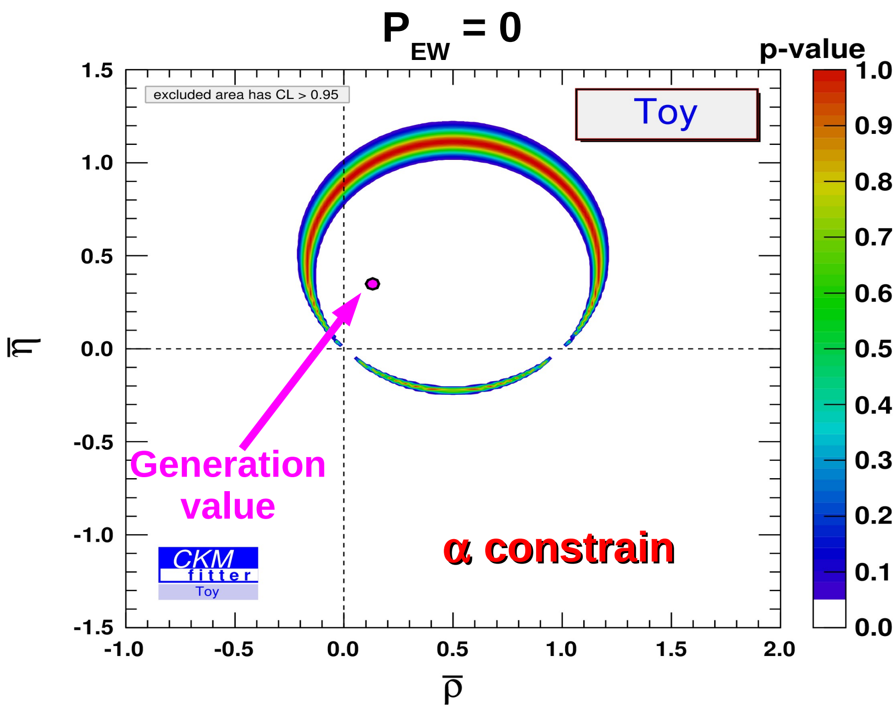
Hadronic par.	magnitude	phase (deg)	Physical observable	Measurement	Value
T^{+-}	2.540	0.00	$\mathcal{B}(B^0 \to K^{*+}\pi^-)$	8.2 ± 0.9	7.1
T^{00}	0.762	75.74	$\mathcal{B}(B^0 \to K^{*0}\pi^0)$	3.3 ± 0.6	1.6
N^{0+}	0.143	108.37	$\mathcal{B}(B^+ \to K^{*+}\pi^0)$	9.2 ± 1.5	8.5
P^{+-}	0.091	-6.48	$\mathcal{B}(B^+ \to K^{*0}\pi^+)$	11.6 ± 1.2	10.9
$P_{\rm EW}$	0.038	15.15	$A_{CP}(B^0 \to K^{*+}\pi^-)$	-24.0 ± 7.0	-12.9
$P^{\rm C}_{\rm EW}$	0.029	101.90	$A_{CP}(B^0 \to K^{*0}\pi^0)$	-15.0 ± 13.0	-46.5
$\left\lvert \frac{V_{ts}V^*_{tb}P^{+-}}{V_{us}V^*_{ub}T^{+-}} \right\rvert$	1.801		$A_{CP}(B^+ \to K^{*+}\pi^0)$	-0.52 ± 15.0	-35.4
$\lvert T^{00}/T^{+-} \rvert$	0.300		$A_{CP}(B^+ \to K^{*0}\pi^+)$	$+5.0 \pm 5.0$	$+3.9$
$\lvert N^{0+}/T^{00} \rvert$	0.187				
$\lvert P_{\rm EW}/P^{+-} \rvert$	0.420				
$\lvert P_{\rm EW}/(T^{+-}+T^{00}) \rvert /R$	1.000				
$\lvert P_{\rm EW}/P^{\rm C}_{\rm EW} \rvert$	0.762				

Explored hypothesis

- **CPS/GPSZ-like assumption**
- **Hypothesis on the annihilation**

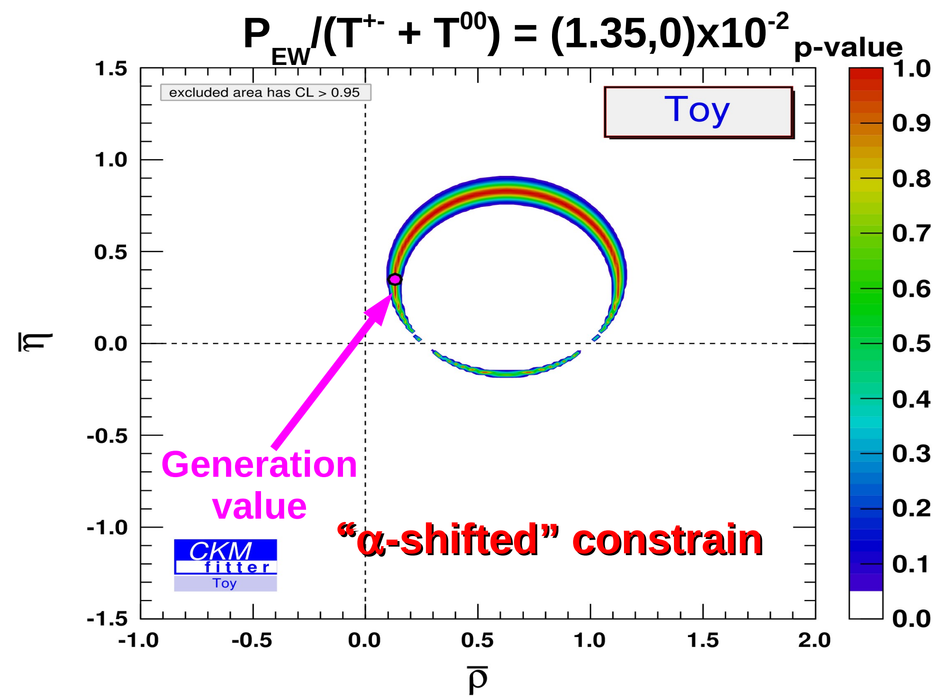
Scenarios to constrain CKM: CPS/GPSZ-like (I)

- The CKM α is extracted from $B\to\pi\pi$, $\rho\pi$ and $\rho\rho$ isospin analysis by neglecting the P_{EW} contributions to the decay amplitudes
- A similar approach is tested here ***CPS PRD74:051301, GPSZ PRD75:014002***



Only for $P_{EW} = 0$

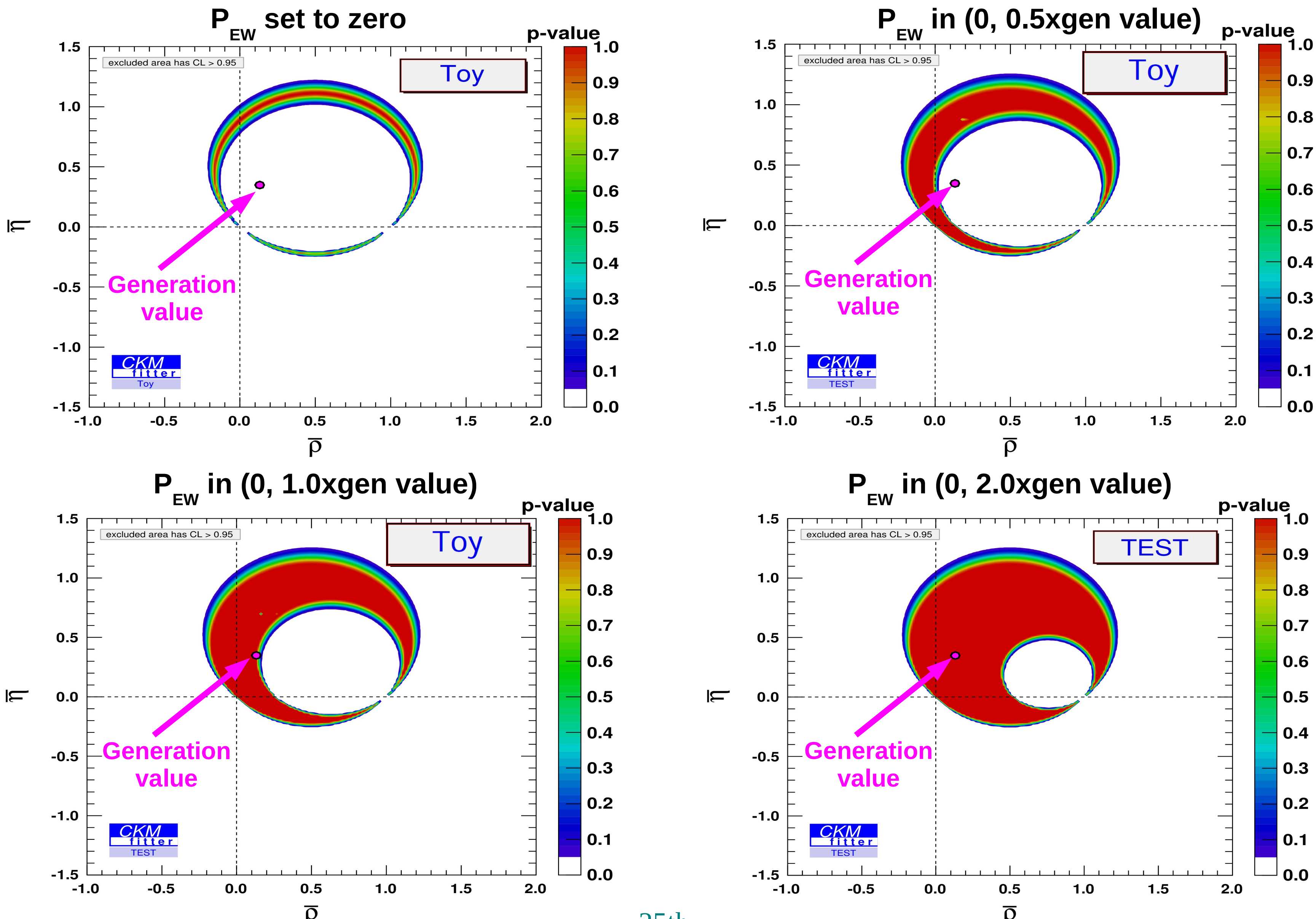
- Yields constraint on ρ–η following α contours
- But fails (by large amounts!) to reproduce true α



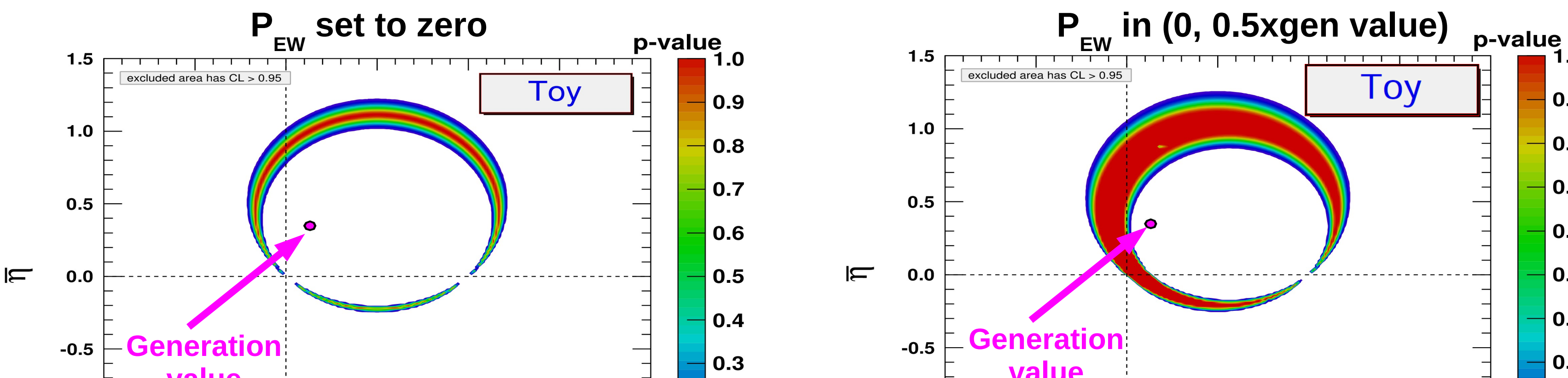
If $P_{EW} \neq 0$ (fixed to its true value)

- Yields unbiased constraint
- Which does not follow α contour

Scenarios to constrain CKM: CPS/GPSZ-like (II)

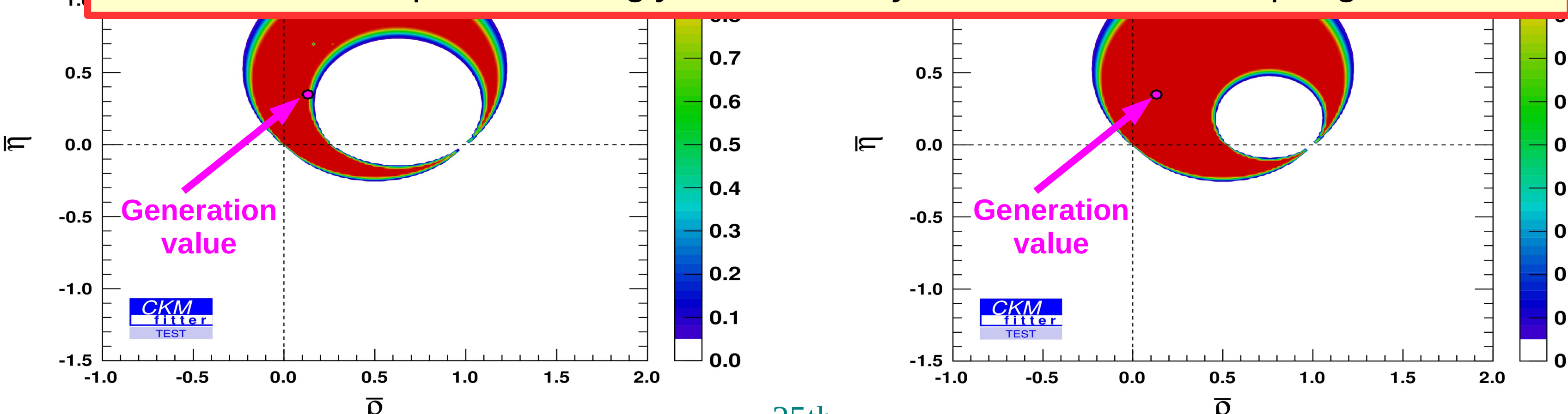


Scenarios to constrain CKM: CPS/GPSZ-like (II)



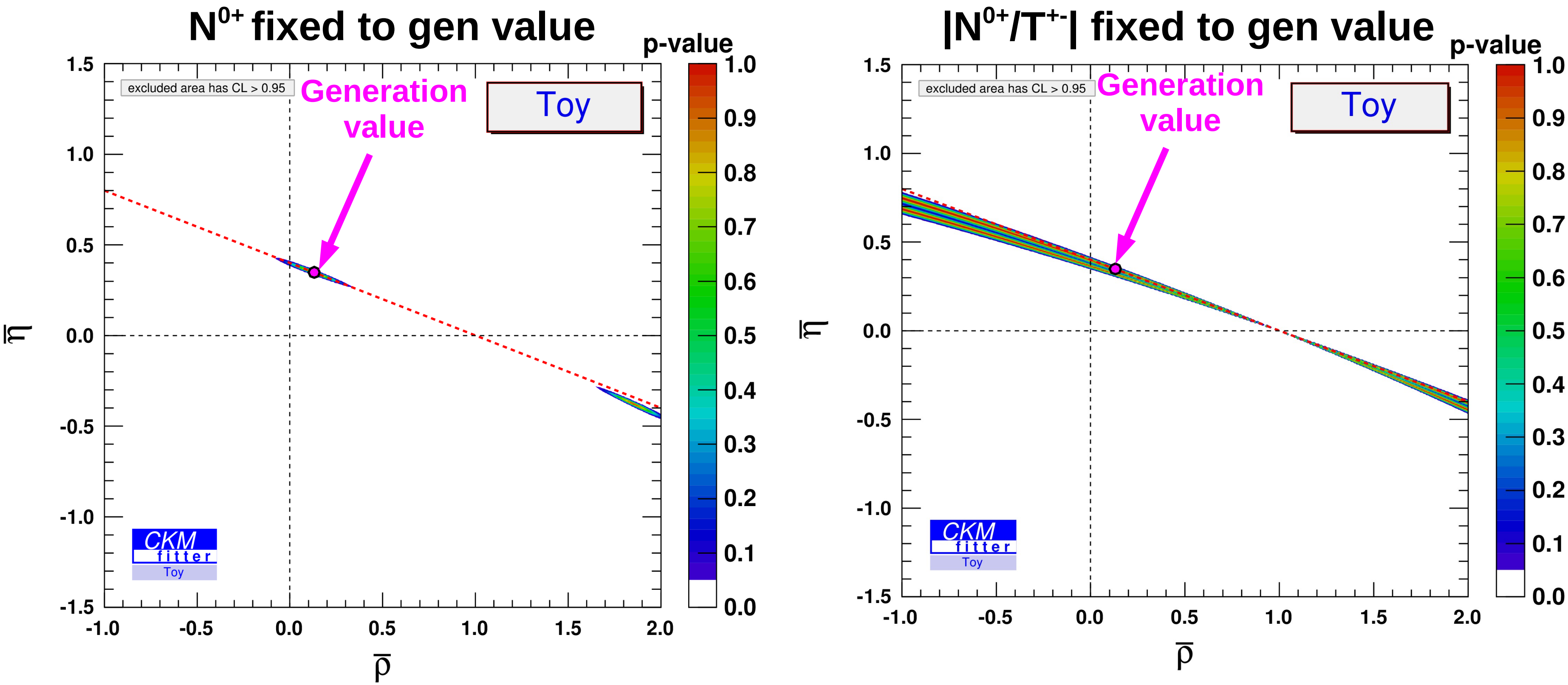
The method is overly sensitive to the assumed P_{EW} values

- A strong hypothesis on P_{EW} provides a strong, but biased constraint
- Relaxing the hypothesis spoils the predictability of the method
  - Remember the “true” P_{EW} is 1.35% smaller than the tree amplitudes!
  - But its impact is strongly enhanced by the CKM factors on penguin terms



Scenarios to constrain CKM: hypothesis on N^{0+} (I)

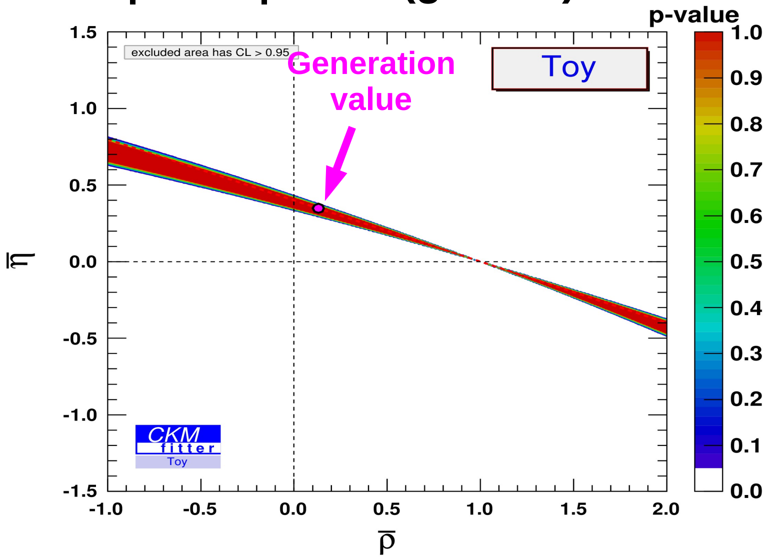
- CKM enhancement does not affect tree terms
- Furthermore, the annihilation N^{0+} is naïvely expected to be small
- May be constrained from theory and/or from annihilation-dominated modes



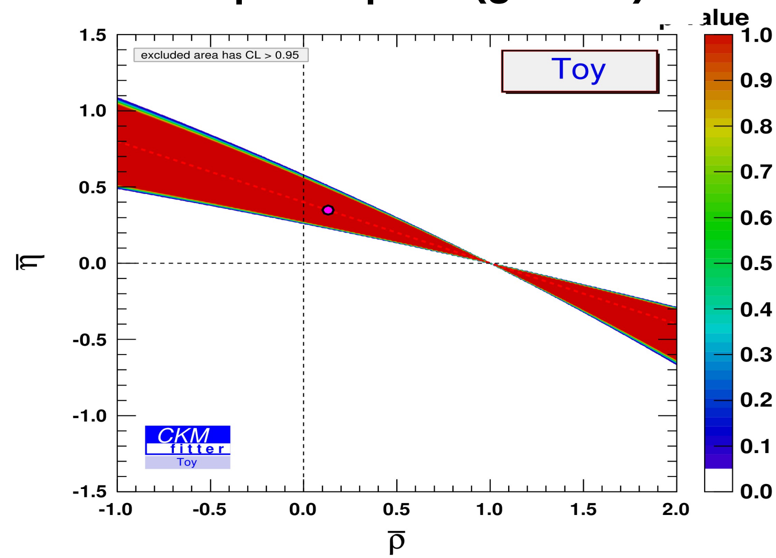
Hypotheses in the $|N^{0+}/T^{+-}|$ provides a "β-like" constraint in ρ–η

Scenarios to constrain CKM: hypothesis on N^{0+} (II)

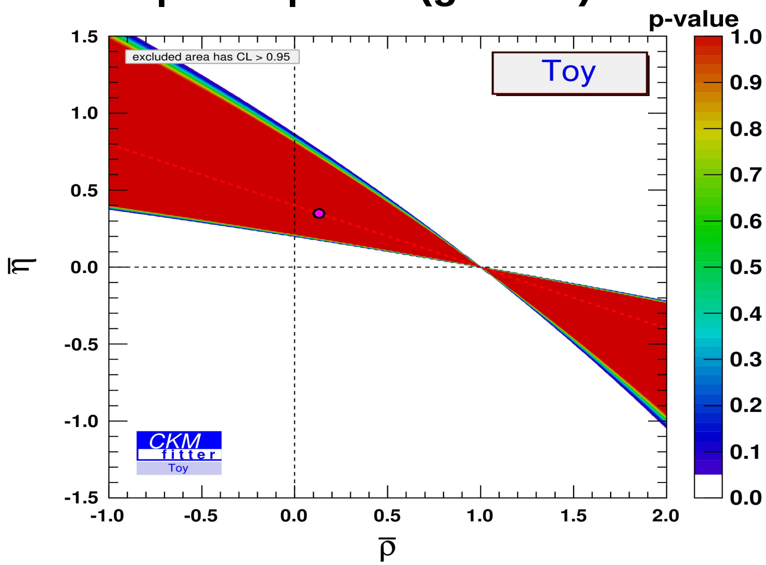
$|N^{0+}/T^{+-}| < 1.5x$(gen val)



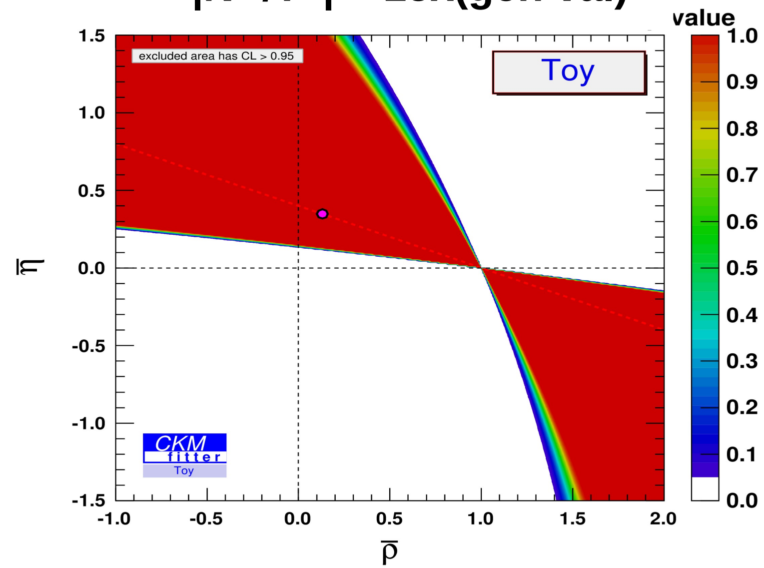
$|N^{0+}/T^{+-}| < 5x$(gen val)



$|N^{0+}/T^{+-}| < 10x$(gen val)

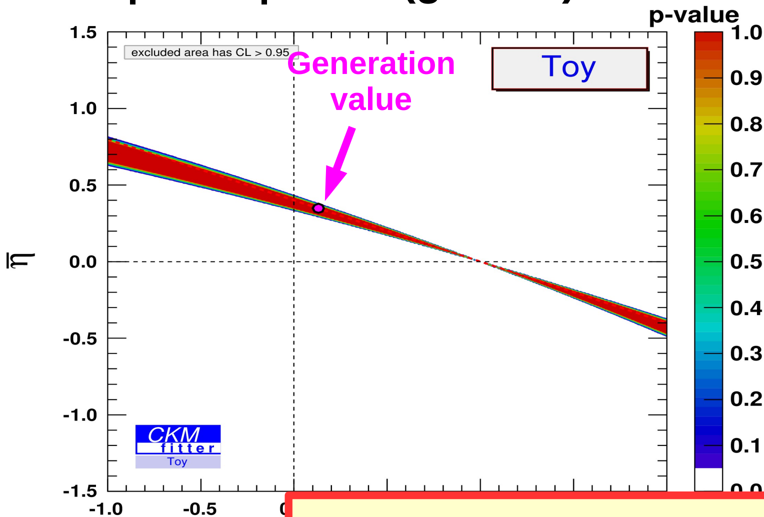


$|N^{0+}/T^{+-}| < 15x$(gen val)

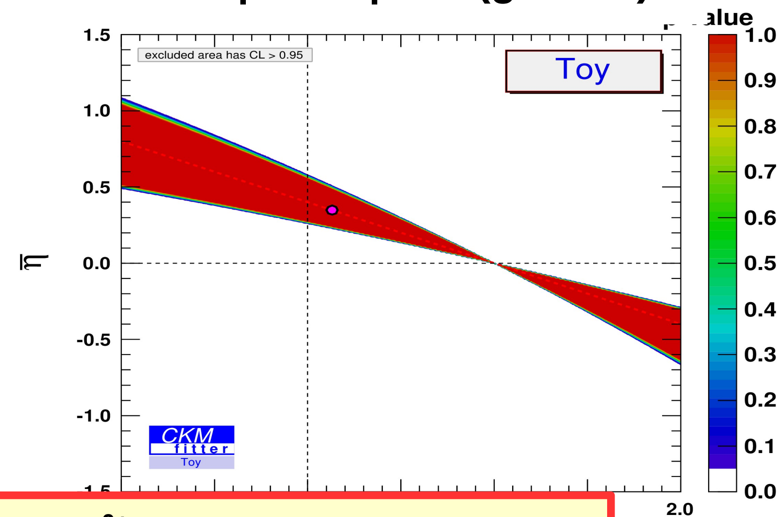


Scenarios to constrain CKM: hypothesis on N^{0+} (II)

$|N^{0+}/T^{+-}| < 1.5x(\text{gen val})$

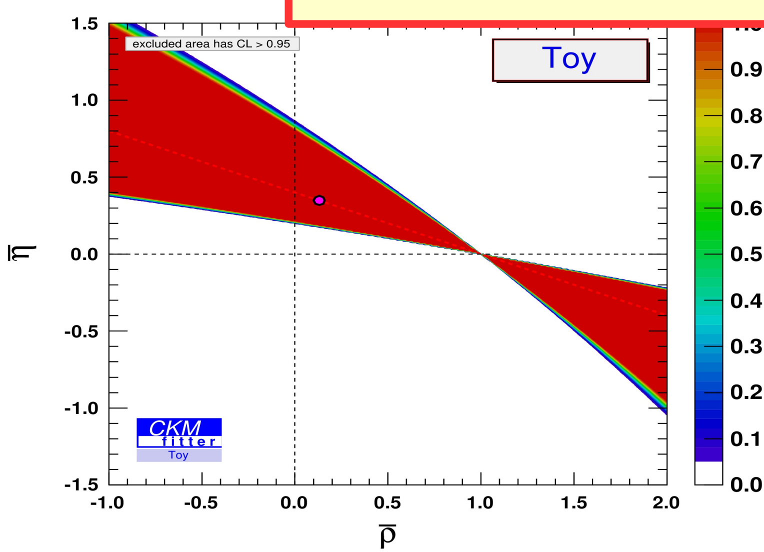


$|N^{0+}/T^{+-}| < 5x(\text{gen val})$



Relaxing the hypothesis on N^{0+} yields only a mild deterioration on the constraints

$|N^{0+}/T^{+-}$



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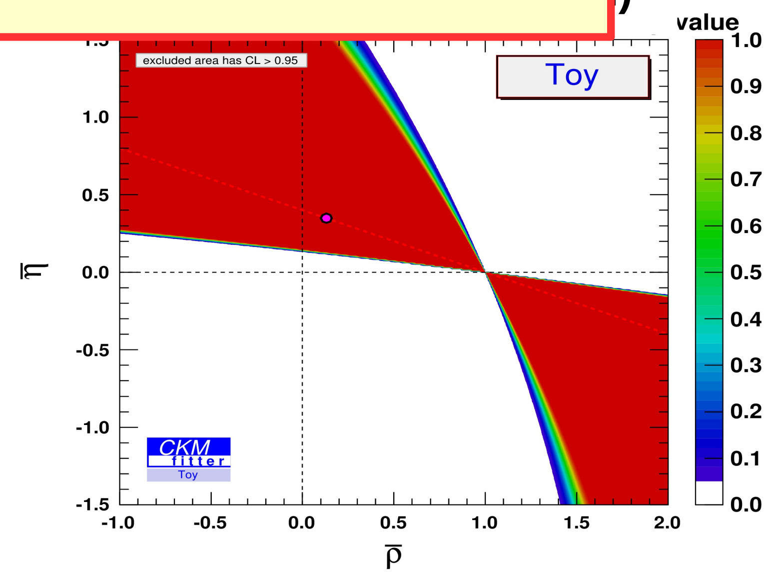
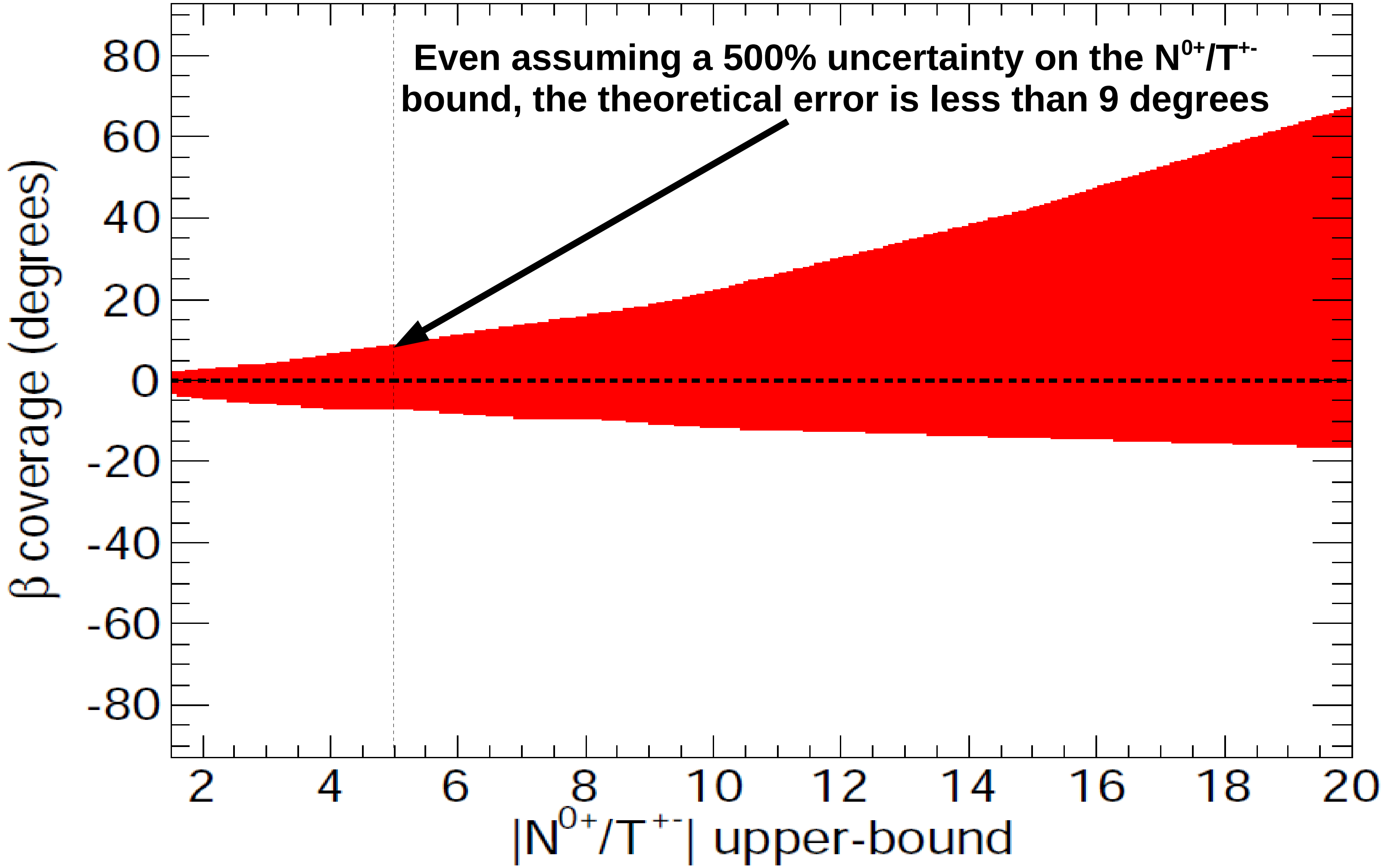


Scenarios to constrain CKM: hypothesis on N^{0+} (III)

β coverage vs Upper bound on $|N^{0+}/T^{+-}|$ (in units of the generation value)



Scenarios to constrain CKM: Summary

- **CPS/GPSZ-like hypothesis:**
  - Conservative values on the uncertainty of the P_{EW} prediction gives uncontrollable effects of the ρ-η constraints

    ⇒ The method is dominated by the theoretical uncertainties
  - This is expected due to the CKM enhancement ($|V_{ts}V^*_{tb}/V_{us}V^*_{ub}| \sim 55$) of “penguin” w.r.t “tree” terms

- **Hypothesis on the annihilation (N^{0+})**
  - It is possible to set a constraint in ρ-η by just setting a upper bound on the $|N^{0+}/T^{+-}|$
  - Constraint on CKM less sensitive to theoretical uncertainties as there is no CKM enhancement

    Uncertainty of 500% on $|N^{0+}/T^{+-}|$ gives a theory error of less than 9 degrees
  - Possibility to get bounds on the annihilation from data by measuring the annihilation-dominated mode $B^+_s \rightarrow K^{*0}K^+$ which is U-spin related to $B^0 \rightarrow K^{*0}\pi^+$

    ⇒ Accessible to LHCb

Current constraints on Hadronic amplitudes

Experimental inputs: *BABAR* (I)

- ***BABAR*** **$B^0 \to K^+\pi^-\pi^0$ analysis:** PRD83:112010 (2011)

$|A(K^{*-}\pi^+)/A(K^{*+}\pi^-)| = 0.74 \pm 0.09$

$\mathrm{Re}(K^{*0}\pi^0/K^{*+}\pi^-) = 0.80 \pm 0.20;$

$\mathrm{Im}(K^{*0}\pi^0/K^{*+}\pi^-) = -0.32 \pm 0.42;$

$\mathrm{Re}(\overline{K}^{*0}\pi^0/K^{*-}\pi^+) = 1.00 \pm 0.15$

$\mathrm{Im}(\overline{K}^{*0}\pi^0/K^{*-}\pi^+) = -0.07 \pm 0.53;$

$B(K^{*0}\pi^0) = (3.30 \pm 0.64)\times 10^{-6}$

Full Correlation matrix

$$\begin{pmatrix} 1.0 & 0.06 & 0.02 & -0.35 & -0.11 & -0.06 \\ & 1.0 & 0.78 & 0.30 & -0.01 & 0.29 \\ & & 1.0 & -0.06 & 0.00 & -0.10 \\ & & & 1.0 & 0.30 & 0.42 \\ & & & & 1.0 & -0.02 \\ & & & & & 1.00 \end{pmatrix}$$

- ***BABAR*** **$B^0 \to K^0_s\pi^+\pi^-$ analysis:** PRD80:112001 (2009)

two minima differing by 0.16 2NLL units

Global minimum

$\mathrm{Re}(K^{*-}\pi^+/K^{*+}\pi^-) = 0.43 \pm 0.41;$

$\mathrm{Im}(K^{*-}\pi^+/K^{*+}\pi^-) = -0.69 \pm 0.26;$

$B(K^{*+}\pi^-) = (8.3 \pm 1.2)\times 10^{-6};$

Full Correlation matrix

$$\begin{pmatrix} 1.0 & 0.93 & 0.02 \\ & 1.0 & -0.08 \\ & & 1.0 \end{pmatrix}$$

Local Minimum

$\mathrm{Re}(K^{*-}\pi^+/K^{*+}\pi^-) = -0.82 \pm 0.09;$

$\mathrm{Im}(K^{*-}\pi^+/K^{*+}\pi^-) = -0.05 \pm 0.43;$

$B(K^{*+}\pi^-) = (8.3 \pm 1.2)\times 10^{-6};$

Full Correlation matrix

$$\begin{pmatrix} 1.0 & -0.20 & 0.22 \\ & 1.0 & -0.01 \\ & & 1.0 \end{pmatrix}$$

Experimental inputs: *BABAR* (II)

- ***BABAR*** **$B^+ \to K^+\pi^-\pi^+$ analysis:** PRD78:012004 (2008)

$|A(K^{*0}\pi^-)/A(K^{*0}\pi^+)| = 1.033 \pm 0.047$;

$B(K^{*0}\pi^+) = (10.8 \pm 1.4)\mathrm{x}10^{-6}$;

Full Correlation matrix

$$\begin{pmatrix} 1.0 & 0.02 \\ & 1.0 \end{pmatrix}$$

- ***BABAR*** **$B^+ \to K^0_S\pi^+\pi^0$ analysis:** ArXiv : 1501.00705 [hep-ex] (2015) **New Result!**
  - Currently in communication with authors to get full set of observables and correlation matrices
  - The results shown in next slides just use
    - $B(K^{*+}\pi^0) = (9.2 \pm 1.5)\mathrm{x}10^{-6}$;
    - $C(K^{*+}\pi^0) = -0.52 \pm 0.15$; $\Rightarrow$ ~3.5σ significance

Experimental inputs: Belle

- **Belle $B^0 \to K^0_S \pi^+\pi^-$ analysis:** PRD75:012006 (2007) and PRD79:072004 (2009)

  two minima differing by 7.5 2NLL units

Global minimum

$Re(K^{*-}\pi^+/K^{*+}\pi^-) = 0.79 \pm 0.14;$

$Im(K^{*-}\pi^+/K^{*+}\pi^-) = -0.21 \pm 0.40;$

$B(K^{*+}\pi^-) = (8.4 \pm 1.5)x10^{-6};$

Full Correlation matrix

$$\begin{pmatrix} 1.0 & 0.62 & 0.0 \\ & 1.0 & 0.0 \\ & & 1.0 \end{pmatrix}$$

Local Minimum

$Re(K^{*-}\pi^+/K^{*+}\pi^-) = 0.81 \pm 0.11;$

$Im(K^{*-}\pi^+/K^{*+}\pi^-) = 0.01 \pm 0.44;$

$B(K^{*+}\pi^-) = (8.4 \pm 1.5)x10^{-6};$

Full Correlation matrix

$$\begin{pmatrix} 1.0 & 0.01 & 0.0 \\ & 1.0 & 0.0 \\ & & 1.0 \end{pmatrix}$$

- **Belle $B^+ \to K^+\pi^-\pi^+$ analysis:** PRL96:251803 (2006)

  $|A(K^{*0}\pi^-)/A(K^{*0}\pi^+)| = 0.86 \pm 0.09;$

  $B(K^{*0}\pi^+) = (9.7 \pm 1.1)x10^{-6};$

  Full Correlation matrix

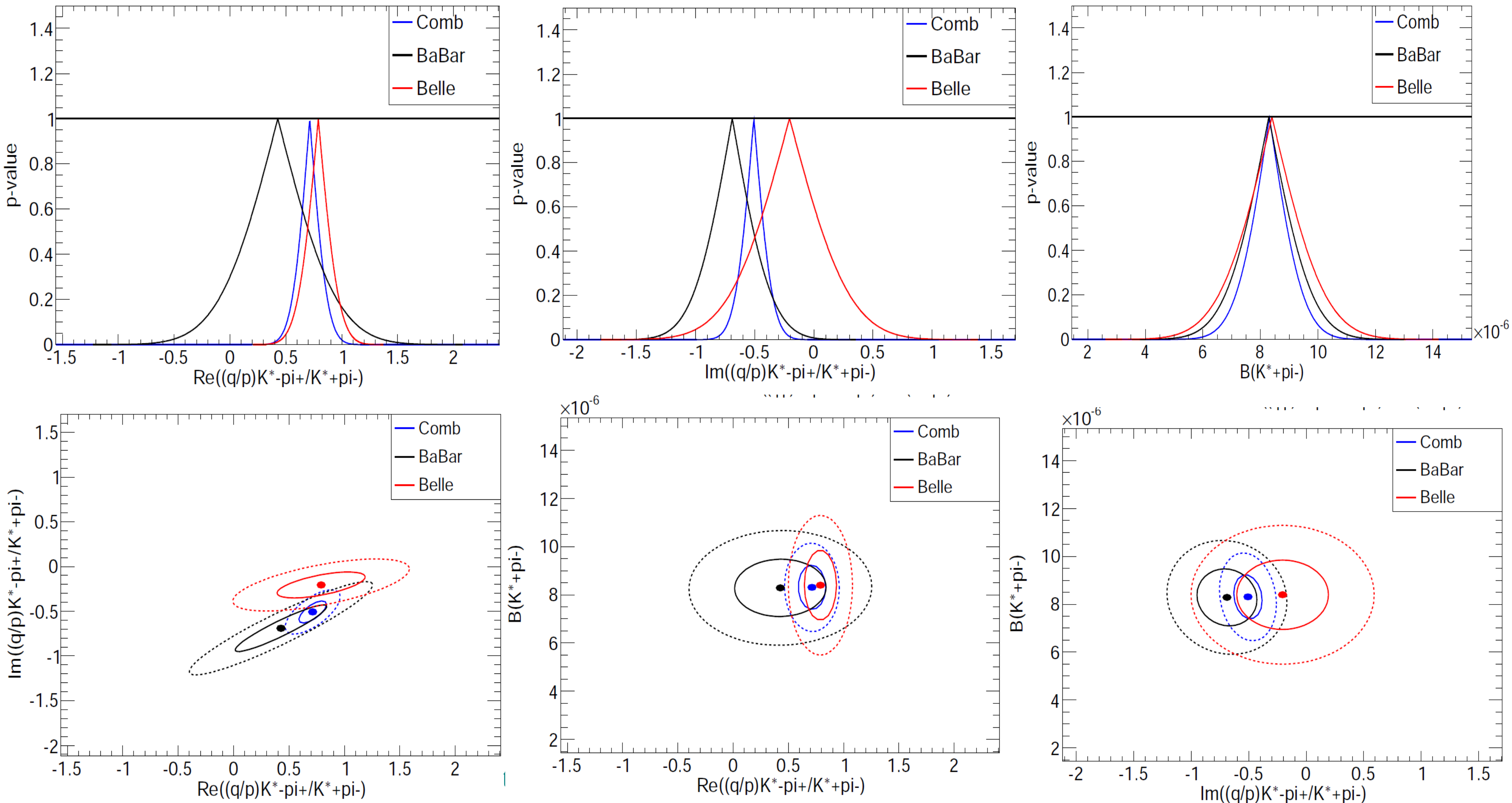
$$\begin{pmatrix} 1.0 & 0.0 \\ & 1.0 \end{pmatrix}$$

- **No Belle results on:**

  $B^0 \to K^+\pi^+\pi^0$ and $B^+ \to K^0_S\pi^+\pi^0$

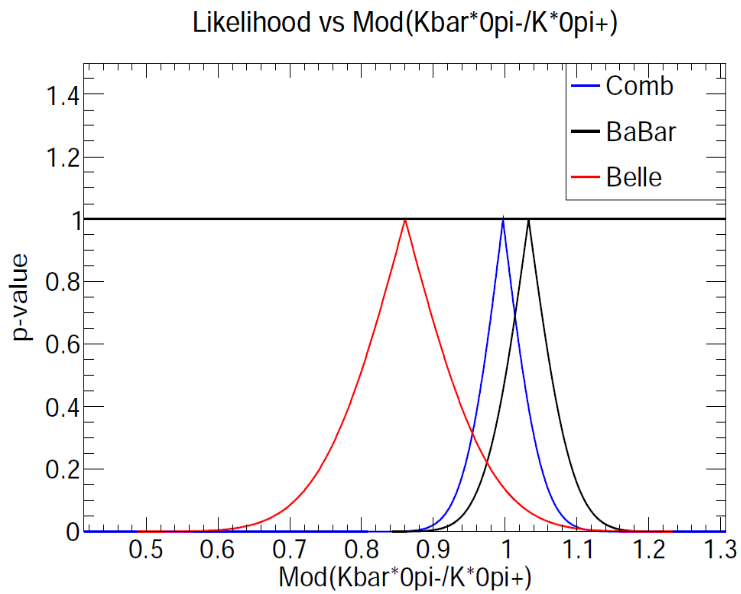
Combining *BABAR* + Belle: $B^0 \to K^0_S \pi^+ \pi^-$

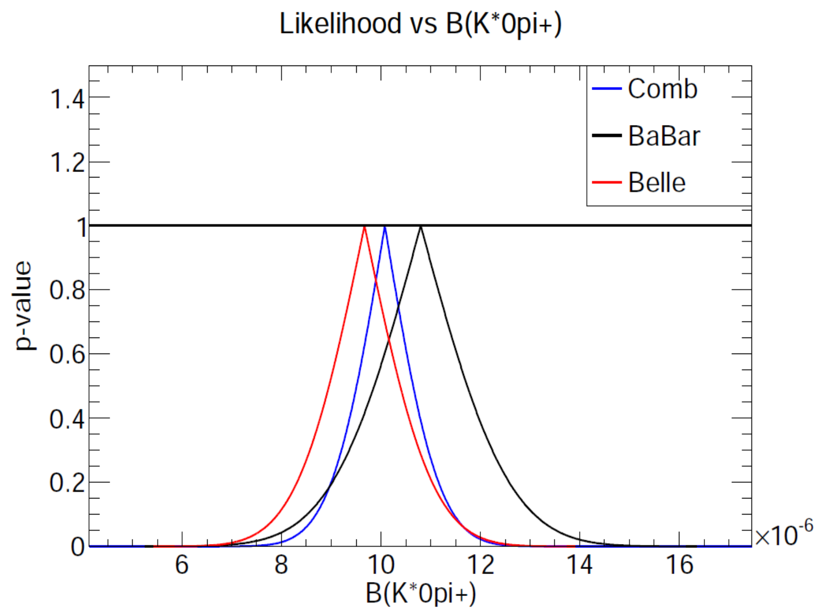
- Two solutions for both *BABAR* and Belle analyses
  - Combine all possible combinations of *BABAR* and Belle solutions taking into account the difference in 2NLL
  - Results: 4 solutions differing in χ^2: 0, 7.7, 8.4 and 97.2. Consider only the global minimum

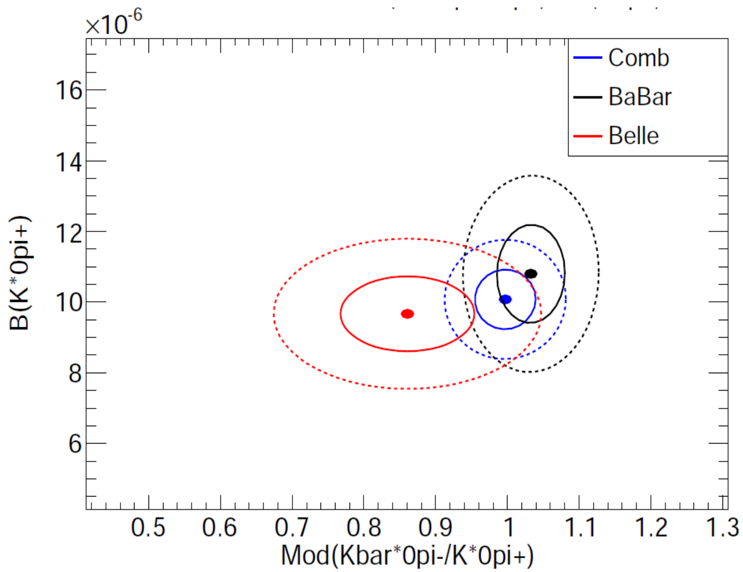


Combining *BABAR* + Belle: $B^+ \to K^+\pi^-\pi^+$

- Single solution for both *BABAR* and Belle







Results on Had. Amplitudes: CP violation (I)

- Decay amplitudes (δ_i and φ_i are weak/strong phases)

  $A = M_1 \exp(i\delta_1)\exp(i\varphi_1) + M_2 \exp(i\delta_2)\exp(i\varphi_2)$

  $A = M_1 \exp(i\delta_1)\exp(-i\varphi_1) + M_2 \exp(i\delta_2)\exp(-i\varphi_2)$

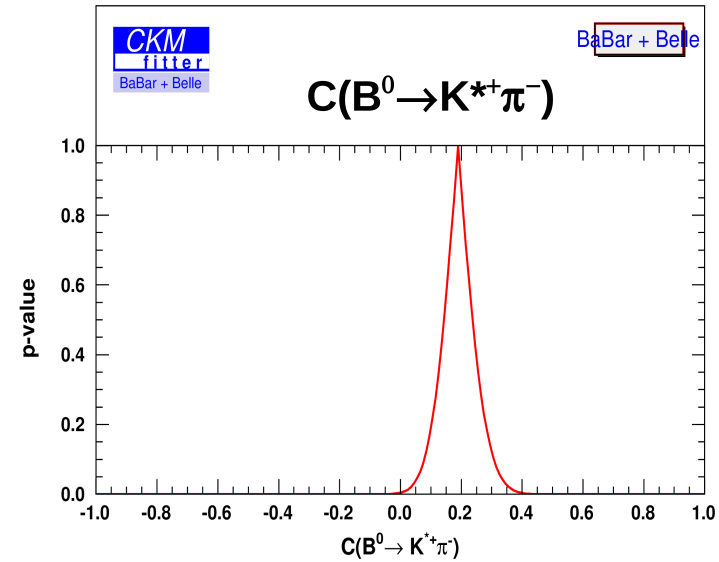
$$A_{CP} = 2\frac{\sin(\Delta\delta)\sin(\Delta\varphi)}{(M_1/M_2)+(M_2/M_1)+2\cos(\Delta\delta)\cos(\Delta\varphi)}$$

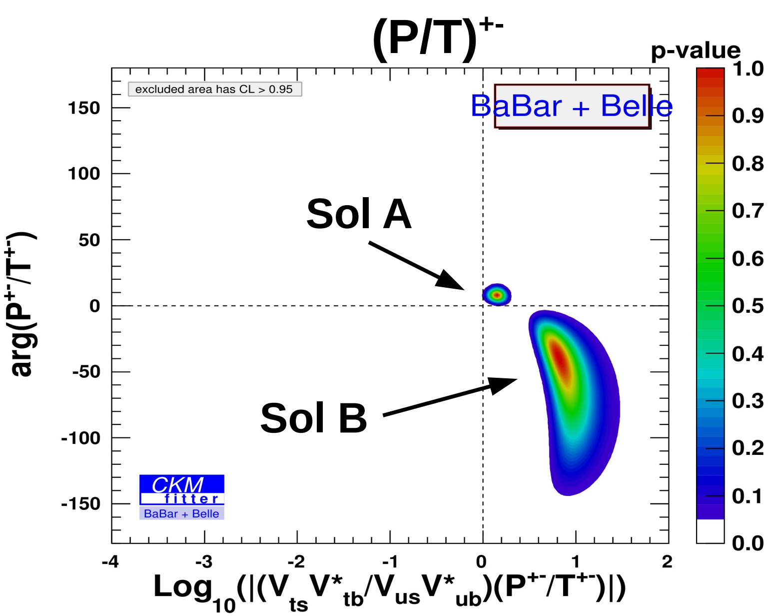
- In our case $\Delta\varphi = \arg(V_{ts}V^*_{tb}/V_{us}V^*_{ub}) = 2\gamma \neq 0$
- If A_{CP} is significantly different from zero then
  - |CKM*(P/T)| ~ 1
  - $\arg(P/T) \neq 0$

- 3σ significance for $C(B^0 \to K^{*+}\pi^-)$

  $\mathbf{A(B^0 \to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P^{+-}}$

  - Two solutions with same χ^2 (Sol A and B)
  - Both inconsistent with arg(P/T) = $0/\pi$
  - Only solution A has |CKM*(P/T)| ~ 1





Results on Had. Amplitudes: CP violation (II)

- Decay amplitudes (δ_i and φ_i are weak/strong phases)

  $$A = M_1 \exp(i\delta_1)\exp(i\varphi_1) + M_2 \exp(i\delta_2)\exp(i\varphi_2)$$

  $$A = M_1 \exp(i\delta_1)\exp(-i\varphi_1) + M_2 \exp(i\delta_2)\exp(-i\varphi_2)$$

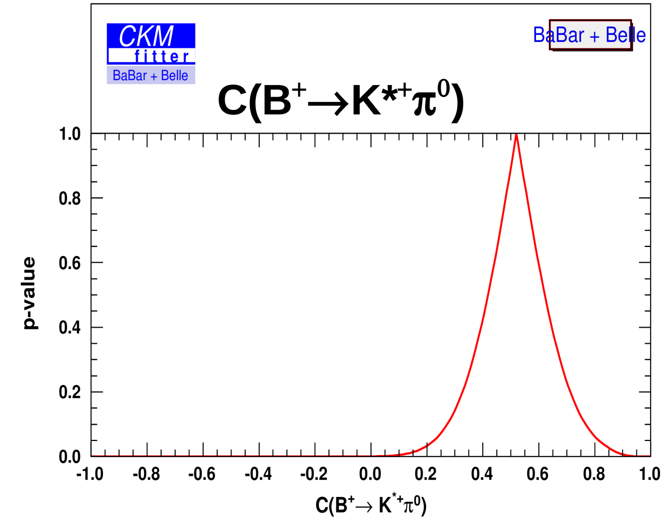
  $$A_{CP} = 2\frac{\sin(\Delta\delta)\sin(\Delta\varphi)}{(M_1/M_2)+(M_2/M_1)+2\cos(\Delta\delta)\cos(\Delta\varphi)}$$

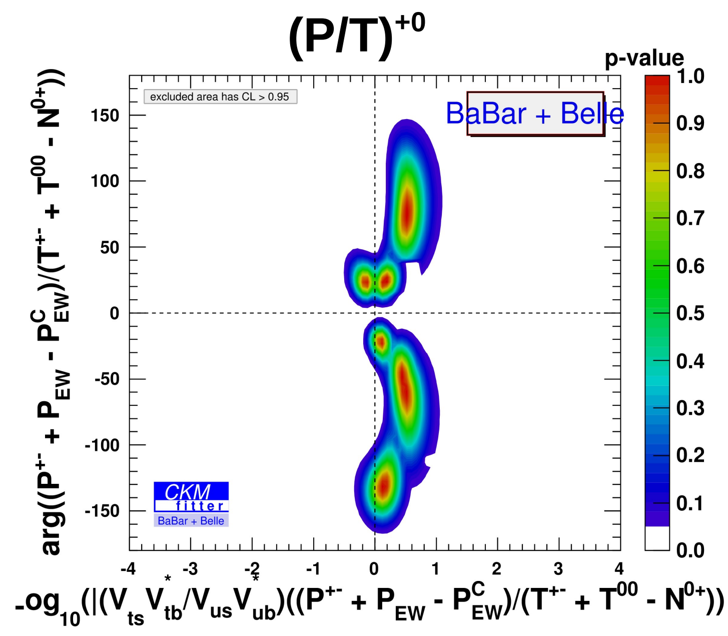
- In our case $\Delta\varphi = \arg(V_{ts}V^*_{tb}/V_{us}V^*_{ub}) = 2\gamma \neq 0$
- If A_{CP} is significantly different from zero then
  - $|CKM^*(P/T)| \sim 1$
  - $\arg(P/T) \neq 0$

- 3.4σ significance for $C(B^+ \to K^{*+}\pi^0)$

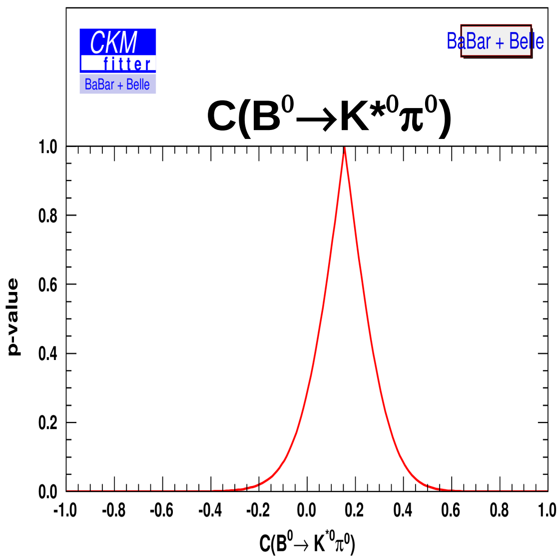
  $$\sqrt{2}A(B^+ \to K^{*+}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00}_C-N^{0+}) + V_{ts}V^*_{tb}(P^{+-}-P^C_{EW}+P_{EW})$$

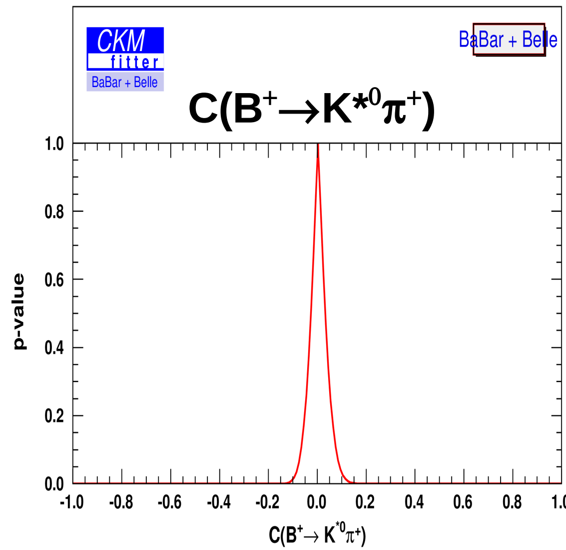
  - Both solutions inconsistent with $\arg(P/T) = 0/\pi$ and with $|CKM^*(P/T)| \sim 1$
  - Appearance of other local minima





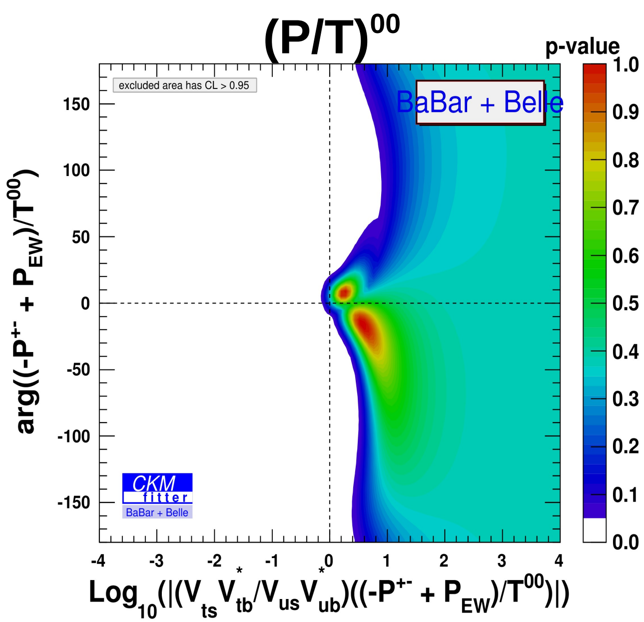
Results on Had. Amplitudes: CP violation (III)

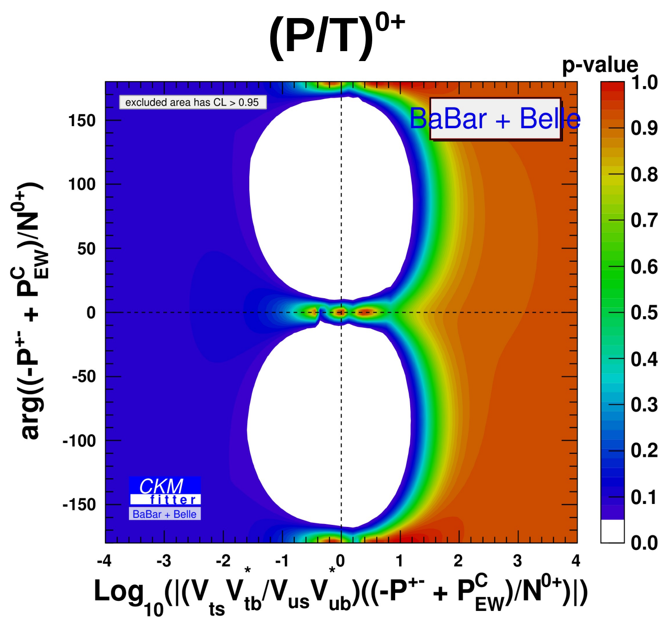




$A(B^+ \to K^{*0}\pi^+) = V_{us}V^*_{ub}N^{0+} + V_{ts}V^*_{tb}(-P^{+-} + P^C_{EW})$

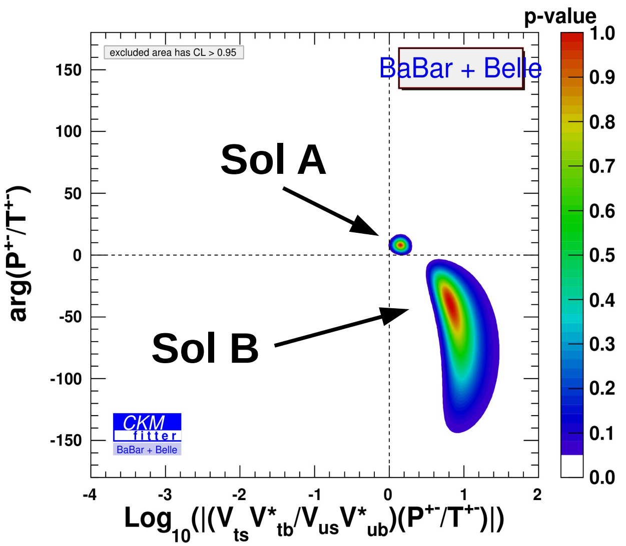
$A(B^0 \to K^{*0}\pi^0) = V_{us}V^*_{ub}T^{00}_C + V_{ts}V^*_{tb}(-P^{+-} + P_{EW})$

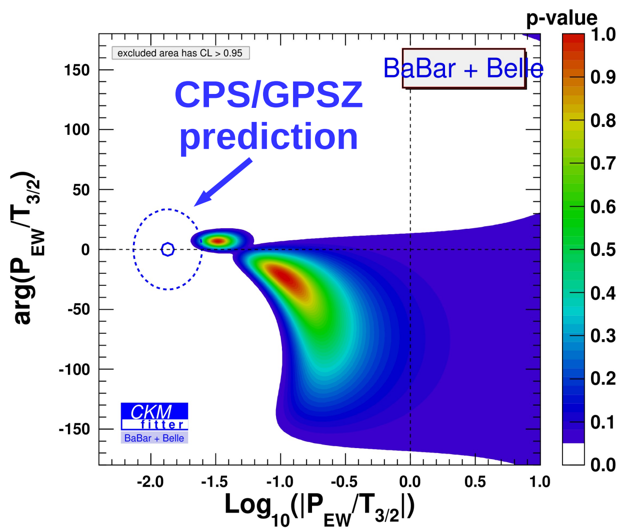


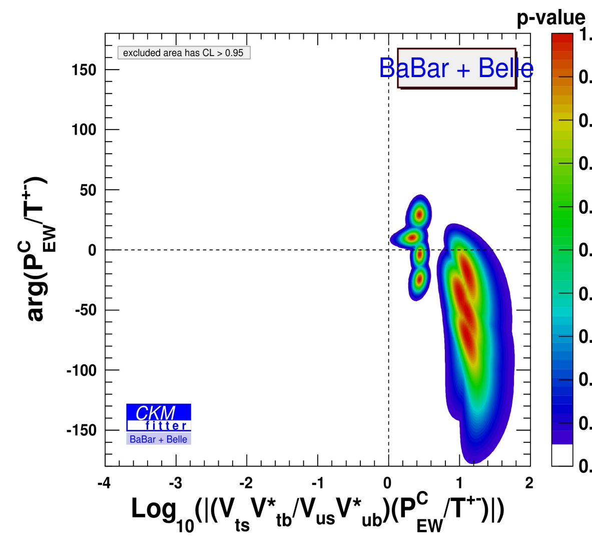


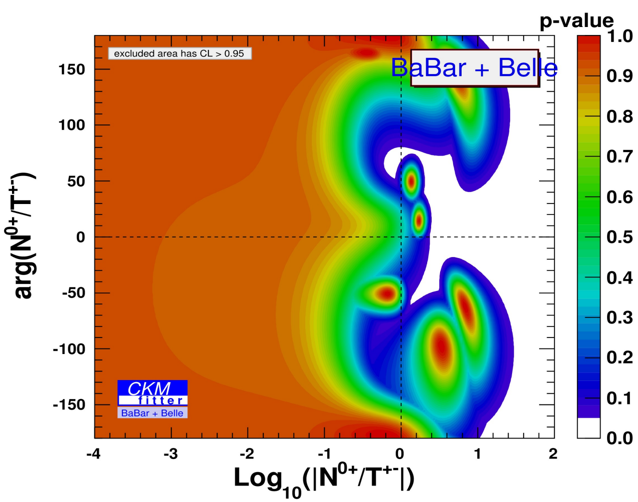
- $A_{CP}(K^{*0}\pi^0)$ and $A_{CP}(K^{*0}\pi^+)$ consistent with zero @ 1σ
- P/T constraints are consistent either with
  - $|CKM^*(P/T)| \gg 1$ or $\ll 1$
  - $\arg(P/T) = 0$ or $\pm\pi$

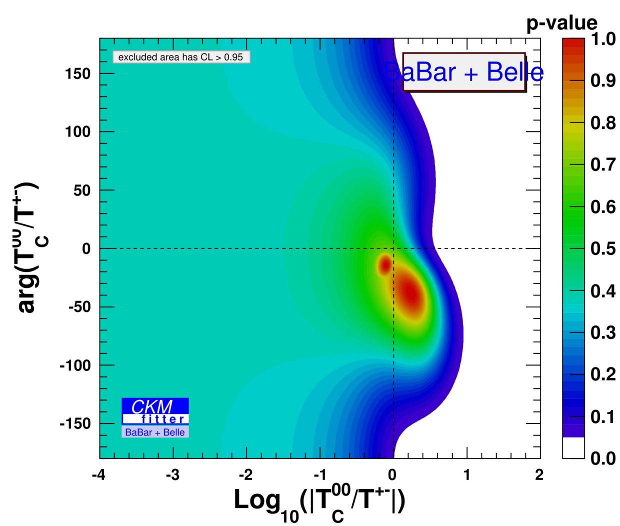
Results on Had. Amplitudes: all together







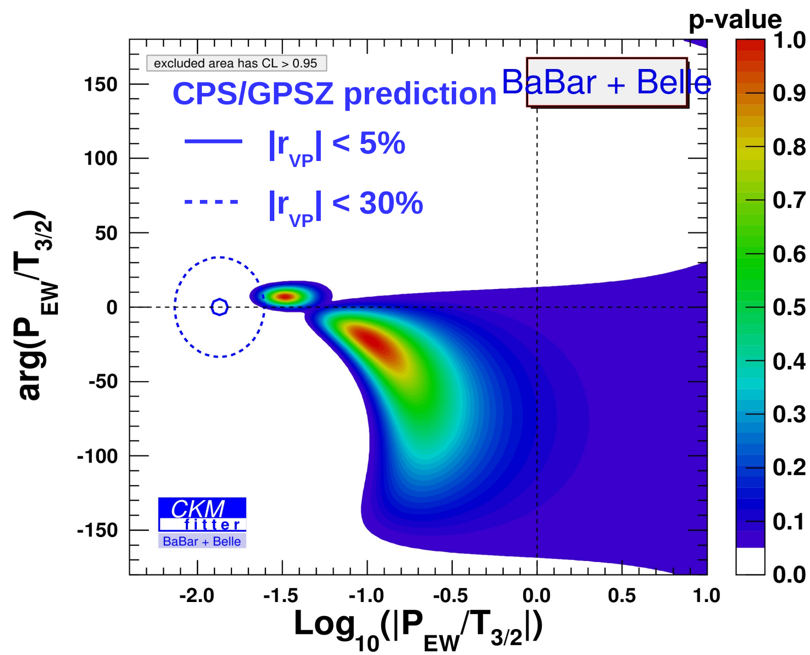


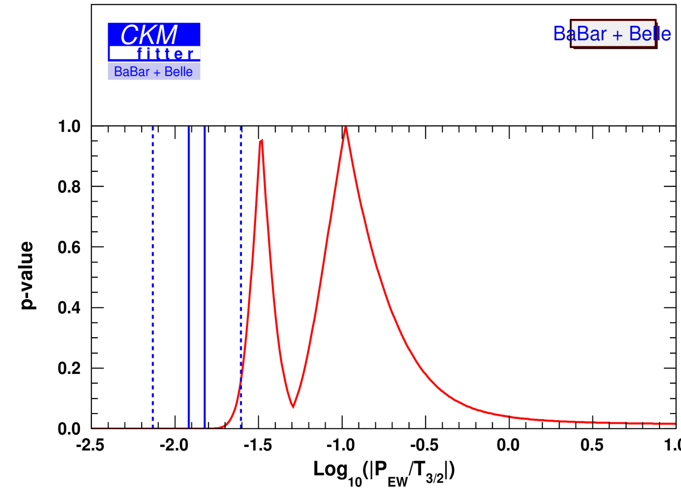


- Two solutions for the P^{+-}/T^{+-} with same χ^2 (sol: A and B)
  - Those generate multiple solution on the other had. parameters
- Essentially no constrain on N^{0+} and T^{00}
- Marginal agreement with CPS/GPSZ prediction

Results on Had. Amplitudes: agreement with CPS/GPSZ

- CPS/GPSZ prediction
  $P_{EW}/(T^{+-} + T^{00}) = R(1-r_{VP})/(1+r_{VP})$
  with R = 1.35% and $|r_{VP}| < 5\%$
- The current experimental constraints in poor agreement with the CPS/GPSZ prediction
- Marginal agreement only reached by inflating the uncertainty on $|r_{VP}|$ up to 30%

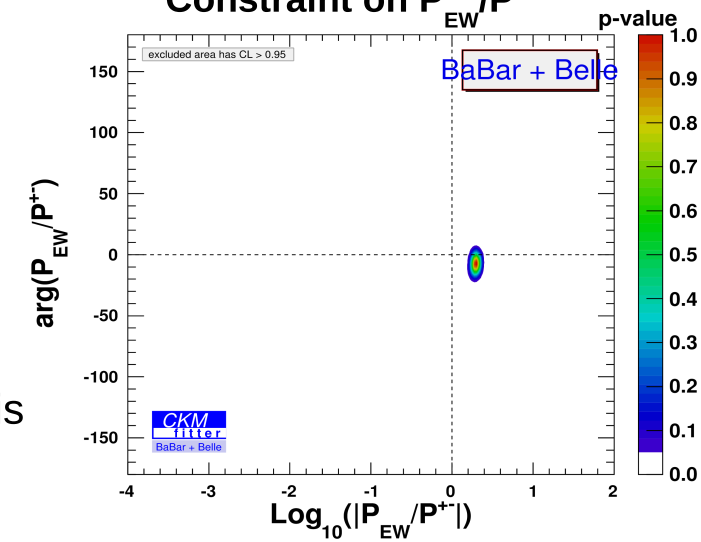




Results on Had. Amplitudes: Hierarchies (I)

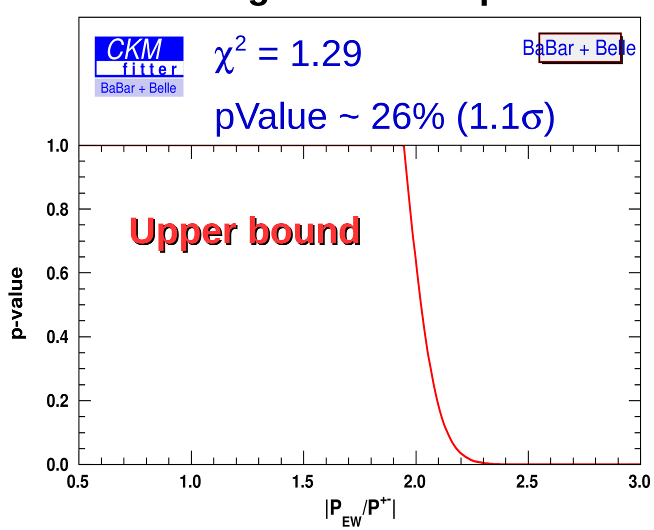
- Current data favours a relatively high P_{EW}
- This results is mainly driven by the $K^{*+}\pi^-/K^{*0}\pi^0$ phase differences measured in $B^0 \to K^+\pi^-\pi^0$
- Without these phases there is good agreement among the experimental observables ($\chi^2 = 1.29$, p-Value ~1.1σ)
- Adding the phases brings slight tension ($\Delta\chi^2 = 7.7$, 2.6σ)
- Only one experiment has performed the $B^0 \to K^+\pi^-\pi^0$ analysis
- An independent confirmation is needed to claim non-zero (and large!) value of P_{EW}

Constraint on P_{EW}/P^{+-}

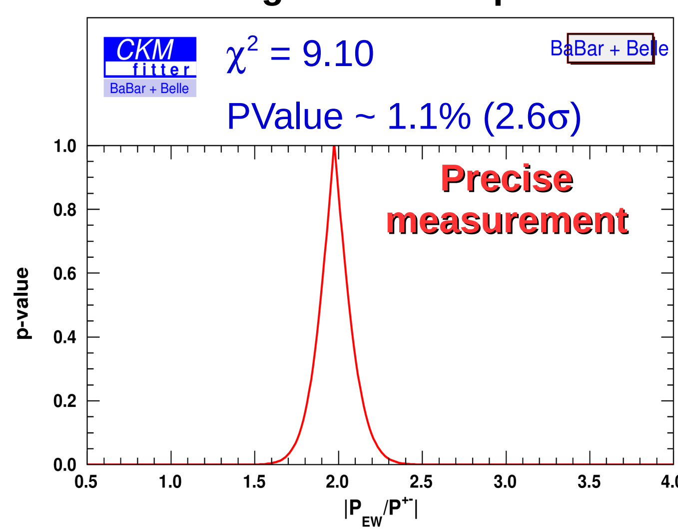


Constraints on $|P_{EW}/P^{+-}|$

Excluding $K^{*+}\pi^-/K^{*0}\pi^0$ phases

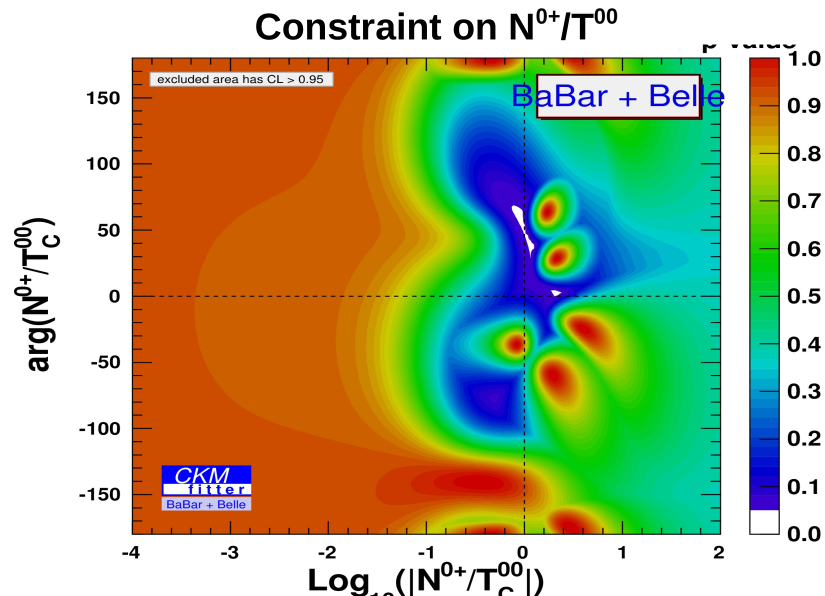


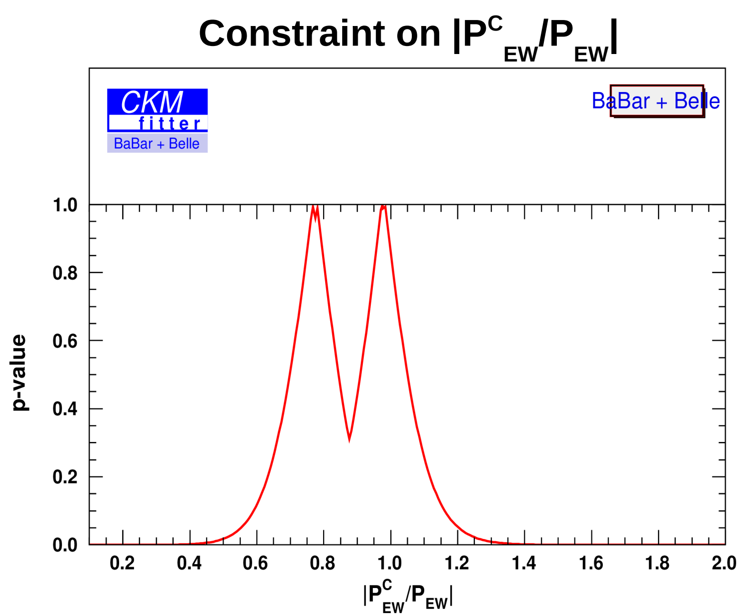
Including $K^{*+}\pi^-/K^{*0}\pi^0$ phases

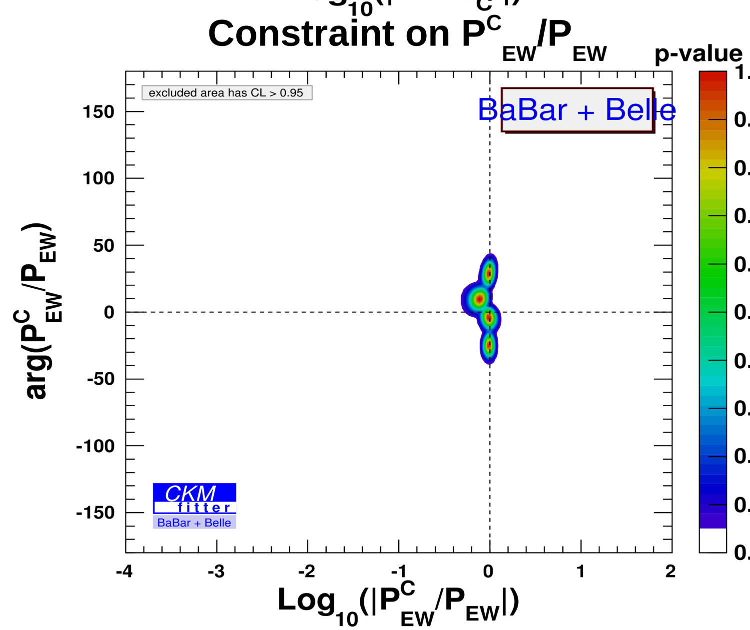


Results on Had. Amplitudes: Hierarchies (II)

- Essentially no constraint is possible on N^{0+}/T^{00} with current data
- Strong constrain on P^{C}_{EW}/P_{EW}
  - 2 solutions at ~0.8 and ~1.0
  - Result on P^{C}_{EW}/P_{EW} is also consequence of the large P_{EW}
  - Needs also confirmation for the $B^0 \to K^+\pi^-\pi^0$ analysis







Prospects for future LHCb and Belle-II data

Prospects for LHCb and Belle-II (I)

- Assume future experiments will measure central values used in the closure test study

- **LHCb will have high statistic measurements in the fully charged modes: $B^0 \to K^0_S(\to\pi^+\pi^-)\pi^+\pi^-$ and $B^+ \to K^+\pi^-\pi^+$**
  - Expect a significant improvement of signal/background ratio w.r.t *BABAR*/Belle
  - Error on $\Delta\phi$(K*-pi+/K*+pi-) scale as $1/\sqrt{Q}$ (effective tagging efficiency)

    $\Rightarrow$ degrade the error by a factor sqrt(30.5/2.38) ~ 3.6
  - Resolution in Dalitz plot $\Rightarrow$ negligible effect according to LHCb experts
  - Scale the errors by the expected statistics
  - LHCb will have signal for $B^0 \to K^+\pi^-\pi^0/B^+ \to K^0_S\pi^+\pi^0$, but difficult to anticipate performances due to π^0 reconstruction efficiency and resolution

- **Belle II will measure all modes: $B^0 \to K^0_S\pi^+\pi^-$, $B^0 \to K^+\pi^-\pi^0$, $B^+ \to K^+\pi^-\pi^+$ and $B^+ \to K^0_S\pi^+\pi^0$**
  - Experimental environment similar to *BABAR*/Belle. Will scale uncertainties by luminosity

    $\Rightarrow$ errors should get reduced by a factor of $\sqrt{(50ab^{-1}/1.0ab^{-1})}$ ~ 7

- **Both LHCb and Belle II will be able to measure $B^+ \to K^+\pi^-\pi^+$ mode with high precision**
  - Will be able to well define the signal model and probe line-shapes of the main components
  - Model systematics will be significantly reduced $\Rightarrow$ assume negligible model uncertainty

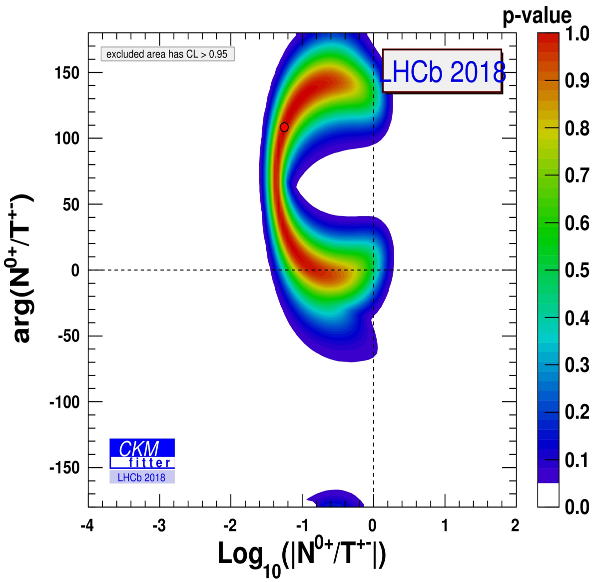
Prospects for LHCb and Belle-II (II)

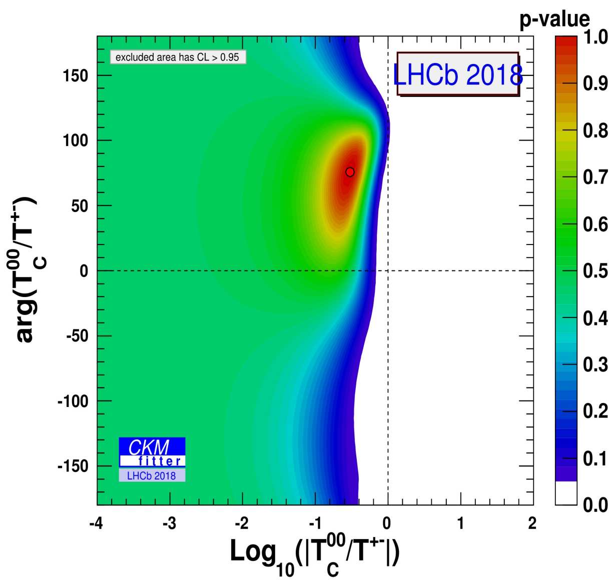
Expected evolution of the uncertainties on the observables

Observable	Analysis	Current	LHCb (run1+run2)	Belle-II
$\mathrm{Re}(A(K^{*-}\pi^+)/A(K^{*+}\pi^-))$	$B^0\to K^0\pi^+\pi^-$	0.11	0.04	0.014
$\mathrm{Im}(A(K^{*-}\pi^+)/A(K^{*+}\pi^-))$	$B^0\to K^0\pi^+\pi^-$	0.16	0.11	0.023
$B(K^{*-}\pi^+)\mathrm{x}10^{-6}$	$B^0\to K^0\pi^+\pi^-$	0.69	0.32	0.094
$\lvert A(K^{*-}\pi^+)/A(K^{*+}\pi^-)\rvert$	$B^0\to K^+\pi^-\pi^0$	0.06	0.06	0.008
$\mathrm{Re}(A(K^{*0}\pi^0)/A(K^{*+}\pi^-))$	$B^0\to K^+\pi^-\pi^0$	0.11	0.11	0.016
$\mathrm{Im}(A(K^{*0}\pi^0)/A(K^{*+}\pi^-))$	$B^0\to K^+\pi^-\pi^0$	0.23	0.23	0.033
$\mathrm{Re}(A(\overline{K^{*0}}\pi^0)/A(K^{*+}\pi^-))$	$B^0\to K^+\pi^-\pi^0$	0.10	0.10	0.014
$\mathrm{Im}(A(\overline{K^{*0}}\pi^0)/A(K^{*+}\pi^-))$	$B^0\to K^+\pi^-\pi^0$	0.30	0.30	0.042
$B(K^{*0}\pi^0)\mathrm{x}10^{-6}$	$B^0\to K^+\pi^-\pi^0$	0.35	0.35	0.05
$\lvert A(\overline{K^{*0}}\pi^-)/A(K^{*0}\pi^+)\rvert$	$B^+\to K^+\pi^-\pi^+$	0.04	0.005	0.004
$B(K^{*0}\pi^+)\mathrm{x}10^{-6}$	$B^+\to K^+\pi^-\pi^+$	0.81	0.50	0.113
$\lvert A(K^{*-}\pi^0)/A(K^{*+}\pi^0)\rvert$	$B^+\to K^0\pi^+\pi^0$	0.15	0.15	0.021
$\mathrm{Re}(A(K^{*+}\pi^0)/A(K^{*0}\pi^+))$	$B^+\to K^0\pi^+\pi^0$	0.16	0.16	0.023
$\mathrm{Im}(A(K^{*+}\pi^0)/A(K^{*0}\pi^+))$	$B^+\to K^0\pi^+\pi^0$	0.30	0.30	0.042
$\mathrm{Re}(A(K^{*+}\pi^0)/A(\overline{K^{*0}}\pi^+))$	$B^+\to K^0\pi^+\pi^0$	0.21	0.21	0.030
$\mathrm{Im}(A(K^{*+}\pi^0)/A(\overline{K^{*0}}\pi^+))$	$B^+\to K^0\pi^+\pi^0$	0.13	0.13	0.018
$B(K^{*+}\pi^0)\mathrm{x}10^{-6}$	$B^+\to K^0\pi^+\pi^0$	0.92	0.92	0.130

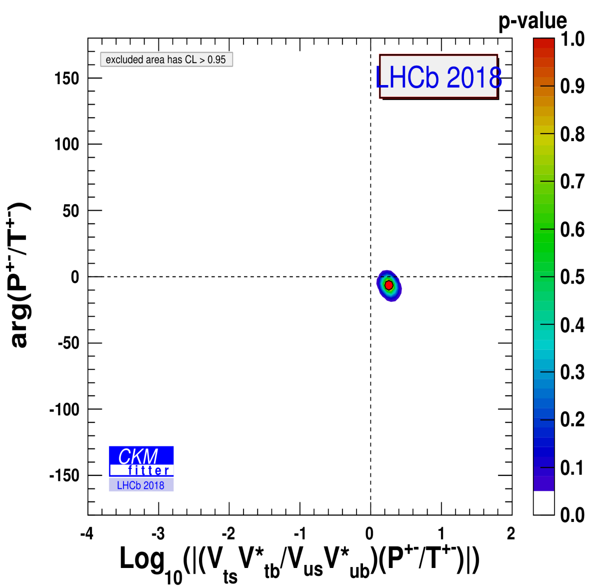
- LHCb cannot perform B-counting like in B-factories
- BF are normalized w.r.t modes measured somewhere else (mainly @ B-factories)
- Error contribution from norm. modes not scaling with stat.
- $B(B^0\to K^{*+}\pi^-)$ norm. mode: $B(B^0\to K^0\pi^+\pi^-)$ (σ_{rel} ~4%)
- $B(B^+\to K^{*0}\pi^+)$ norm. mode: $B(B^+\to K^+\pi^-\pi^+)$ (σ_{rel} ~5%)

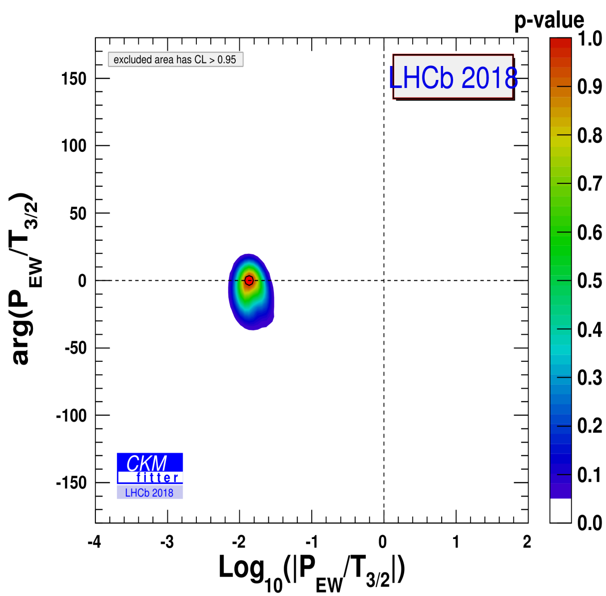
Had. Pars. : LHCb (run1+run2) 2018

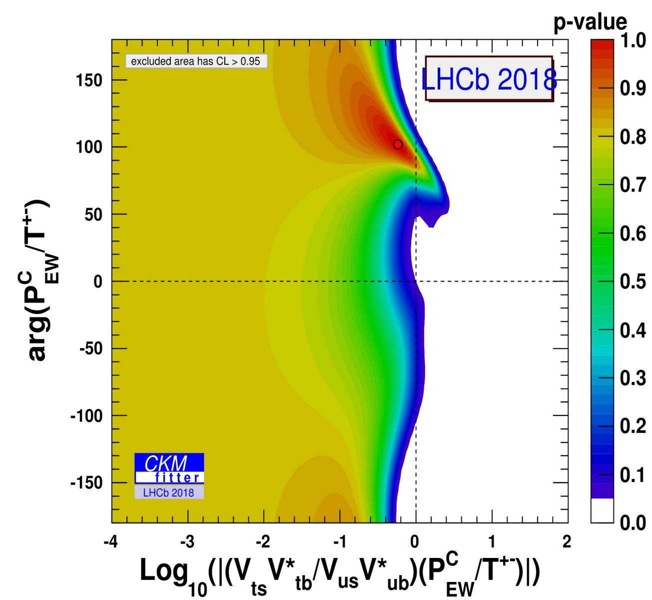




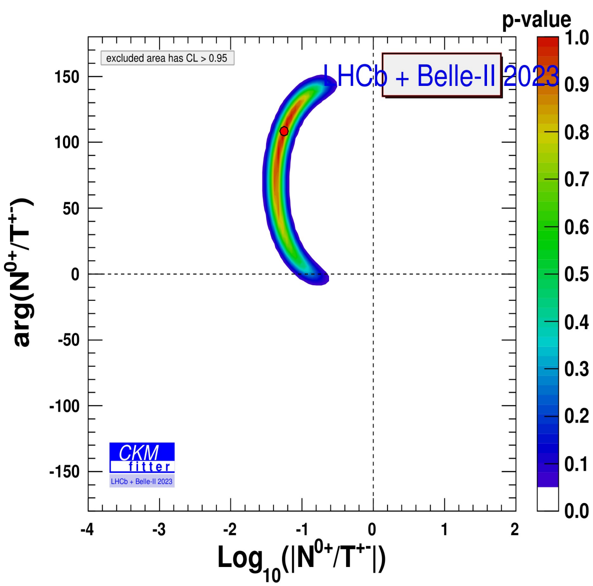
- Main impact of LHCb data on N^{0+}, P^{+-} and P_{EW}
- Only upper limits on T^{00} and P^{C}_{EW}

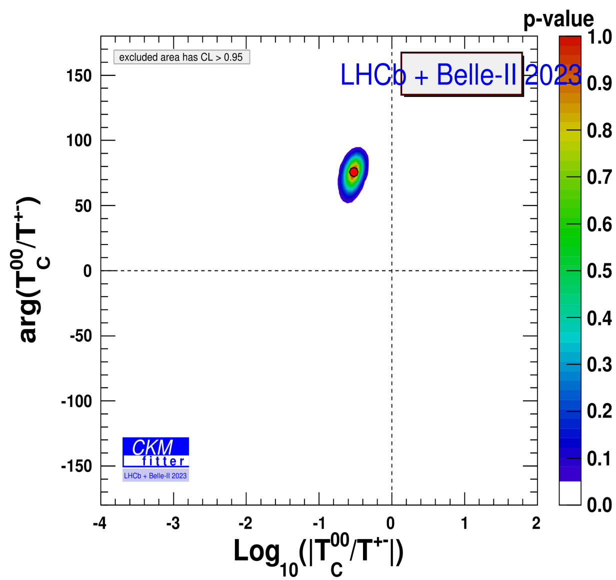




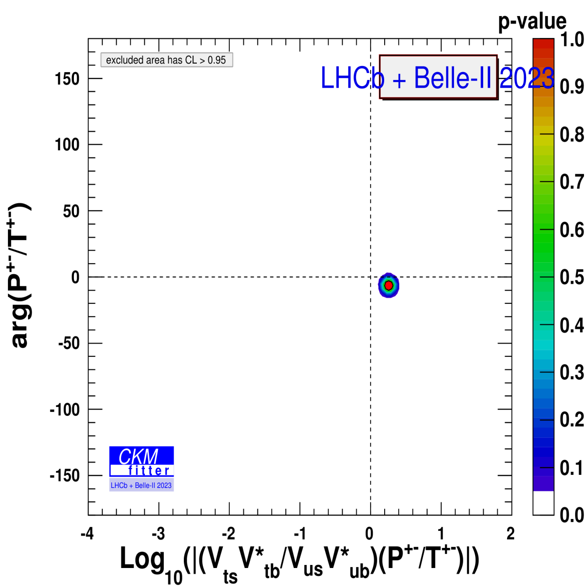


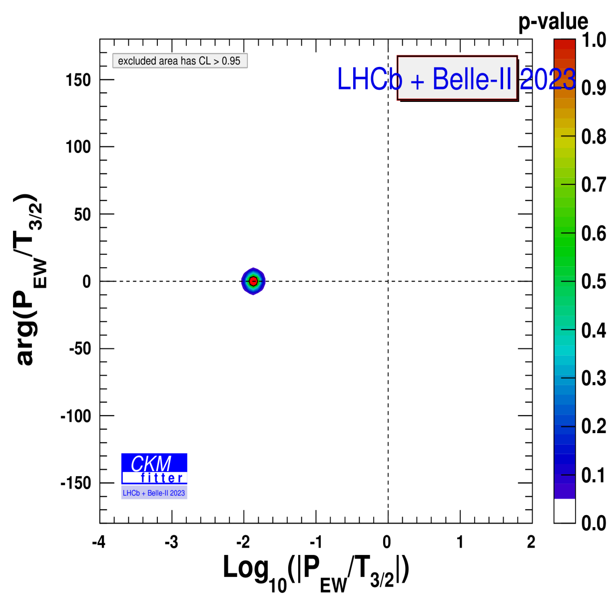
Had. Pars. : LHCb + Belle-II 2023

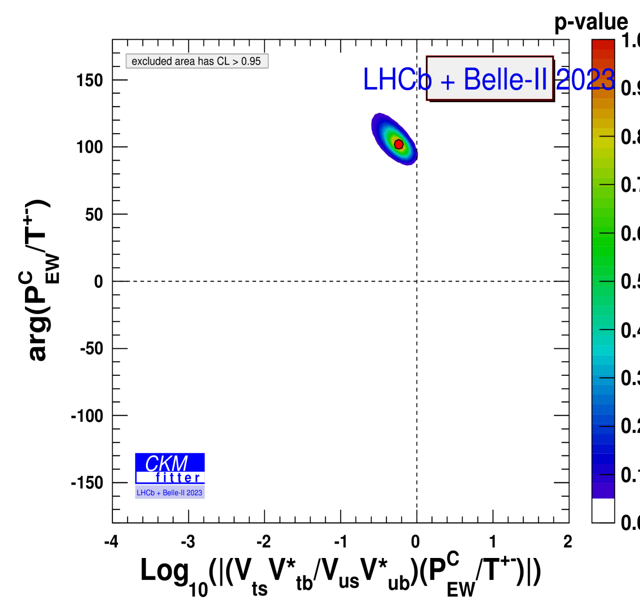




- With LHCb + Belle-II data will be able to make precision measurements on the hadronic parameters
- Precision test of QCD predictions







Summary and Outlook

Summary and Outlook (I)

- **$B \to K^*\pi$ system has a large amount of physical observables among charmless decays**
  - Charmless B decay system with as many observables as unknowns
  - Large potential for phenomenology of charmless B decays
    - Model-independent extraction of hadronic parameters (assuming CKM and SU(2) as only hypotheses)
    - Extraction of CKM parameters limited by hadronic uncertainties

- **Extraction of CKM parameters**
  - α-like constraints spoiled by sensitivity to electroweak penguins
  - β-like constraints in the vanishing annihilation approximation
    - Future constraints from annihilation-dominated $B \to PV$ modes could be used
    - LHCb measurement of $B_{(s)} \to K^*K$ will play an important contribution to this program

Summary and Outlook (II)

- **Study of hadronic amplitudes with available experimental data**
  - For the first time, at least one complete amplitude analysis of each $B\to K\pi\pi$ mode available
  - Evidence of CP-violation provides strong constraints on the relevant tree-to-penguin ratios
  - Loose bounds on colour-suppressed tree and annihilation amplitudes
  - Current data favours relatively large EWPs
    - Mainly driven by *BABAR* $B^0\to K^+\pi^-\pi^0$ analysis
    - If confirmed, would set evidence for EWPs in charmless B decays
    - Until now, EWPs only established in $\varepsilon'/\varepsilon\neq0$ (radiative B decays are different operators)

- **Expect significant improvements with LHCb and Belle II data**
  - Model-independent measurement of all hadronic parameters
    - Both amplitudes and phases can be measured with outstanding accuracy
  - Results on hadronic $B\to K^*\pi$ parameters can be used as “standard candles” to study other $B_{(s)}\to PV$ modes
    - $B_s\to K^*\pi$, $B_{(s)}\to K^*K$, $B_{(s)}\to\rho K$

Back up Slides

Parameterization

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot Isobar Model

$$\begin{cases} A(DP) = \sum a_j F_j(DP) \\ \overline{A}(DP) = \sum \overline{a}_j \overline{F}_j(DP) \end{cases}$$

Shapes of intermediate states over DP

$$F_j^L(DP) = R_j(m) \times X_L(|\vec{p}^\star|r) \times X_L(|\vec{q}|r) \times T_j(L, \vec{p}, \vec{q})$$

Rela

Gou

$$R_j(m_{K\pi}) = \underbrace{\frac{m_{K\pi}}{q\cot\delta_B - iq}}_{\text{Effective Range Term}} + e^{2i\delta_B} \frac{m_0\Gamma_0 \frac{m_0}{q_0}}{(m_0^2 - m_{K\pi}^2) - i m_0 \Gamma_0 \frac{q}{m_{K\pi}} \frac{m_0}{q_0}}$$

S-wave Kπ: **LASS lineshape.**

Nucl. Phys., B296:493, 1988

$B \to \rho K$ System: Physical Observables

$$A(B^0 \to \rho^+ K^-) = V_{us} V^*_{ub} t^{+-} + V_{ts} V^*_{tb} p^{+-}$$

$$A(B^+ \to \rho^0 K^+) = V_{us} V^*_{ub} n^{0+} + V_{ts} V^*_{tb} (-p^{+-} + p^C_{EW})$$

$$\sqrt{2}A(B^+ \to \rho^+ K^0) = V_{us} V^*_{ub} (t^{+-} + t^{00}_C - n^{0+}) + V_{ts} V^*_{tb} (p^{+-} - p^C_{EW} + p_{EW})$$

$$\sqrt{2}A(B^0 \to \rho^0 K^0) = V_{us} V^*_{ub} t^{00}_C + V_{ts} V^*_{tb} (-p^{+-} + p_{EW})$$

11 QCD and 2 CKM = 13 unknowns

Same Isospin relations as $K^*\pi$

Observables:

- 4 BFs and 4 A_{CP} from DP and Q2B analyses.
- 1 phase differences:
  * $2\beta_{eff} = \arg((q/p)\overline{A}(\overline{B^0} \to \rho^0 \overline{K^0}) A^*(B^0 \to \rho^0 K^0))$ from $B^0 \to K^0_S \pi^+ \pi^-$

A total of 9 observables

Under constraint system. Still some constrains possible

$\rho K + K^{*}\pi$ system: Physical Observables

Global phase between $K^{*}\pi$ and ρK now accessible:

- $K^{*}\pi$: 11 hadronic parameters (1 global phase fixed)
- ρK: 12 parameters
- CKM: 2 parameter

A total of = 25 unknowns

Observables:

- $K^{*}\pi$ only: 13 observables
- ρK only: 9 observables
- 7 phase differences from: interference between $K^{*}\pi$ and ρK resonances contributing to the same DP
  - $\phi = \arg(A(B^0 \to \rho^0 K^0) A^*(B^0 \to K^{*+}\pi^-))$ from $B^0 \to K^0_S \pi^+\pi^-$
  - $\phi = \arg(A(B^0 \to \rho^- K^+) A^*(B^0 \to K^{*+}\pi^-))$ and CP conjugated from $B^0 \to K^+\pi^-\pi^0$
  - $\phi = \arg(A(B^0 \to \rho^0 K^+) A^*(B^0 \to K^{*0}\pi^+))$ and CP conjugated from $B^+ \to K^+\pi^-\pi^+$
  - $\phi = \arg(A(B^0 \to \rho^+ K^0) A^*(B^0 \to K^{*+}\pi^0))$ and CP conjugated from $B^+ \to K^0\pi^+\pi^0$

A total of 29 experimentally independent observables

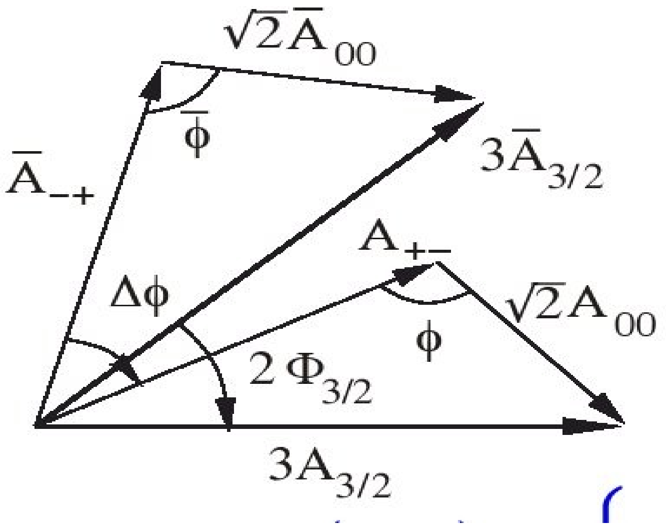
$B \to K^{*}\pi$ System: extraction of α (CPS/GPSZ)

Neglecting P_{EW}, the amplitude combinations:

$$3A_{3/2} = A(B^0 \to K^{*+}\pi^-) + \sqrt{2}.A(B^0 \to K^{*0}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00})$$

$$3\overline{A}_{3/2} = \overline{A}(\overline{B^0} \to \overline{K}^{*-}\pi^+) + \sqrt{2}.\overline{A}(\overline{B^0} \to \overline{K}^{*0}\pi^0) = V^*_{us}V_{ub}(T^{+-}+T^{00})$$

which gives: $R_{3/2} = (q/p)(3A_{3/2})/(3\overline{A}_{3/2}) = e^{-2i\beta}e^{-2i\gamma} = e^{-2i\alpha}$



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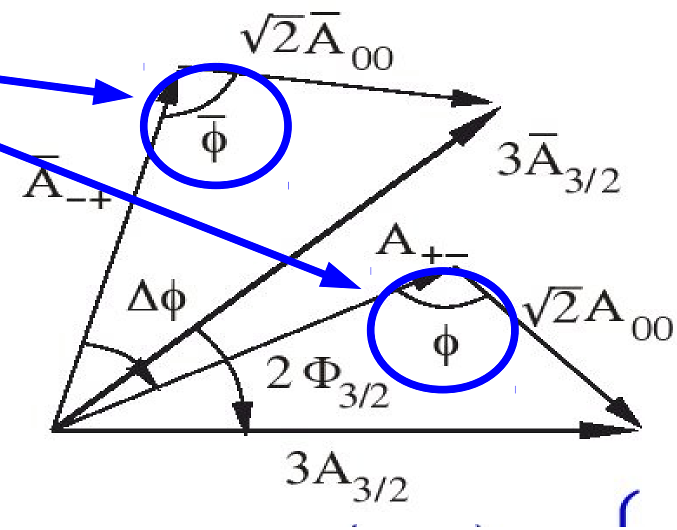
which gives: $R_{3/2} = (q/p)(3A_{3/2})/(3\overline{A}_{3/2}) = e^{-2i\beta}e^{-2i\gamma} = e^{-2i\alpha}$

From experiment:

$$\phi = \arg(A(B^0\to K^{*+}\pi^-)A^*(B^0\to K^{*0}\pi^0))$$

$$\overline{\phi} = \arg(\overline{A}(\overline{B^0}\to K^{*-}\pi^+)\overline{A}^*(\overline{B^0}\to \overline{K^{*0}}\pi^0))$$

Measured from an amplitude analysis of $B^0\to K^+\pi^-\pi^0$ decays



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$$3A_{3/2} = A(B^0 \to K^{*+}\pi^-) + \sqrt{2}.A(B^0 \to K^{*0}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00})$$

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From experiment:

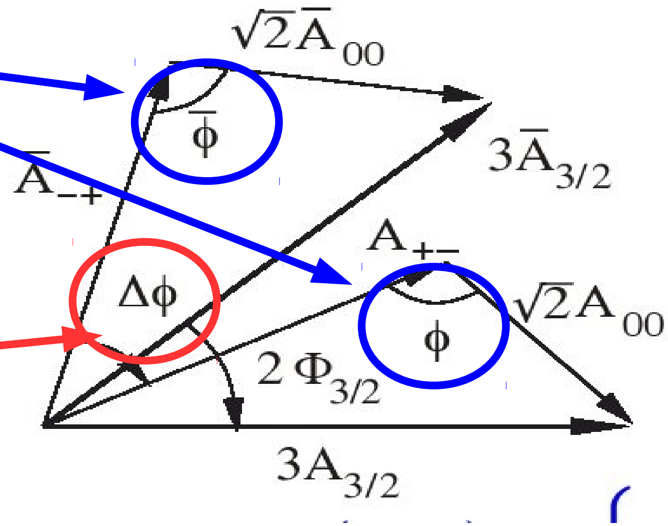
$$\phi = \arg(A(B^0 \to K^{*+}\pi^-)A^*(B^0 \to K^{*0}\pi^0))$$

$$\overline{\phi} = \arg(\overline{A}(\overline{B^0} \to K^{*-}\pi^+)\overline{A}^*(\overline{B^0} \to \overline{K^{*0}}\pi^0))$$

Measured from an amplitude analysis of $B^0 \to K^+\pi^-\pi^0$ decays

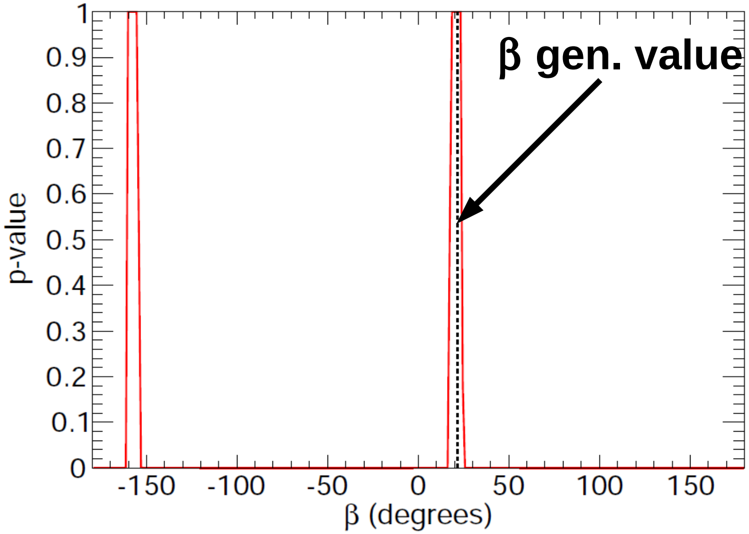
$$\Delta\phi = \arg((q/p)\overline{A}(\overline{B^0} \to K^{*-}\pi^+)A^*(B^0 \to K^{*+}\pi^-))$$

Measured from a time-dependent amplitude analysis of $B^0 \to K^0_s\pi^+\pi^-$ decays

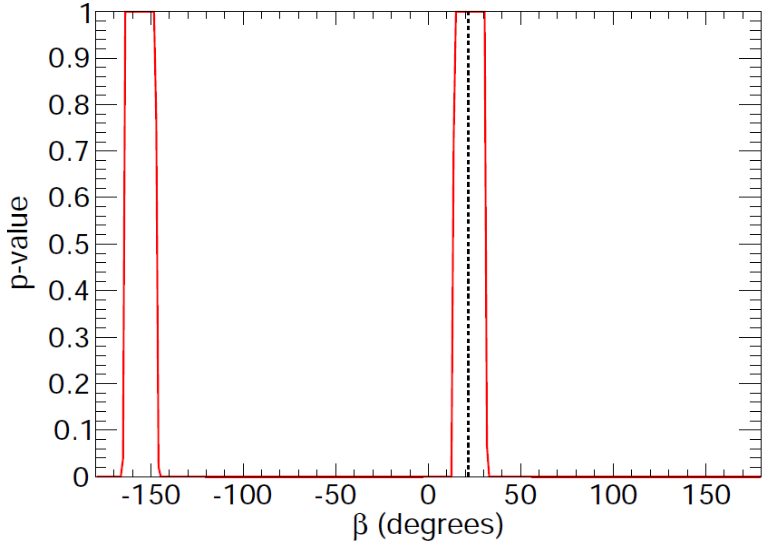


Scenarios to constrain CKM: hypothesis on N^{0+} (III)

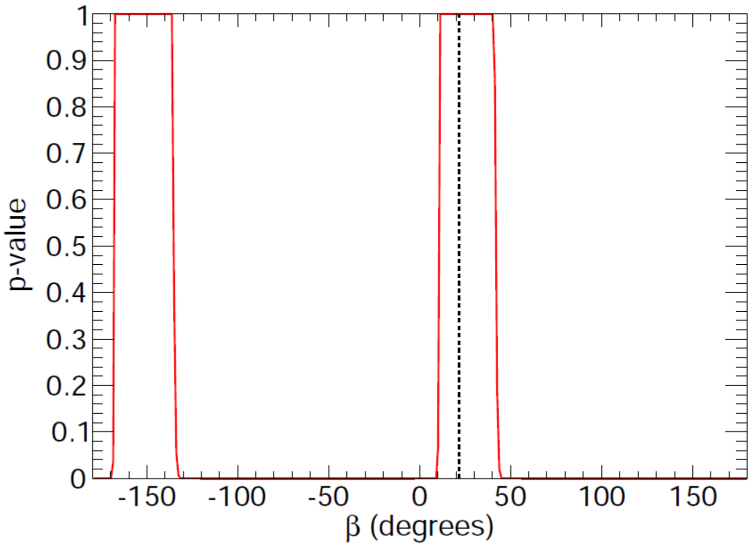
$|N^{0+}/T^{+-}|$ < 1.5x(gen val)



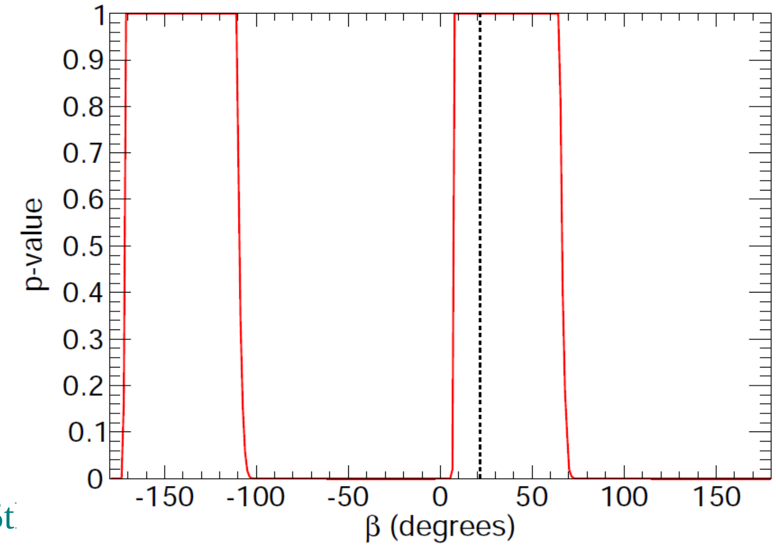
$|N^{0+}/T^{+-}|$ < 5x(gen val)



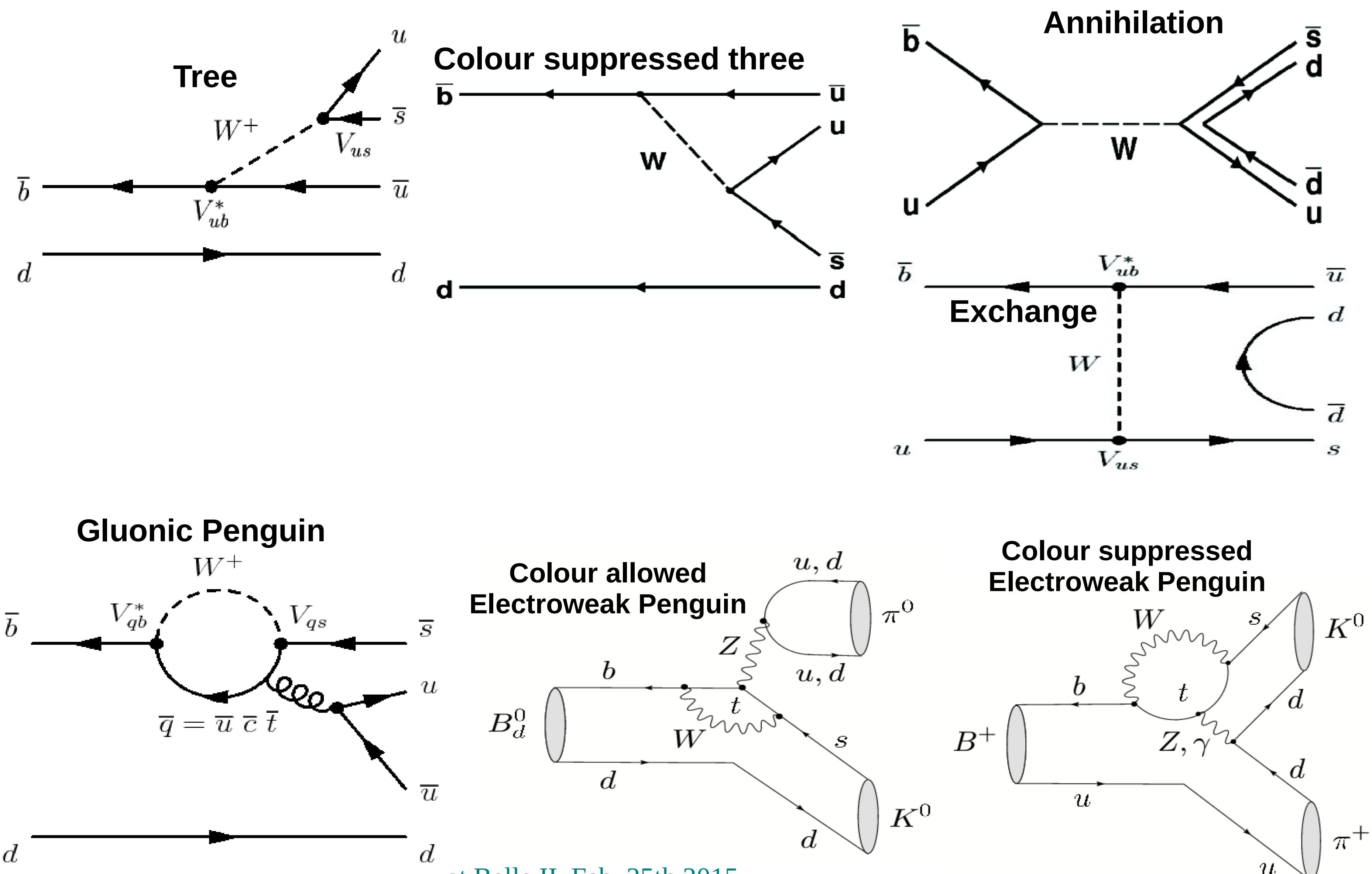
$|N^{0+}/T^{+-}|$ < 10x(gen val)



$|N^{0+}/T^{+-}|$ < 15x(gen val)



Feynman Diagrams



CPS/GPSZ theoretical prediction

- Effective Hamiltonian of B→K*π

$$\mathcal{H} = \frac{G_F}{\sqrt{2}} \left\{ \sum_{i=1,2} c_i \left(\Omega_u Q_i^u + \Omega_c Q_i^c \right) - \Omega_t \sum_{i=3}^{10} c_i Q_i \right\} + \texttt{h.c.}, \text{ with } \quad \Omega_q = V_{qs} V_{qb}^*$$

- Hierarchy of Wilson coefficients for electro-weak operators $|c_{9,10}| \gg |c_{7,8}|$

$$[\mathcal{H}_{EWP}]_{\Delta I=1} = \frac{3}{2}\frac{c_9 + c_{10}}{2}\left[Q_1^u + Q_2^u\right]_{\Delta I=1} + \frac{3}{2}\frac{c_9 - c_{10}}{2}\left[Q_1^u - Q_2^u\right]_{\Delta I=1}$$ Electro-weak Hamiltonian

$$[\mathcal{H}_{CC}]_{\Delta I=1} = \frac{c_1 + c_2}{2}\left[Q_1^u + Q_2^u\right]_{\Delta I=1} + \frac{c_1 - c_2}{2}\left[Q_1^u - Q_2^u\right]_{\Delta I=1}$$ Current-current Hamiltonian

- Using $\left(\frac{c_9 + c_{10}}{c_1 + c_2} \simeq -0.0084\right) \simeq \left(\frac{c_9 - c_{10}}{c_1 - c_2} \simeq +0.0084\right)$

$$[\mathcal{H}_{EWP}]_{\Delta I=1} = R\frac{c_1 + c_2}{2}\left[Q_1^u + Q_2^u\right]_{\Delta I=1} - R\frac{c_1 - c_2}{2}\left[Q_1^u - Q_2^u\right]_{\Delta I=1}$$

$R = (3/2)(c_9 + c_{10})/(c_1 + c_2)$
R = (1.35 ± 0.12)%

- Obtain the relation $P_{EW} = R_{eff} (T^{+-} + T^{00})$,
  with $R_{eff} = R(1 + r_{VP})/(1 - r_{VP})$ $\quad r_{VP} = \frac{\langle K^*\pi(I=3/2)|Q_-|B\rangle}{\langle K^*\pi(I=3/2)|Q_+|B\rangle}, \quad Q_\pm = (Q_1 \pm Q_2)/2.$

$$r_{VP} = \left| \frac{f_{K^*} F_0^{B\to\pi} - f_\pi A_0^{B\to K^*}}{f_{K^*} F_0^{B\to\pi} + f_\pi A_0^{B\to K^*}} \right| \lesssim 0.05$$

Outlook

- **CKM constraints**
  - $B^0 \to K^{*0}\pi^+$ and $B^0_s \to K^{*0}K^+$ modes related by U-spin

    $\Rightarrow$ expects the same annihilation amplitude (N^{0+}) up to U-spin breaking effects

    $A(B^0_s \to K^{*0}K^+) = V_{ud}V^*_{ub}N^{0+} + V_{ts}V^*_{tb}P^{0+}_s$
  - LHCb will measure this modes in the near future
  - Can include this mode in out phenomenological framework to set a bound on N^{0+} and be able to set constraints on CKM

- **Extending the $B \to K^*\pi$ system: include $B \to \rho K$ modes**
  - $B \to \rho K$ resonances also contribute to the $B \to K\pi\pi$ final states and hav same isospin relations as $B \to K^*\pi$ $\Rightarrow$ same number of hadronic parameters
  - Smaller number of observables (9) than $B \to K^*\pi$ (13), but can measure interference phases (7) between $B \to K^*\pi$ and $B \to \rho K$ modes
  - Combined system $B \to K^*\pi$ + $B \to \rho K$
    - Unknowns: 11 + 12 hadronic from $B \to K^*\pi$ and $B \to \rho K$ + 2 CKM = 25
    - Observables: 13 + 9 from $B \to K^*\pi$ and $B \to \rho K$ + 7 phase differences = 28
    - Still need hypothesis on hadronic or CKM to raise reparametrization invariance