Charm observables and the extraction of the CKM angle γ/ϕ_3

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The UT angle γ/ϕ_3

a key input quantity in any CKM analysis

its determination from experimental data is very clean theoretically (decays with a single CP phase)

it's a 'pure tree' coupling: it's independent of the possible contribution of new particles in loops $\rightarrow$ a SM reference input

it was thought as a difficult challenge for B factories at the time of the BaBar book; the challenge has been met ($\sigma_\gamma \sim 10^\circ$) and the high precision determination of γ is one of the key tasks of LHCb

Main methods

they all rely at the quark level on the interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$ transitions (no penguin contribution)

at the hadronic level, considering $B^- \to \overline{D^0}K^-,\ D^0K^-$ decays, the interference depends critically on the ratio r_B of color-suppressed to color-allowed amplitudes: $r_B \sim 0.10 - 0.20$ depending on modes $(DK,\ D^*K,\ DK^*)$

the actual extraction of γ depends on the D decay: this is where charm physics enter into the game

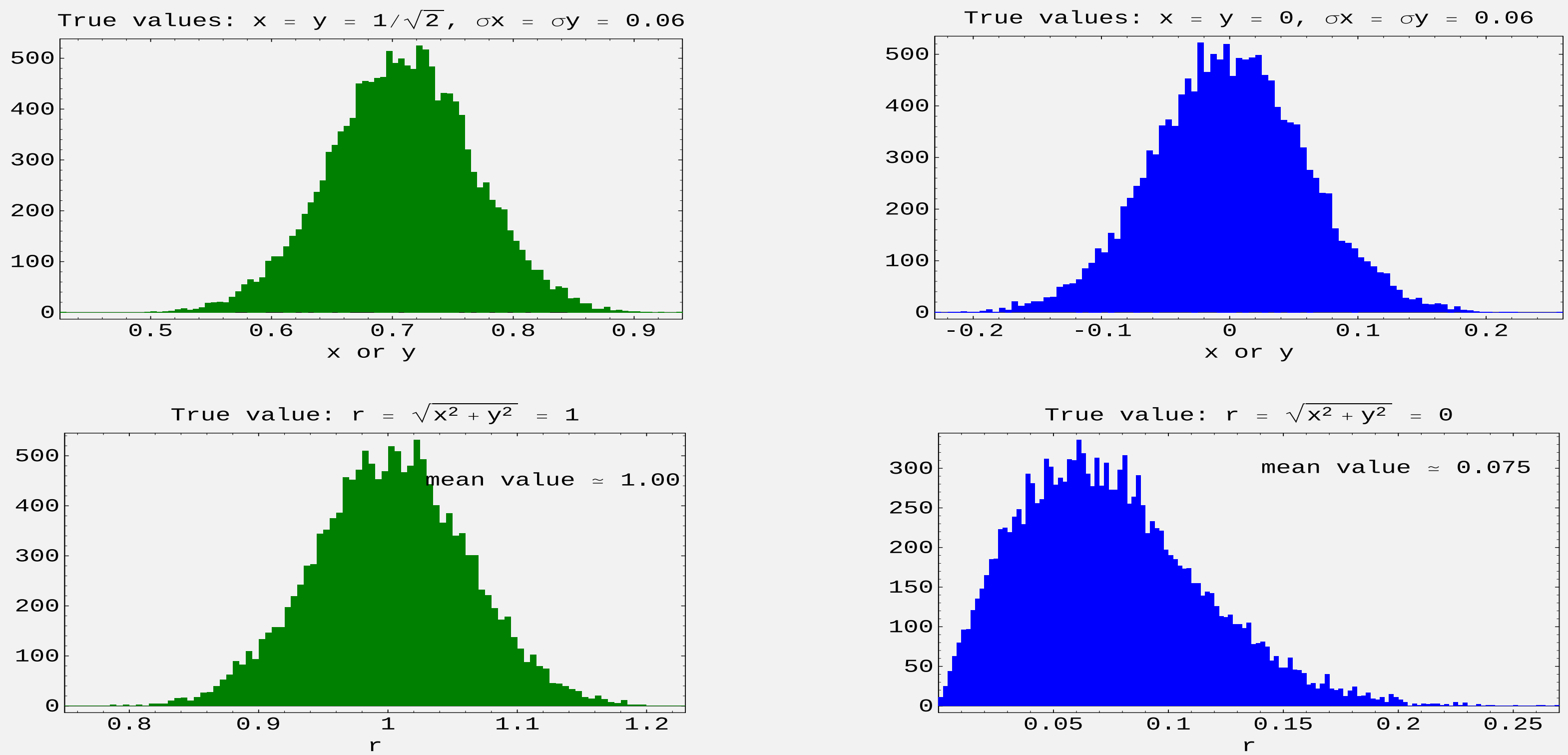
one can use CP eigenstates (GLW), doubly Cabibbo suppressed $K\pi$ modes (ADS), or three-body Dalitz decays (GGSZ)

also $B_s \to D_sK$ will be exploited at LHCb

The small r_B issue

clearly in the $r_B \to 0$ limit the interference disappears and there is no sensitivity to the phase γ

when the true value of r_B is small, then the distribution of $\hat{r}_B$ best fit values for randomly generated data is biased towards larger values, until the experimental errors are sufficiently small to exclude the $r_B \sim 0$ region



on the other hand the error on γ is roughly proportional to $1/r_B$, hence for small r_B it is biased towards smaller values

in the language of frequentist statistics it means that the usual $\Delta \ln \mathcal{L} = 1/2$ rule does not work here, the 68%CL interval extracted from it does not cover the true value of γ at 68% frequency (undercoverage)

to correct for this effect one has to compute the actual distribution of the profile log-likelihood, and from that distribution deduce a p-value or a CL interval

problem: as soon as the log-likelihood is not distributed as a χ^2, its distribution *a priori* depends on the *nuisance parameters*, namely r_B, δ_B etc.

Different treatments of the nuisance parameters

JC, S. T'Jampens, V. Tisserand, K. Trabelsi (CKMfitter) to appear

to compute the distribution of the log-likelihood, depending on the nuisance parameters ν:

- use the best fit estimate, $\nu = \hat{\nu}$ (plugin method): coverage is not guaranteed if the true value of ν is different from $\hat{\nu}$
- use the worst-case distribution, *i.e.* maximize the p-value over all possible values of ν (supremum method): coverage or overcoverage is guaranteed by construction
- maximize the p-value over a well chosen subspace $\nu \in \mathcal{N}$

actual coverage tests for the γ analysis show that the plugin method can significantly undercover, while the supremum method can overcover

Berger and Boos (JASA 89, 427 (1994)) showed that for the third option one can choose $\mathcal{N}$ as a well defined $1-\beta$ confidence region to construct the following valid p-value (constrained supremum method):

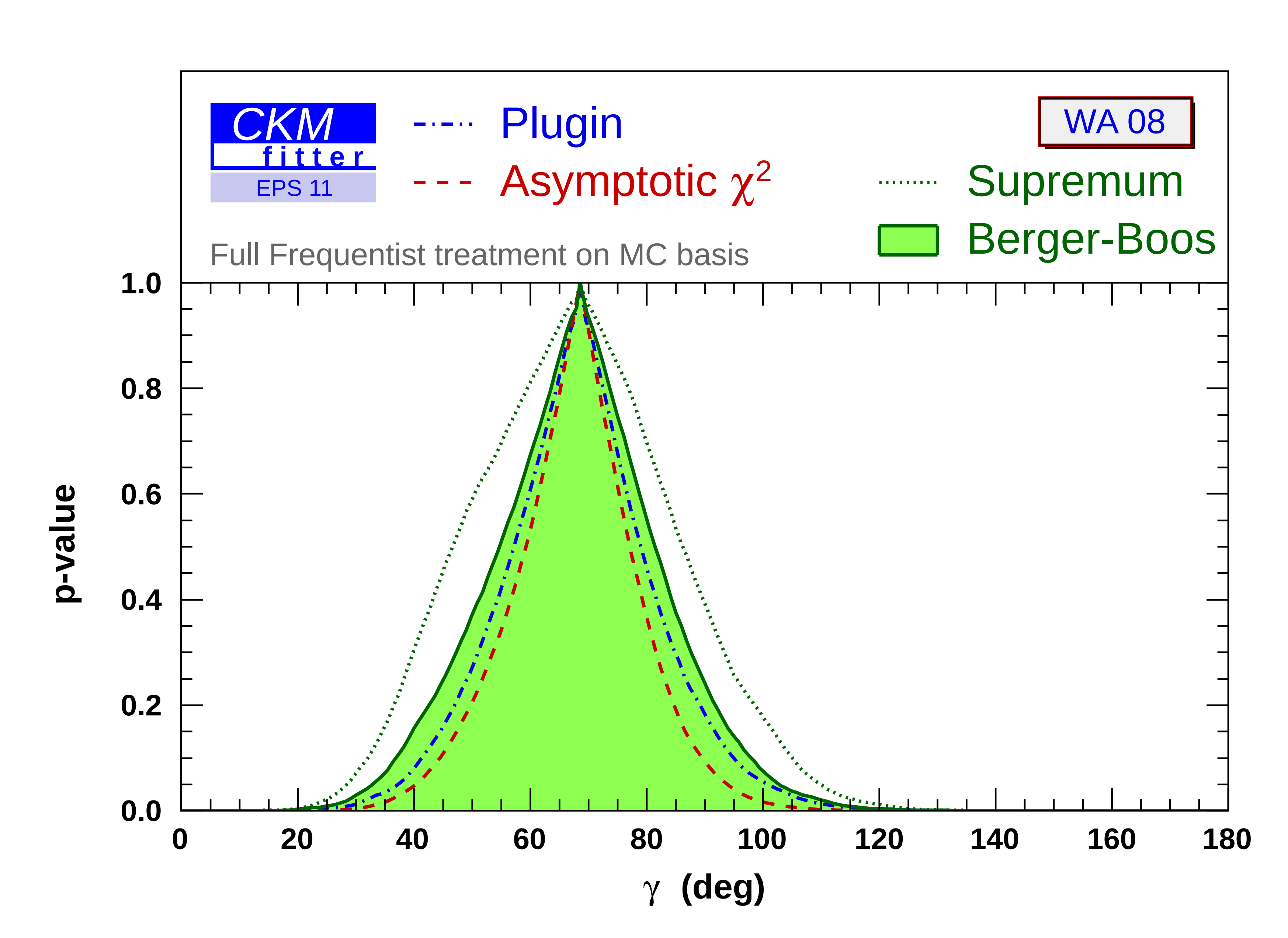
$$p = \text{Max}_{\nu \in \mathcal{N}_\beta}\, p_\nu + \beta$$

in our case we construct $\mathcal{N}_\beta$ from the distribution of the full likelihood as a function of both γ and ν, and choose β as the value that corresponds to 3.3 standard deviations

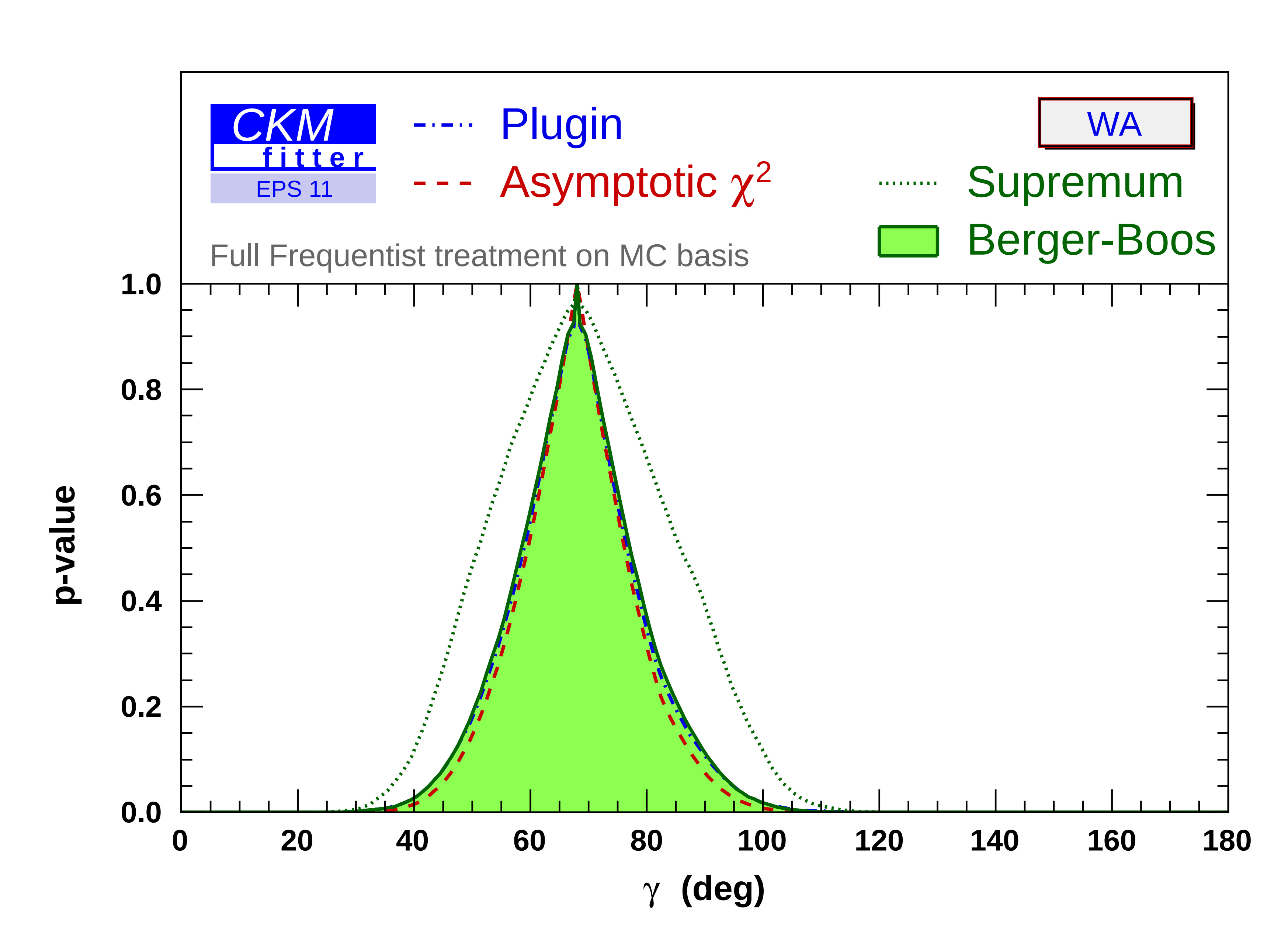
ADS observables recently measured at Belle, CDF and LHCb contribute signicantly to constrain the r_B's away from zero: for the first time the dependence wrt nuisance parameters is weak in the region that is supported by the data $\rightarrow$ convergence between asymptotic χ^2, plugin and constrained supremum method

warning: convergence is not necessarily observed when considering subsets of the full analysis (GGSZ only, or Belle data only, etc.)

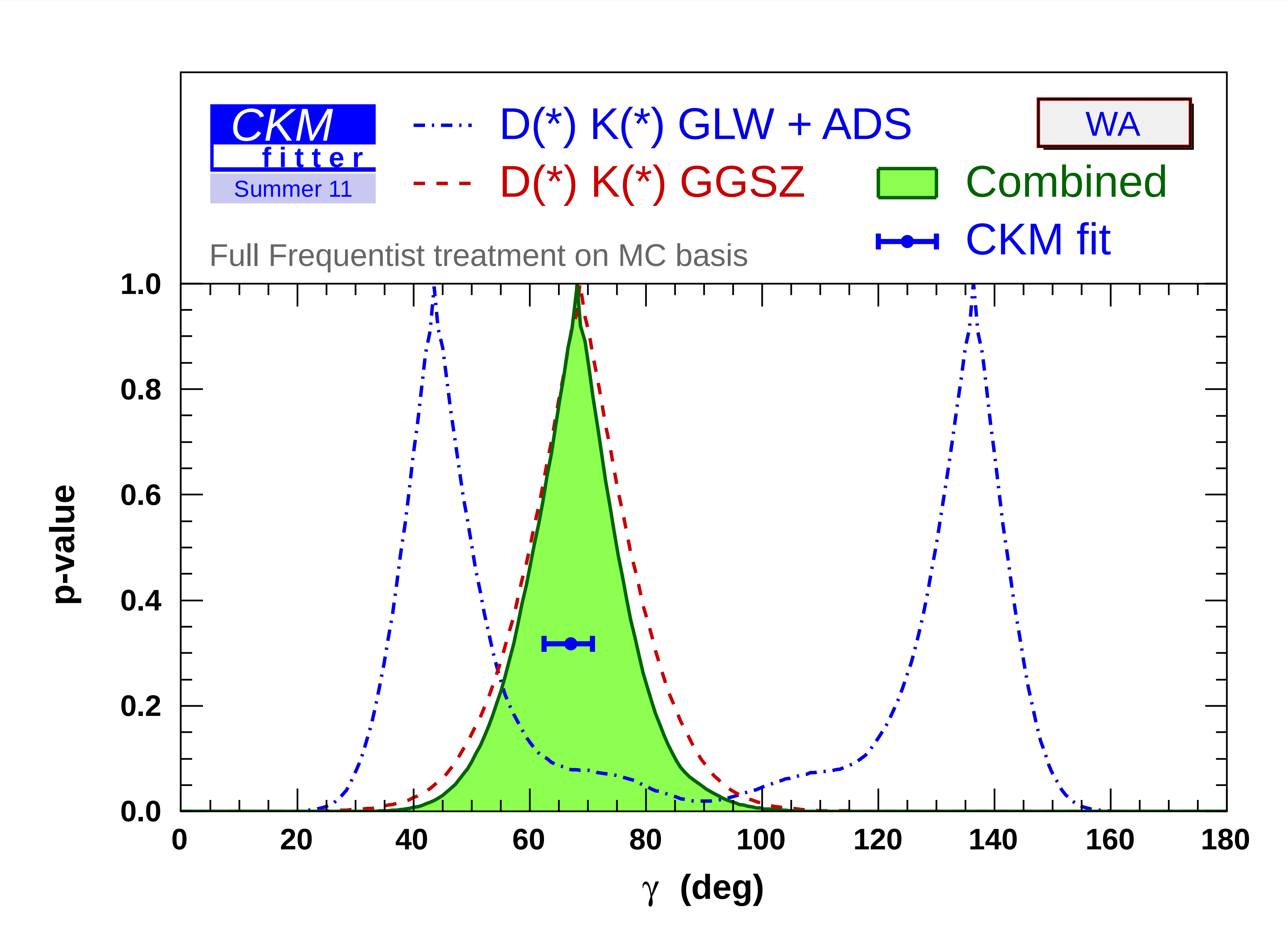
The situation after Summer 2008



The situation in early Summer 2011



After Summer 2011: $\gamma = (68 \pm 10)^\circ$



Consistency tests within the γ analysis

the full GGSZ/GLW/ADS γ analysis depends on 32 observables (may increase in the future): the constraint on γ and its consistency with the indirect CKM global fit is not the whole story

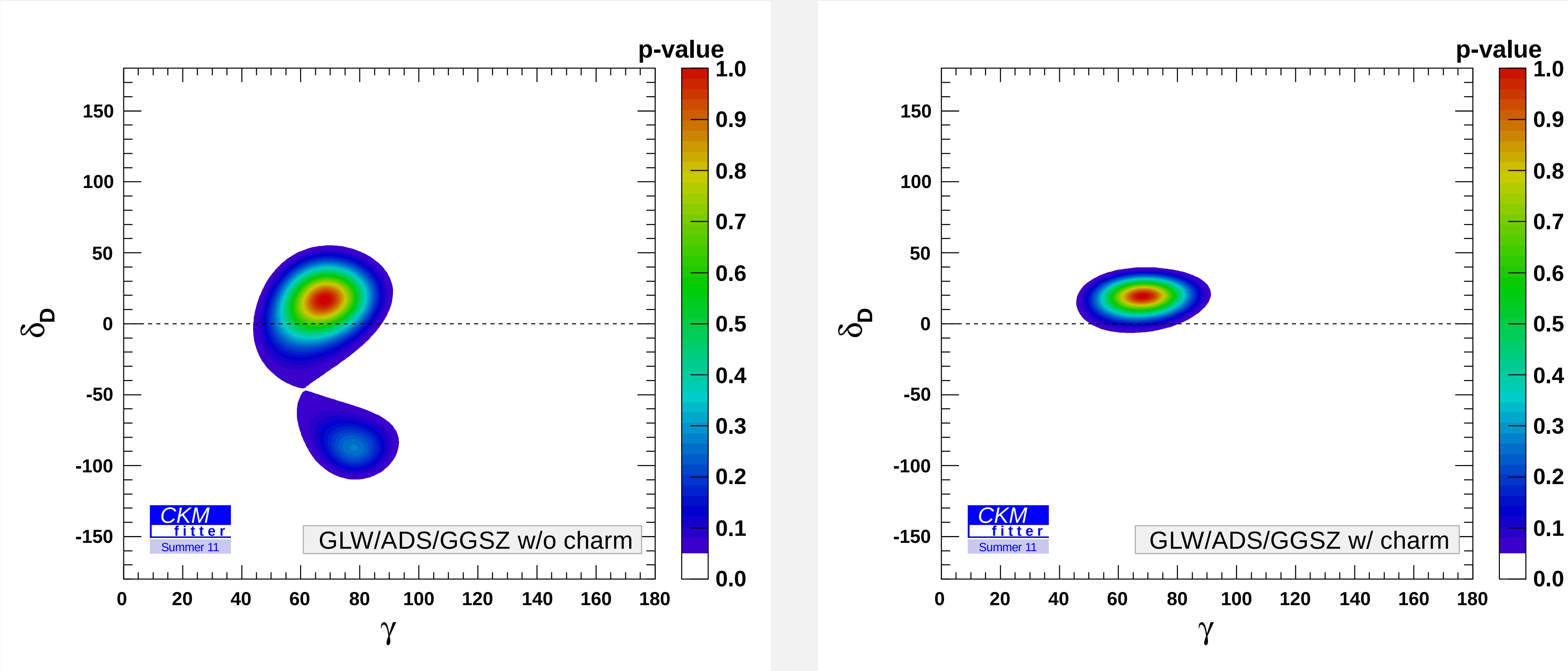
one can perform a partial analysis of a given subset of observables, and predict the remaining ones, to be compared with their direct measurement

this approach is particularly interesting in light of the recent measurements of the charm observables that are related to δ_D, and of the improvement of ADS observables

in the following:

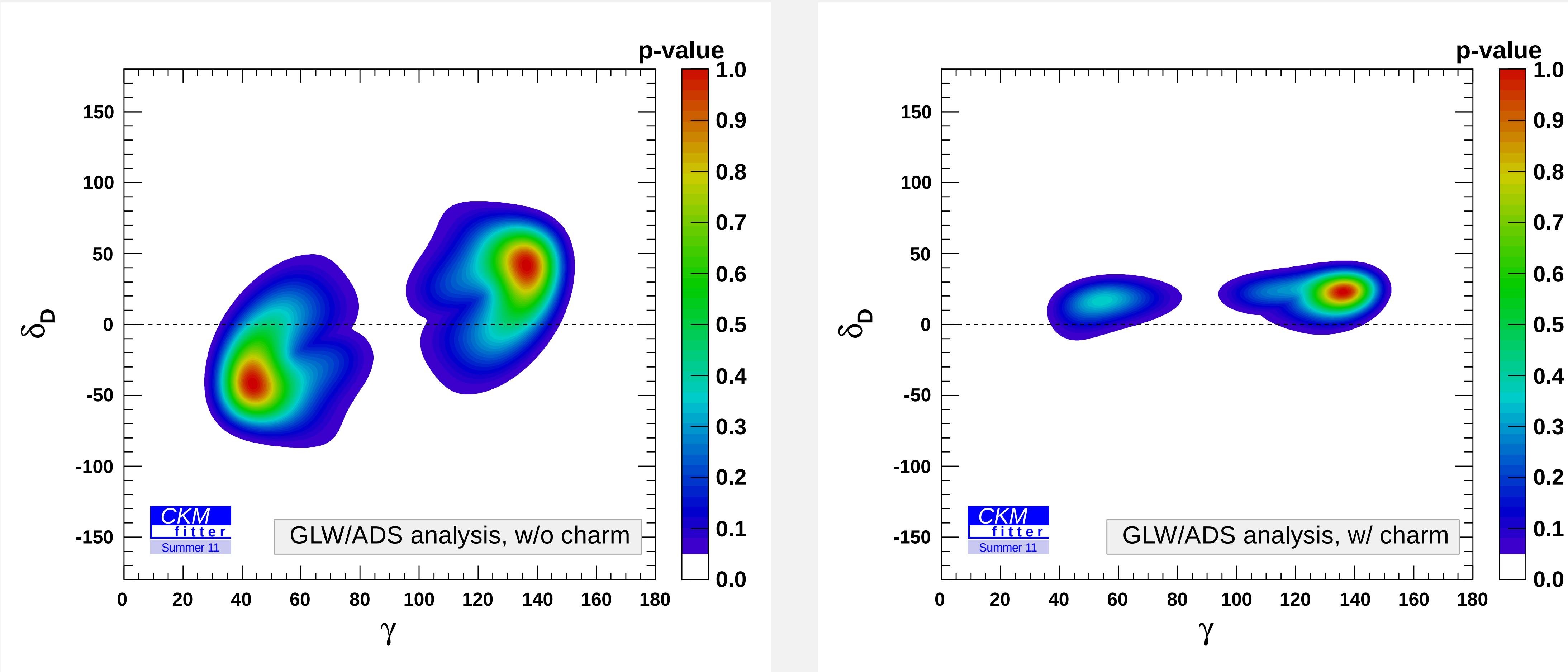
- impact of the charm observables on the γ analysis (δ_D and γ)
- indirect predictions of GLW and ADS observables and comparison with the direct measurements

The full GGSZ/GLW/ADS analysis with and without charm observables



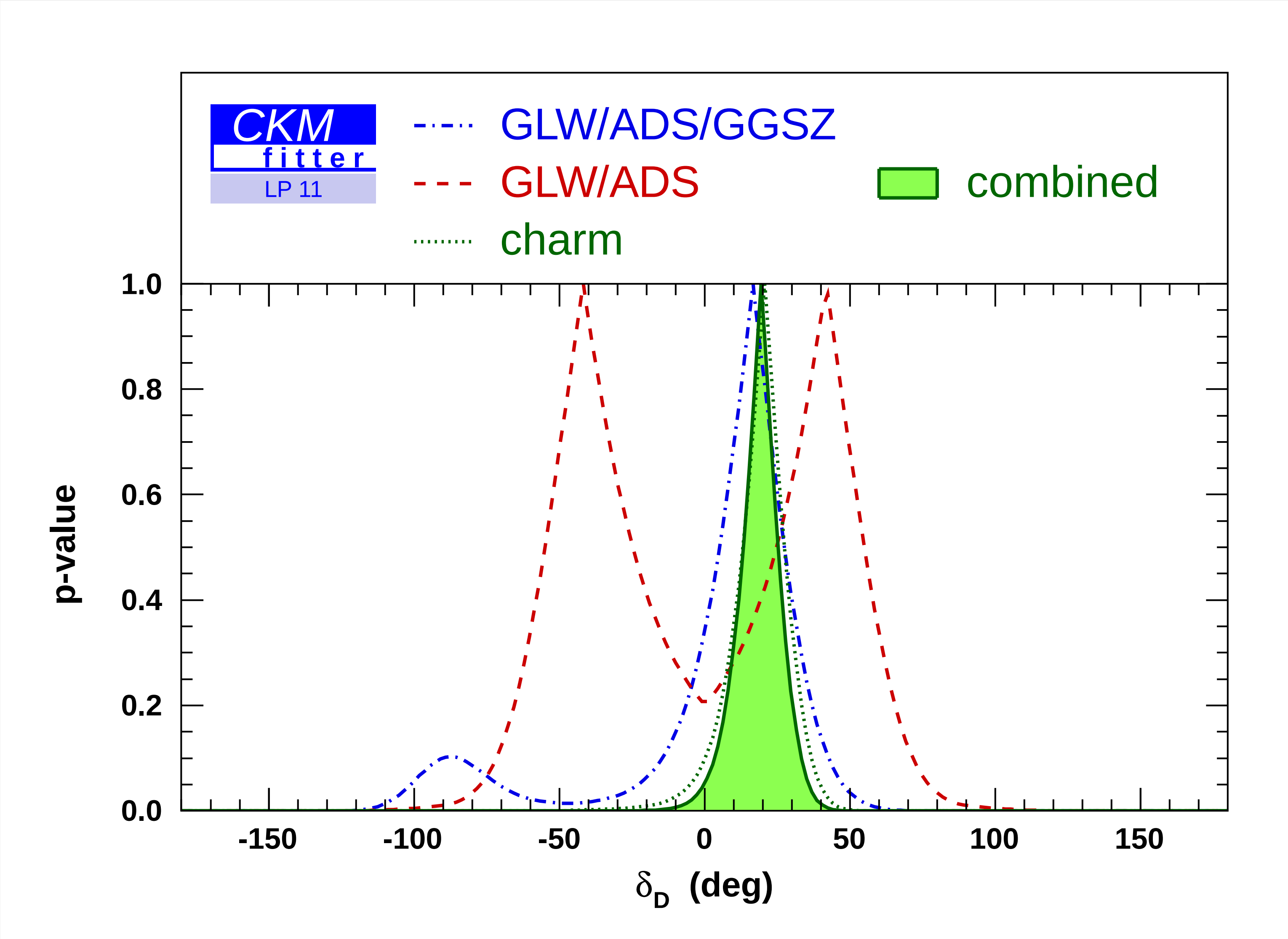
clearly the effect is more in the δ_D direction than the γ one

The GLW/ADS analysis with and without charm observables



without GGSZ observables the impact of charm observables is more important, with a slight preference for the 'wrong' γ solution

Projection on δ_D

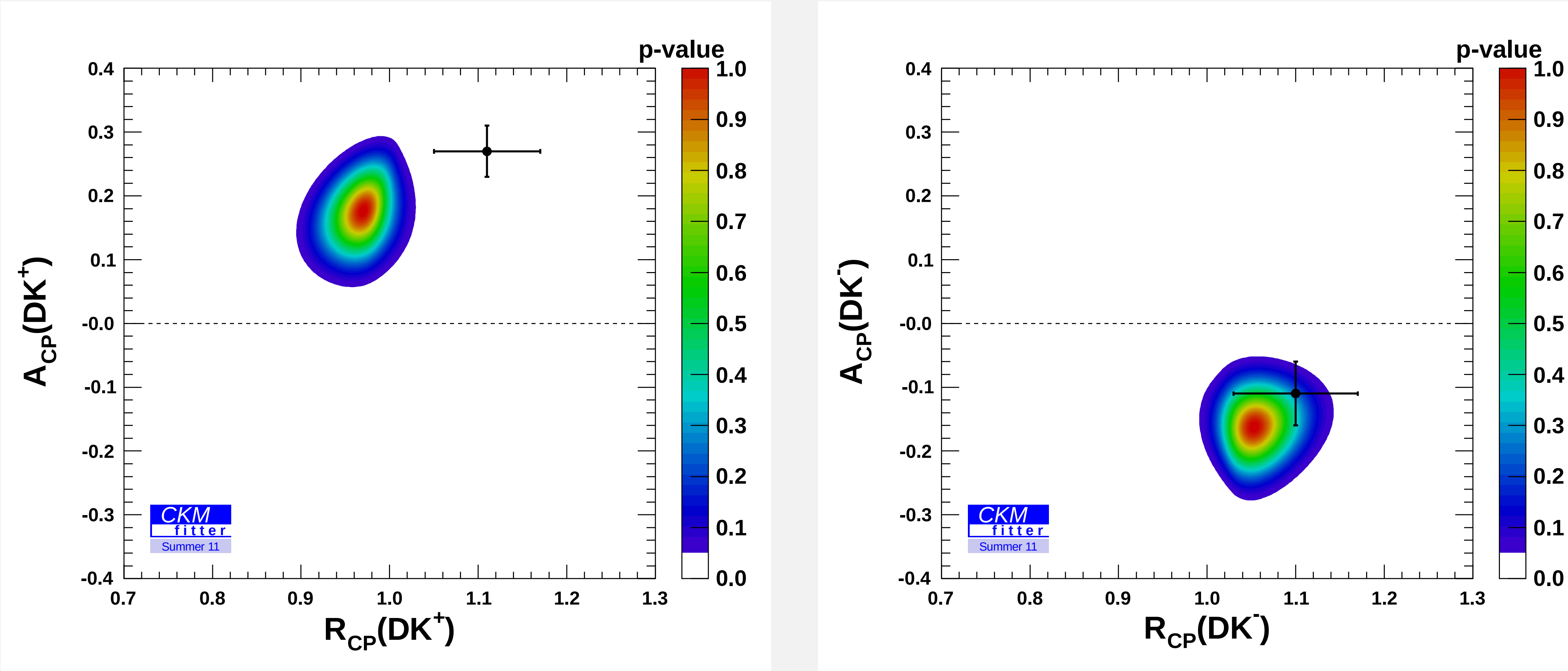


the charm part of the analysis include all the constraints ($D\bar{D}$ mixing, correlated decays...) as done by HFAG the impact of charm observables on γ analysis, through the contraint on $\delta_{\rm D}$, is significant but mainly concern δ and the related ADS observables: it does not significantly improve the error on γ itself

it may change in the future, especially if one decides to remove the model-dependent, resonance-based, version of GGSZ: the binned approach is much cleaner theoretically but less precise at present, so that the contribution of ADS observables on the extraction of γ will be enhanced

GLW observables from GGSZ analysis: DK modes

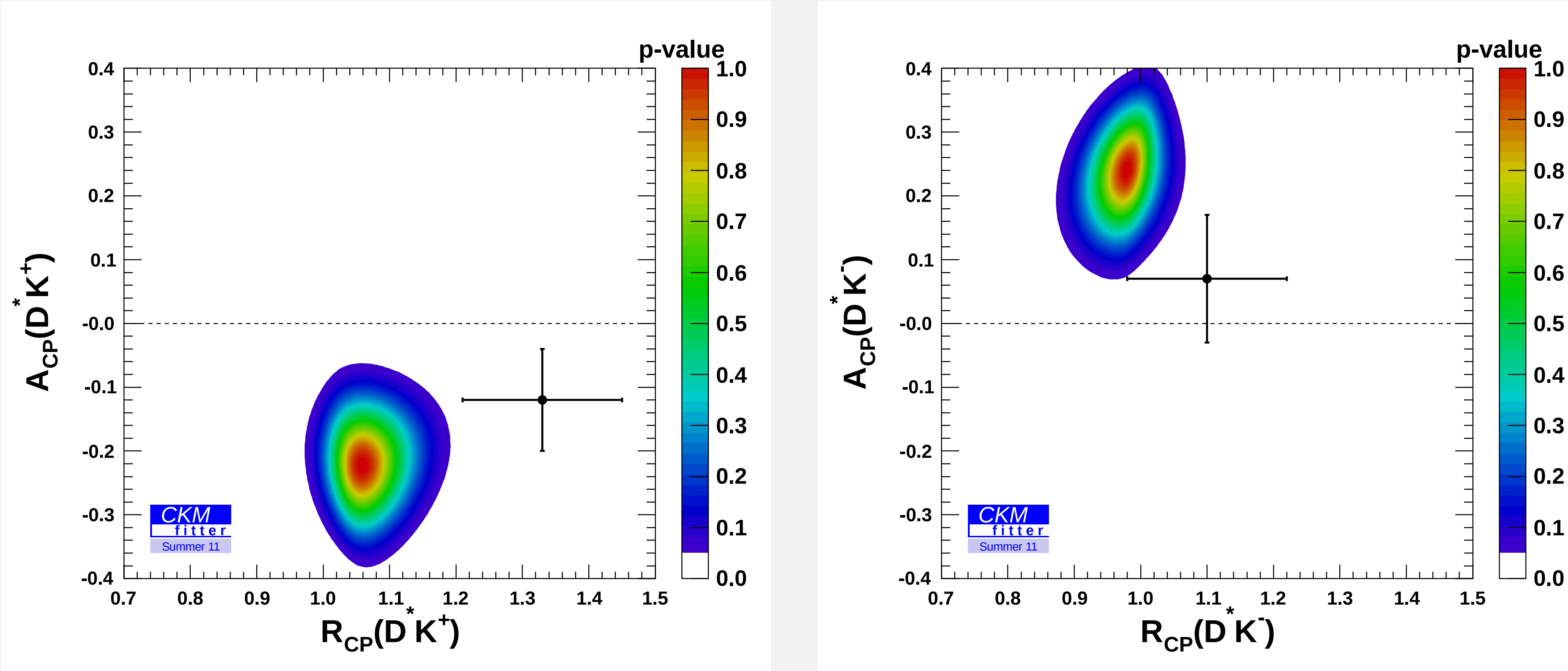
fit prediction vs. direct measurement



DK^+ mode a bit off

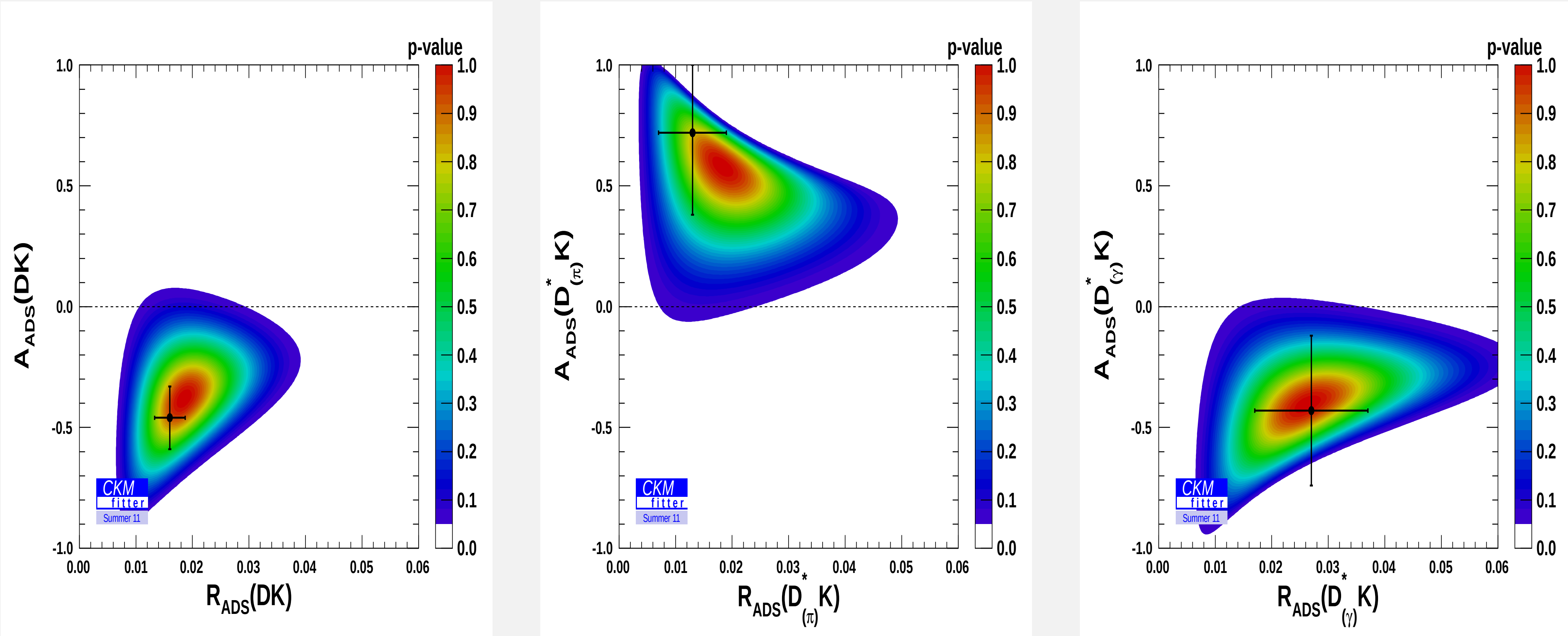
GLW observables from GGSZ analysis: D*K modes

fit prediction vs. direct measurement



ADS observables from GGSZ ⊕ charm analysis

fit prediction vs. direct measurement



the agreement is impressive, both sign and magnitude are correctly predicted

Conclusion

the γ analysis show very non trivial statistical features (related to the non linearities of the equations) that require advanced treatment of nuisance parameters

the approach à la Berger-Boos can be successfully implemented with good frequentist properties

recently measured ADS observables are in impressively good agreement with their indirect prediction: a very non trivial cross check !

some GLW observables are a bit off, but the situation has improved with more data: could be an 'unlucky' statistical fluctuation

in the future more tests will be done, thanks to new measurements at LHCb and precise model-independent GGSZ approach through the crucial input from correlated $D\bar{D}$ decays at threshold