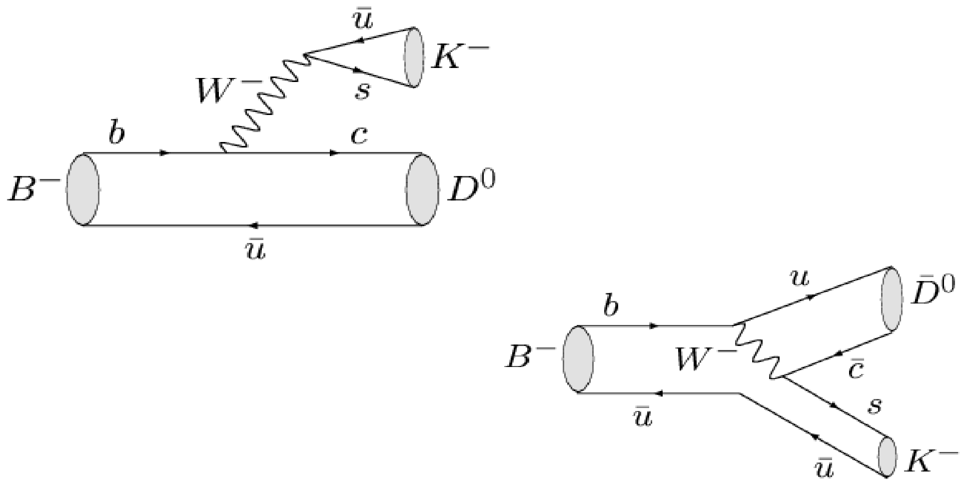
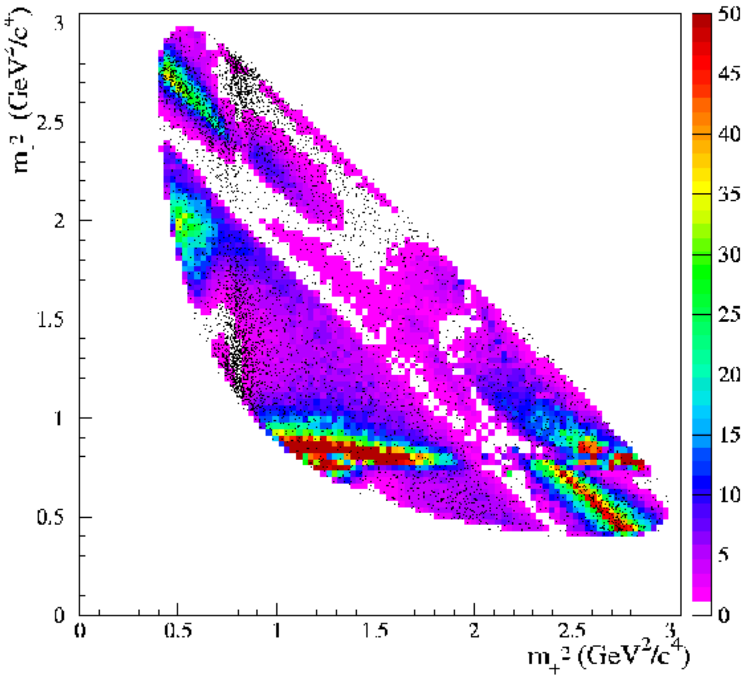
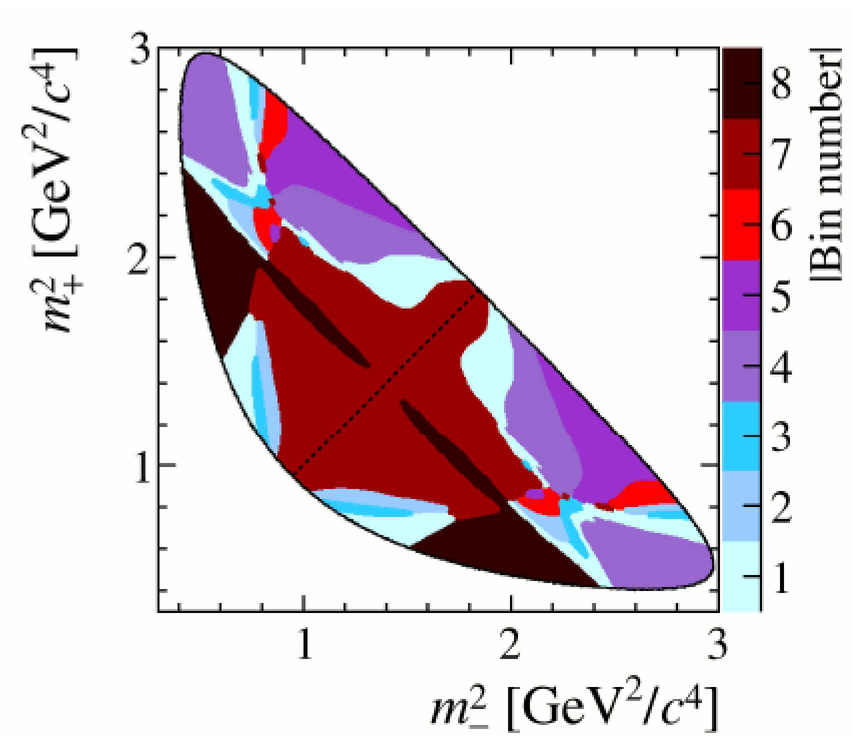
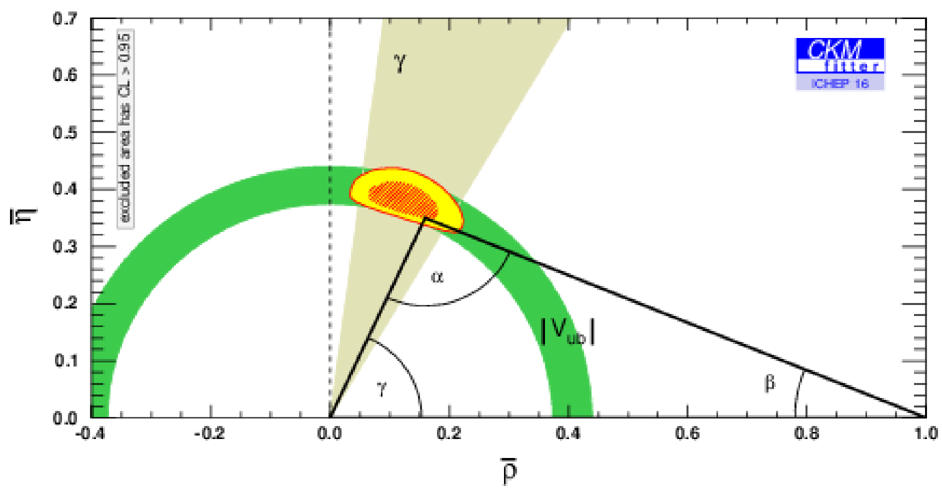
γ and B→DK

K.Trabelsi
2019/05/28









How to get δ_D and related (charm) hadronic parameters ?

- dedicated experiments (CLEO-c, BES III) using quantum correlations, running at $\psi(3770)$
  - CLEO-c: R_D, $\cos\delta$, $\sin\delta$ (but also BES III result...)
  - CLEO-c: $R_{K\pi\pi^0}$, $\delta_{K\pi\pi^0}$, $R_{K3\pi}$, $\delta_{K3\pi}$

R_f: coherence factor, can take any value from 0 to 1
indicates lack coherence between the intermediate states involved in the decay

- mixing/CPV results from BaBar, Belle, CDF, LHCb...
  - $D\to KK, \pi\pi$: y_{CP}, A_Γ (BaBar, Belle, LHCb)
  - $D\to K^0_S\pi\pi$: x, y, $|q/p|$, ϕ (BaBar, Belle)
  - $D\to Kl\nu$: R_M (BaBar, Belle...)
  - $D\to K\pi\pi^0$: x'', y'' (BaBar)
  - $D\to K\pi$: x', y' (BaBar, Belle, CDF, LHCb)
  - ...

- **CLEO-c/BES III, use external inputs to access the relevant physics parameters**
- **strong phases information in B-factories/LHCb**
- **x, y are also needed for D-mixing corrections in ADS observables**

$$R^{\mp} = r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B \mp \gamma + \delta_D)$$

$$\to R^{\mp} = r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B \mp \gamma + \delta_D) - y\, r_D \cos\delta_D - y\, r_B \cos(\delta_B \mp \gamma) + x\, r_D \sin\delta_D - x\, r_B \sin(\delta_B \mp \gamma)$$

⇒ combine charm observables to obtain γ and mixing/CPV charm parameters

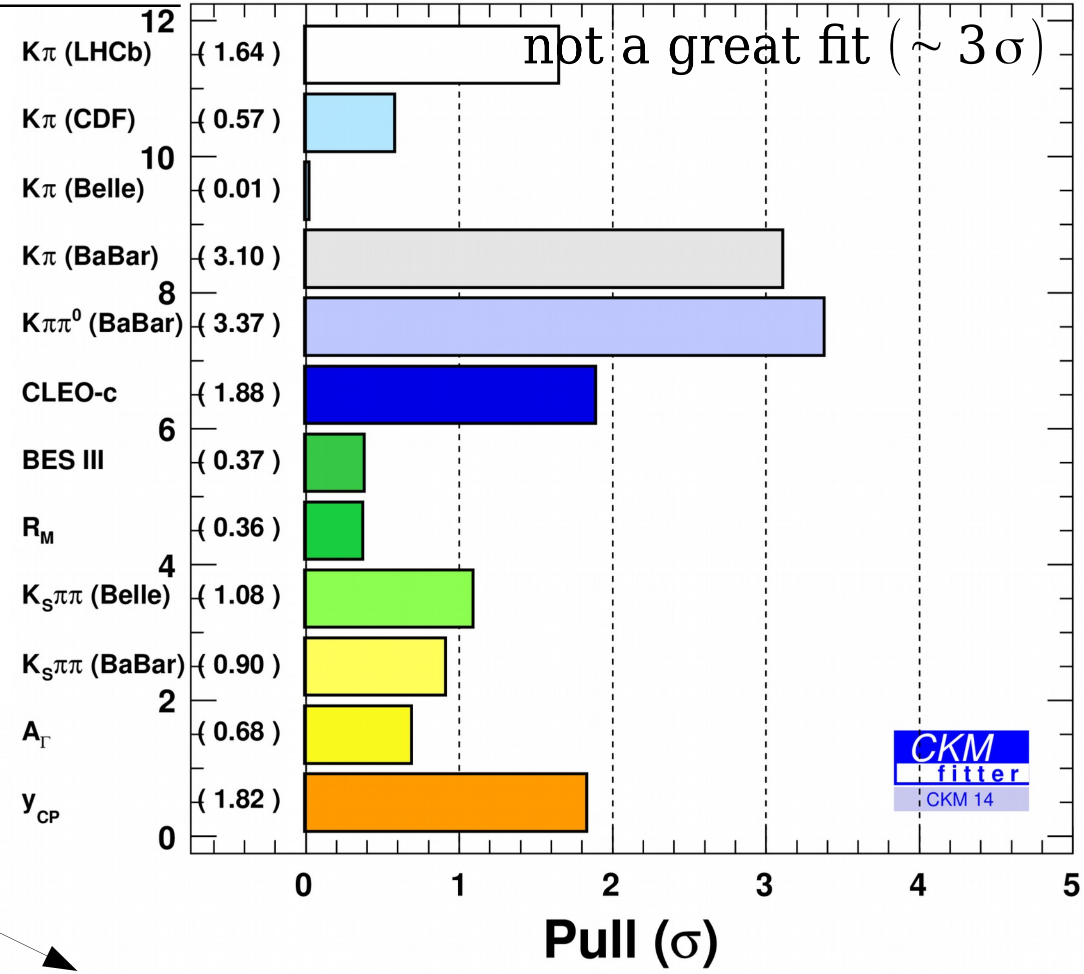
δ_D grand combination à la HFAG

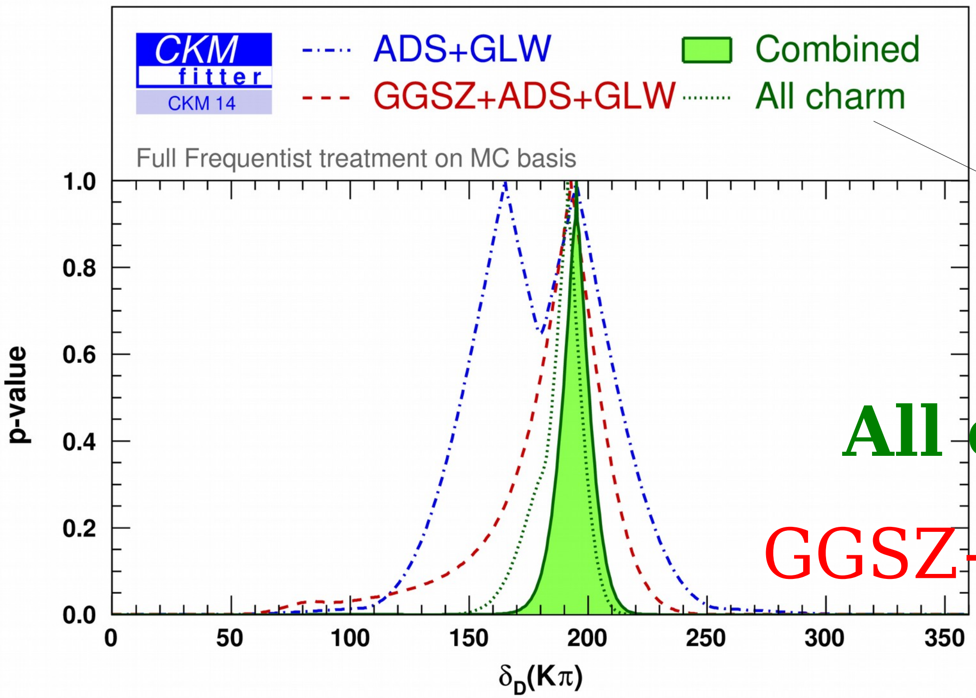
~ 35 observables

8 parameters:

x, y, $\delta_D^{K\pi}$, r_D, A_D, $|q|/|p|$, ϕ, $\delta_D(K\rho)$

not a great fit ($\sim 3\sigma$)





(include $K3\pi$, $K\pi\pi^0$ info, see next slides)

All charm: $\delta_D^{K\pi} = (191.4^{+8.2}_{-11.4})^\circ$ $\left(^{+16}_{-30}\right)$

GGSZ+GLW+ADS: $\delta_D^{K\pi} = (193^{+18}_{-23})^\circ$ $\left(^{+34}_{-77}\right)$

B-factories

γ and r_B… (BaBar example)

analysis with $227\times10^6 B\overline{B}$ **[PRL95, 121802 (2005)]**

$r_B(DK) = 0.12 \pm 0.08 \pm 0.03 \pm 0.04$ $r_B(D^*K) = 0.17 \pm 0.10 \pm 0.03 \pm 0.03$

$$\boldsymbol{\gamma = 70^\circ \pm 31^\circ(\text{stat})^{+12^\circ}_{-10^\circ}(\text{syst})^{+14^\circ}_{-11^\circ}(\text{model})}$$

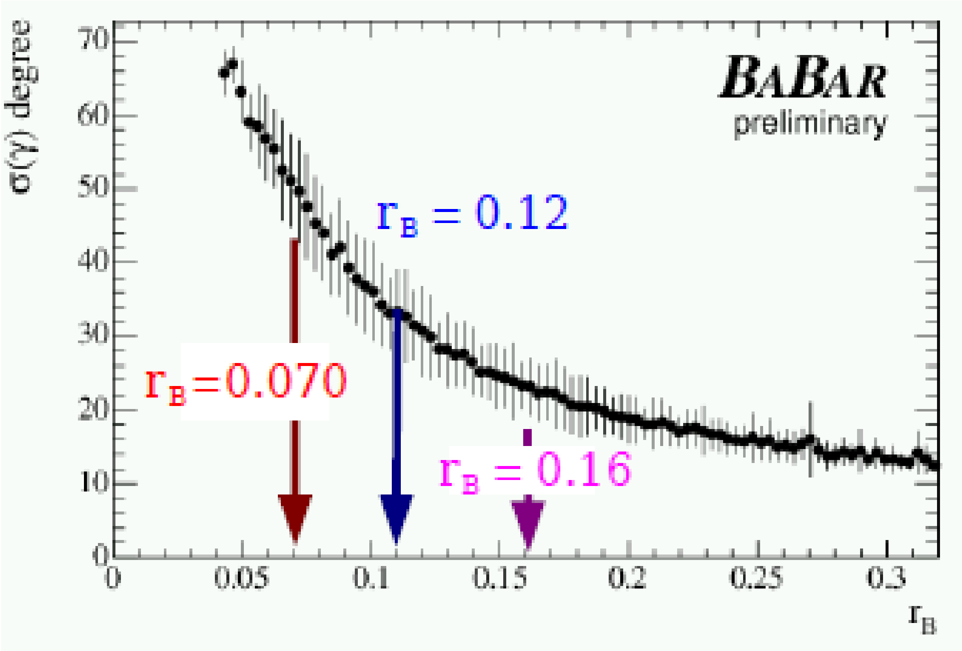
analysis with $347\times10^6 B\overline{B}$ **[hep−ex/0607104]**

$r_B(DK) < 0.140$ $0.017 < r_B(D^*K) < 0.203$

$$\boldsymbol{\gamma = 92^\circ \pm 41^\circ(\text{stat}) \pm 11^\circ(\text{syst}) \pm 12^\circ(\text{model})}$$

uncertainty on γ scales as $1/r_B$! ($r_B = 0 \Rightarrow$ no constraint on γ)

DK case



if r_B is small, the r_B(true) found is biased to higher values and the error on γ is biased toward small values

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.

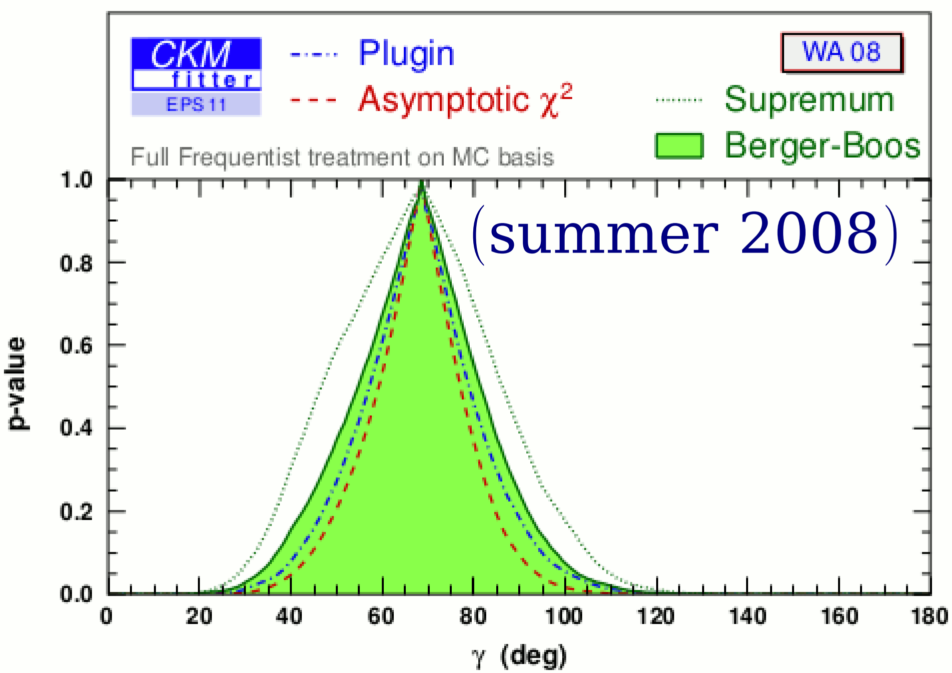
Different treatments of the nuisance parameters

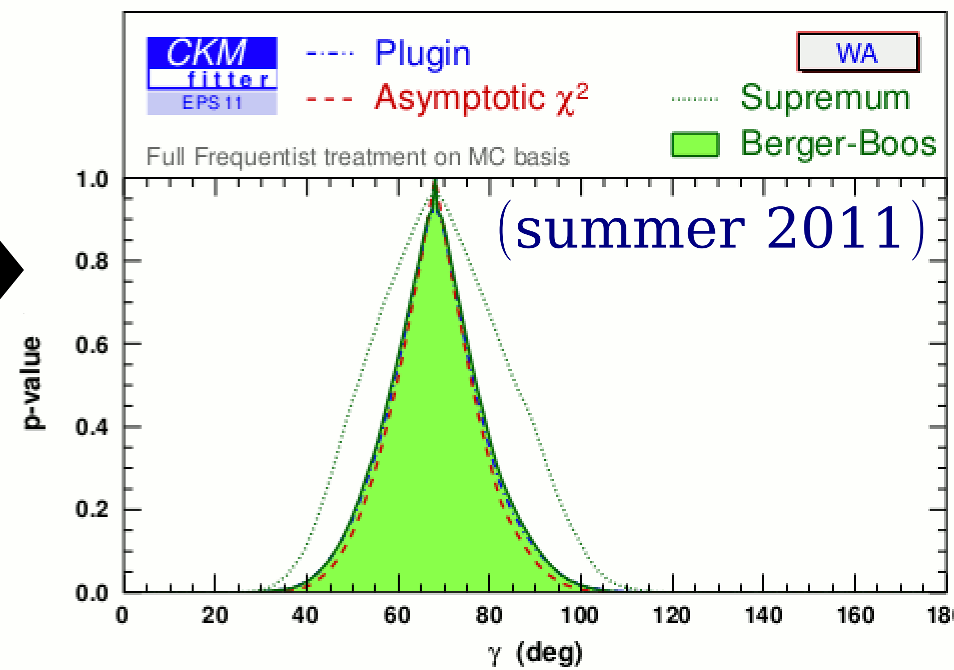
to compute the distributions of the log-likelihood depending on the nuisance parameters ν:

1. use the best fit estimate, $\nu = \hat{\nu}$ (plugin method): coverage not not guaranteed if the true value of ν is different from $\hat{\nu}$

2. use the worst-case distribution: maximize the p-value over all possible values of ν (supremum method): coverage or overcoverage guaranteed by construction

3. maximize the p-value-a well-chosen subspace $\nu \in N$ (constrained supremum method, e.g. Berger-Boos)



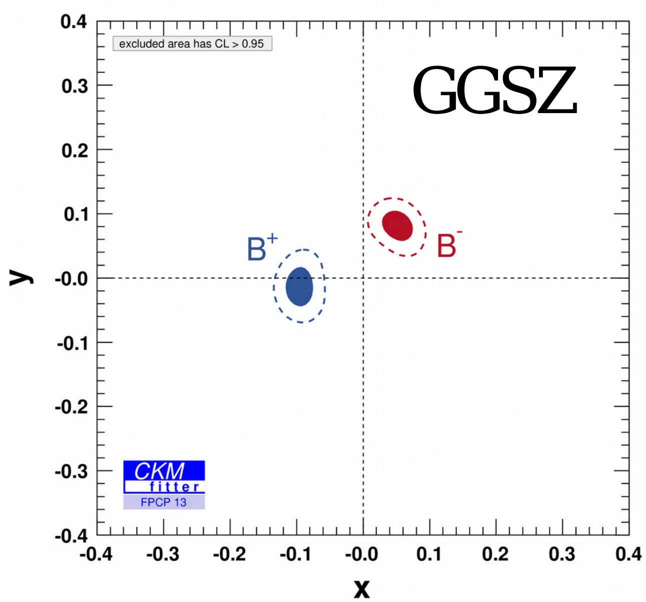


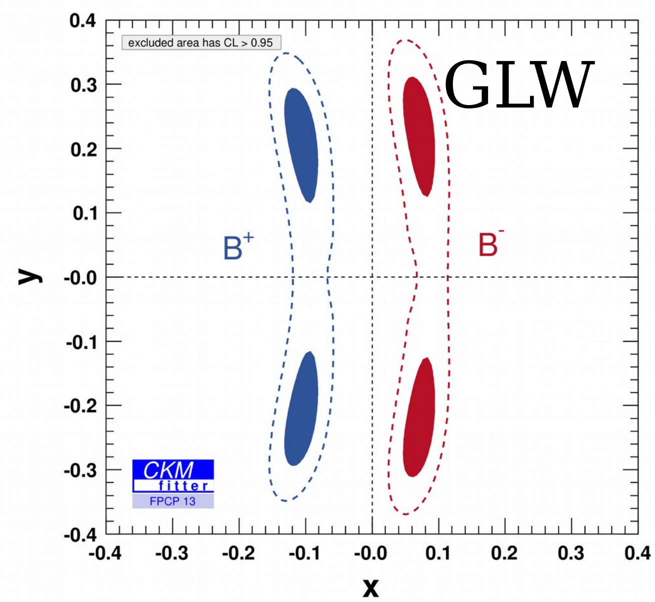
r_B's away from zero, dependence wrt nuisance parameters is now weak

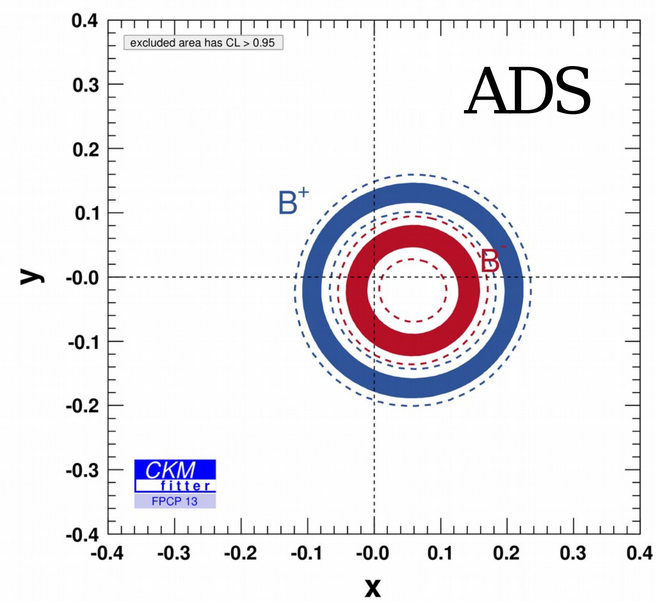
GGSZ , GLW , ADS in charged B decays

GGSZ	GLW	ADS
BaBar $DK+D^*K+DK^*$	BaBar $DK+D^*K+DK^*$	BaBar $DK+D^*K+DK^*$
Belle $DK+D^*K$	Belle $DK+D^*K$	Belle $DK+D^*K,\ K\pi/K\pi\pi^0$
LHCb DK	LHCb DK	LHCb $DK,\ K\pi,\ K3\pi$

$x_\pm = r_B \cos(\delta_B \pm \gamma)$ and $y_\pm = r_B \sin(\delta_B \pm \gamma)$ [just for illustration]



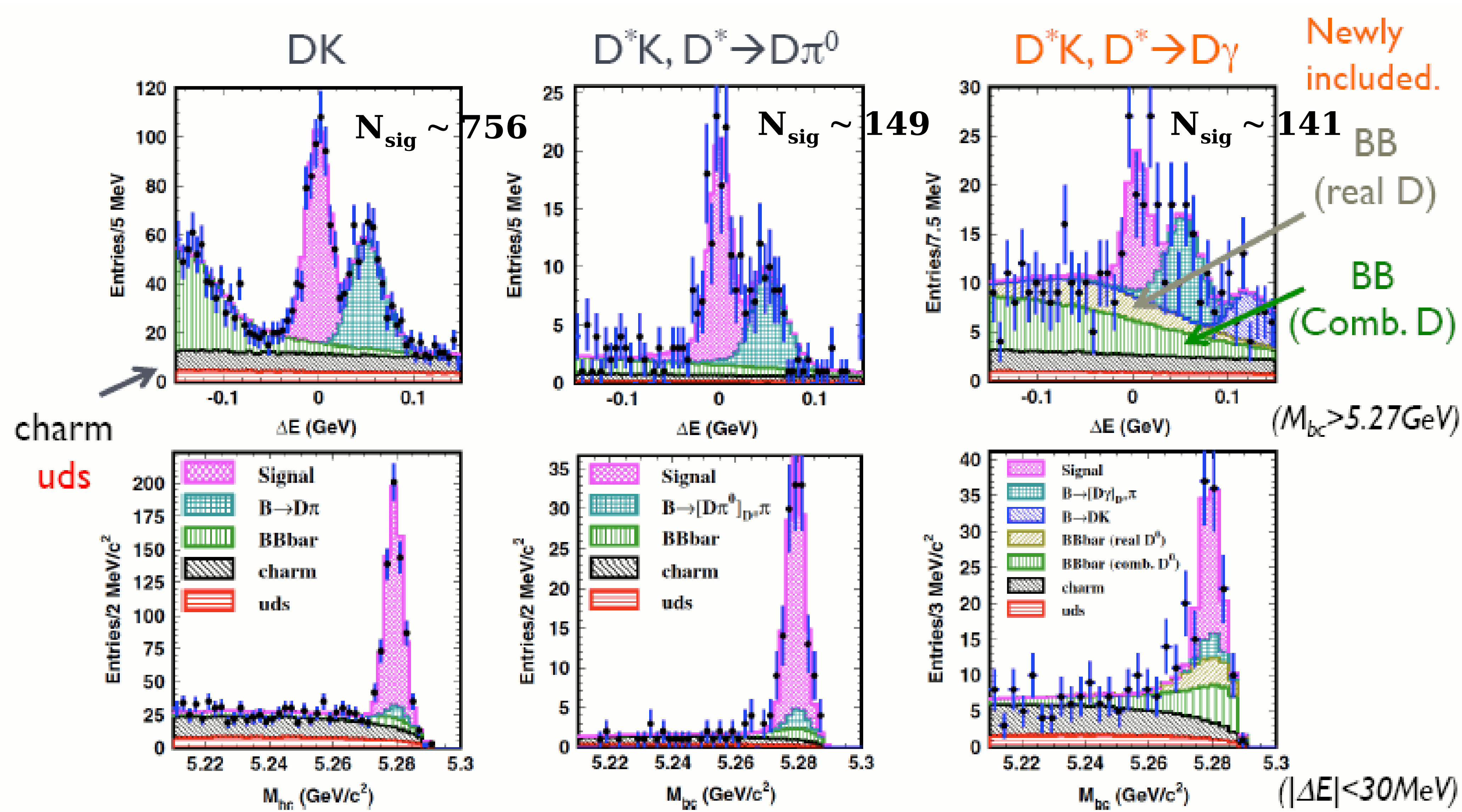




$B^- \to D^{(*)}(K_S\pi\pi)K^-$ Dalitz, ΔE and M_{bc} projections

$|\cos\theta_{thr}| < 0.8$ and $F > -0.7$

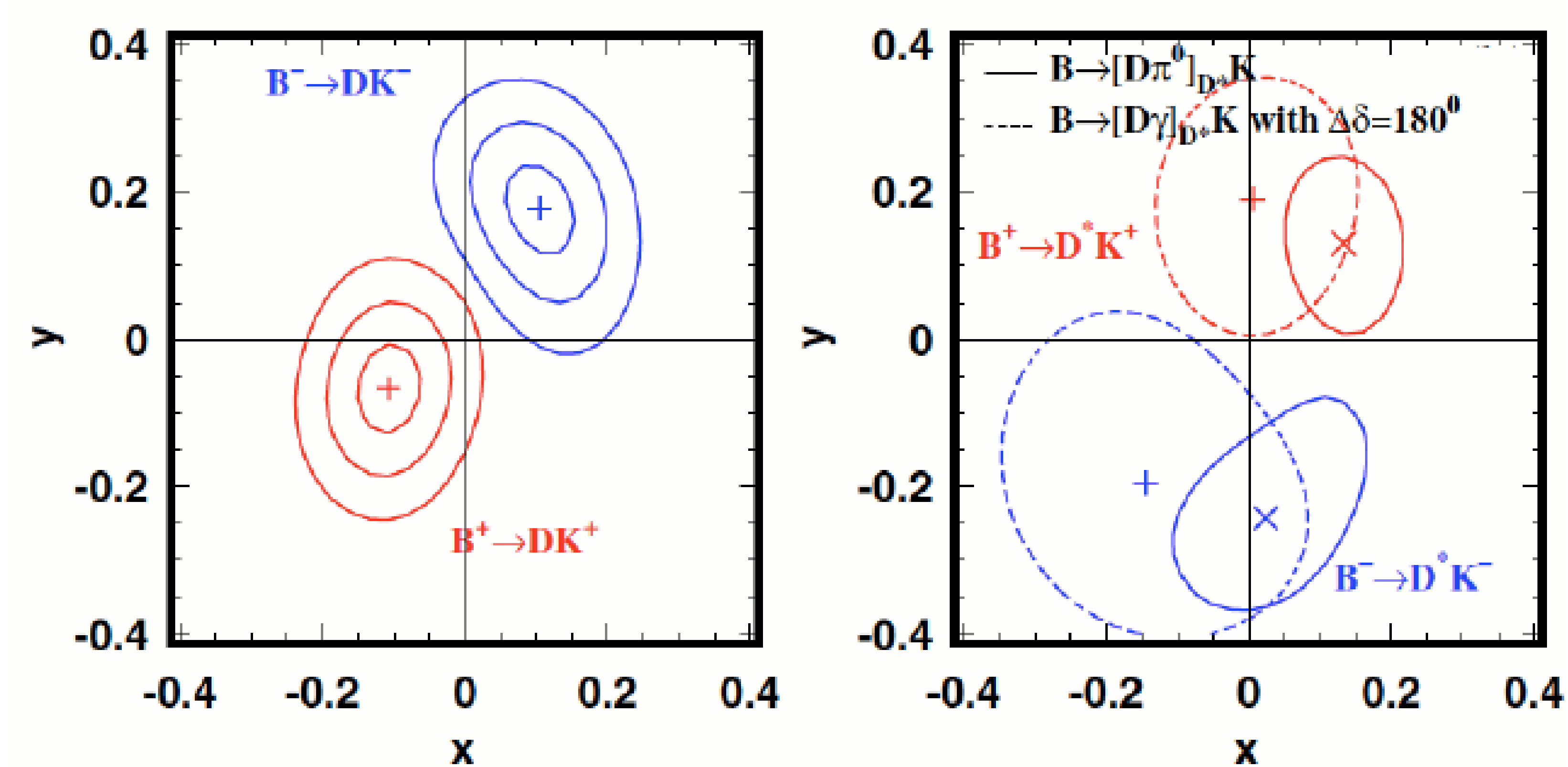
PRD 81, 112002 (2010)
657×10^6 $B\bar{B}$ pairs



γ measurement with $B \to D(K_S\pi\pi)K$

PRD 81, 112002 (2010)
657×10^6 $B\bar{B}$ pairs

$$x_\pm = r_B \cos(\delta_B \pm \gamma), \quad y_\pm = r_B \sin(\delta_B \pm \gamma)$$



$$\gamma = (80.8\,^{+13.1}_{-14.8} \pm 5.0 \pm 8.9)^\circ$$
$$r_B = 0.161\,^{+0.040}_{-0.038} \pm 0.011\,^{+0.050}_{-0.010}$$
$$\delta_B = (137.4\,^{+13.0}_{-15.7} \pm 4.0 \pm 22.9)^\circ$$

$$\gamma = (73.9\,^{+18.9}_{-20.2} \pm 4.2 \pm 8.9)^\circ$$
$$r_B = 0.196\,^{+0.073}_{-0.072} \pm 0.013\,^{+0.062}_{-0.012}$$
$$\delta_B = (341.7\,^{+18.6}_{-20.9} \pm 3.2 \pm 22.9)^\circ$$

combining both B modes (Dalitz): $\boldsymbol{\gamma = (78.4\,^{+10.8}_{-11.6} \pm 3.6 \pm 8.9)^\circ}$

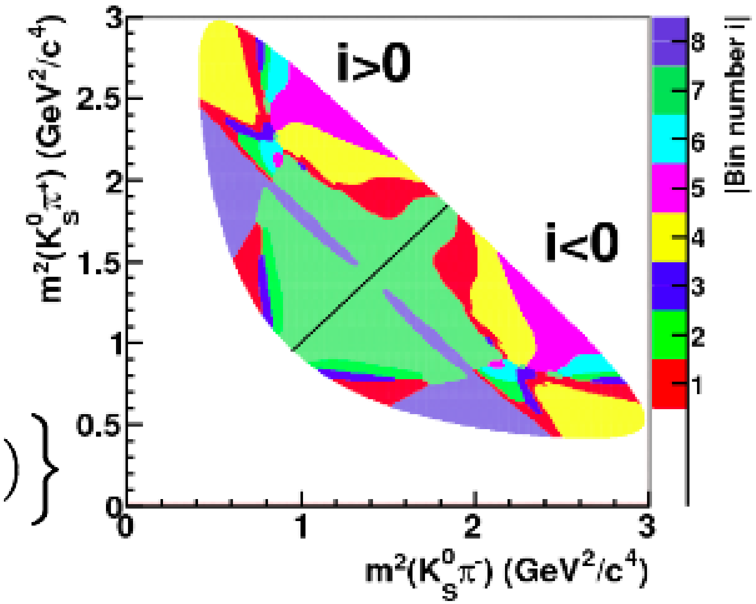
CPV significance is 3.5 standard deviations

(model-dependent error will limit viability of this approach)

Binned Dalitz method: avoid the modeling error by ''optimal'' binning of the Dalitz plot

Bondar and Poluektov EPJ C55, 51 (2008)

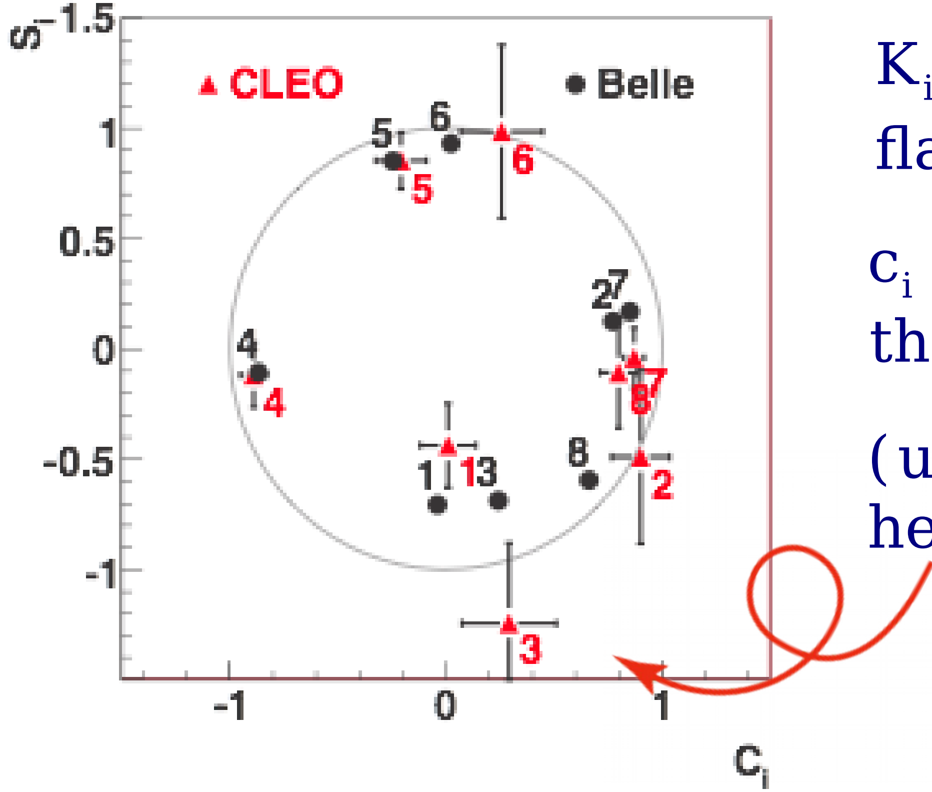
[choice of bins guided by model, but extraction of γ is not biased by this choice]



minimize χ^2 in fit to all bins for each mode

Expected number of $B^\pm \to D K^\pm$ events in bin i is:

$$N_i^\pm = h\left\{K_i + r_B^2 K_{-i} + 2\sqrt{K_i K_{-i}}(x_\pm c_i + y_\pm s_i)\right\}$$



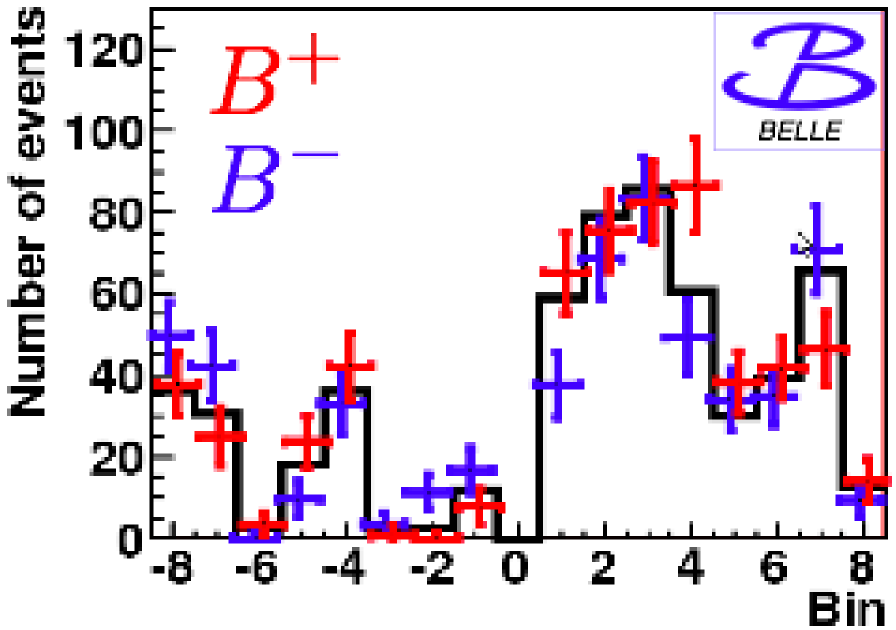
K_i is the # of events in bin i from a flavour-tagged sample ($D^{*\pm} \to D\pi^\pm$)

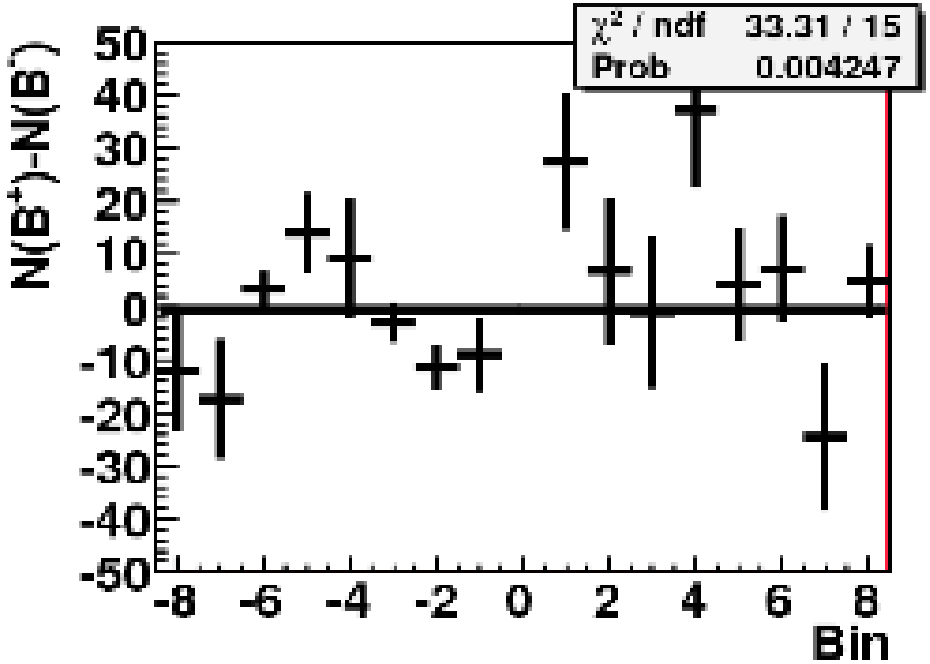
c_i and s_i contain information about the strong-phase difference in bin i

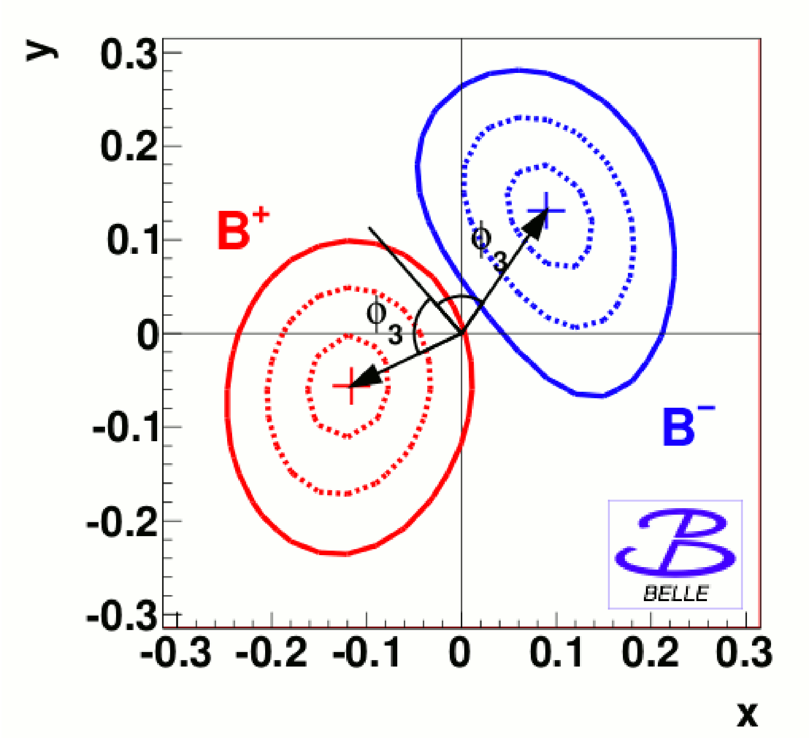
(use CLEO data for $\psi(3770) \to D^0 \overline{D}^0$ here; can be measured by BES-III too)

Binned Dalitz method result in B → DK

772 M $B\bar{B}$
PRD 85, 112014 (2012)
[arXiv:1204.6561]







$$\gamma = (77.3\ ^{+15.1}_{-14.9} \pm 4.1 \pm 4.3)^\circ$$

$$r_B = 0.145 \pm 0.030 \pm 0.010 \pm 0.011$$

$$\delta_B = (129.9 \pm 15.0 \pm 3.8 \pm 4.7)^\circ$$

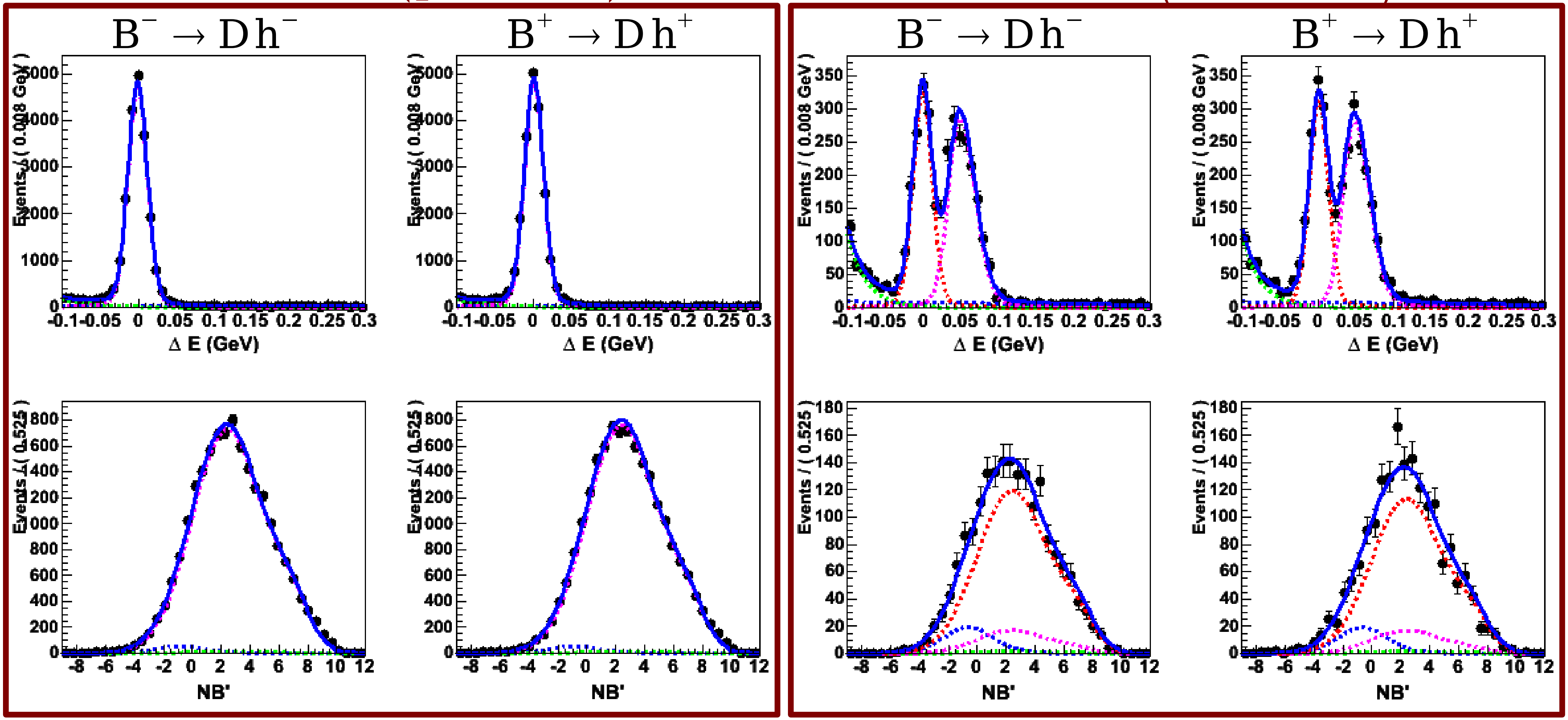
uncertainty in c_i, s_i
from CLEO data size
(can be reduced using
future BES-III data)

Fit for GLW Dh

B → Dπ
B → DK

$B\bar{B}$
continuum

KID< 0.6 (pion-like) **KID> 0.6 (kaon-like)**



$$N^{DK}_{\eta,\,KID>0.6} = \frac{1}{2}\left(1-\eta A^{DK}\right) N^{D\pi}_{tot}\, R_{K/\pi}\, \epsilon$$

$$N^{DK}_{\eta,\,KID<0.6} = \frac{1}{2}\left(1-\eta A^{DK}\right) N^{D\pi}_{tot}\, R_{K/\pi}\, (1-\epsilon)$$

$$N^{D\pi}_{\eta,KID>0.6} = \frac{1}{2}\left(1-\eta A^{D\pi}\right) N^{D\pi}_{tot}\, \kappa$$

$$N^{D\pi}_{\eta,KID<0.6} = \frac{1}{2}\left(1-\eta A^{D\pi}\right) N^{D\pi}_{tot}\, (1-\kappa)$$

$B \to Dh$, $D \to K\pi \to R_{D_{fav}}$

$$N^{DK}_{\eta,\,KID>0.6} = \frac{1}{2}\left(1-\eta A^{DK}\right) N^{D\pi}_{tot}\, R_{K/\pi}\, \epsilon$$

$$N^{DK}_{\eta,\,KID<0.6} = \frac{1}{2}\left(1-\eta A^{DK}\right) N^{D\pi}_{tot}\, R_{K/\pi}\, (1-\epsilon)$$

$$N^{D\pi}_{\eta,KID>0.6} = \frac{1}{2}\left(1-\eta A^{D\pi}\right) N^{D\pi}_{tot}\, \kappa$$

$$N^{D\pi}_{\eta,KID<0.6} = \frac{1}{2}\left(1-\eta A^{D\pi}\right) N^{D\pi}_{tot}\, (1-\kappa)$$

	kaon fake (1-ϵ)	kaon eff ϵ	pion eff (1-κ)	pion fake κ	
MC	14.70 ± 0.06	85.41 ± 0.06	95.42 ± 0.03	4.47 ± 0.03	⇐
data	15.86 ± 0.40	84.32 ± 0.39	92.13 ± 0.46	7.94 ± 0.31	

Efficiency and fake rate (in %) for kaon and pion, for data and MC. ϵ will be fixed in the fit but κ will be floated (see text for further explanations). These numbers are obtained after properly weighting the values provided by PID group for SVD1 and SVD2.

$B \to Dh,\ D \to K\pi \ \to\ R_+$

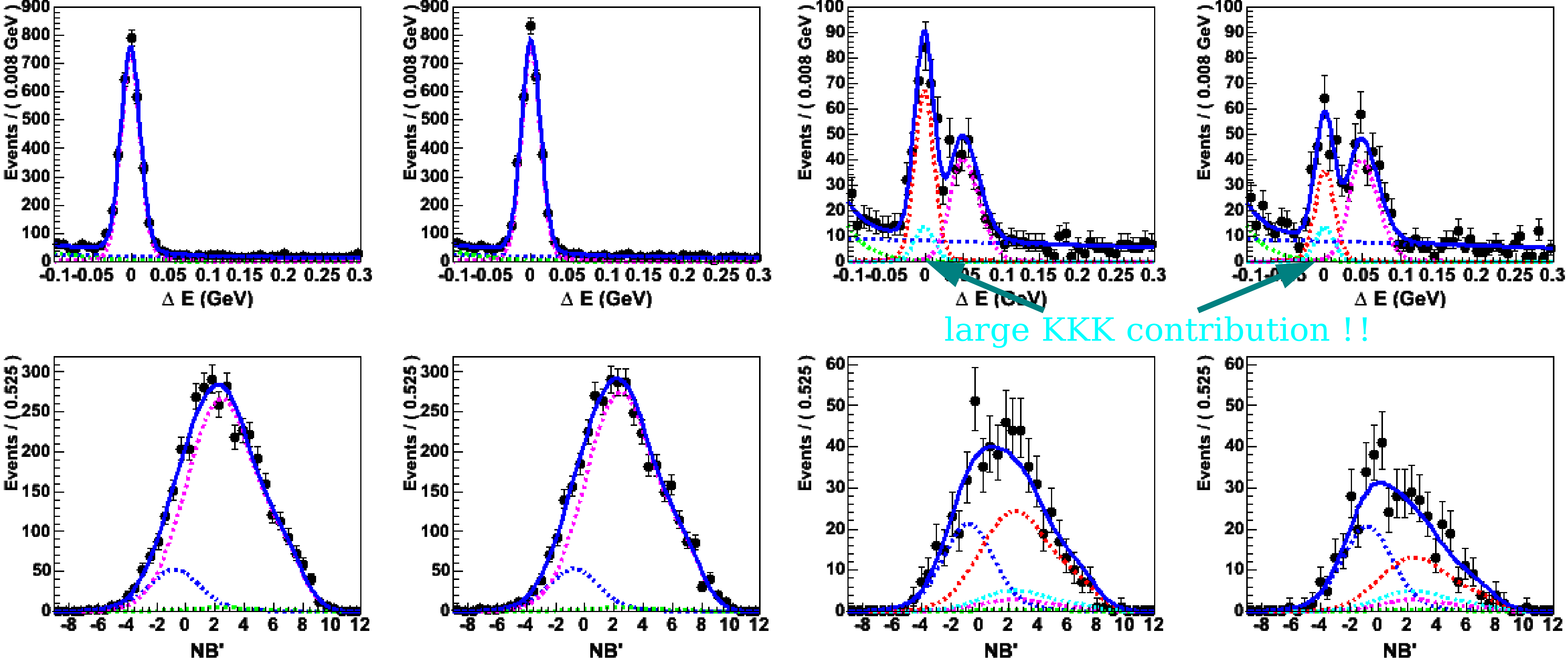
$D \to K^+K^-,\ \pi^+\pi^-$

data (772 $MB\overline{B}$)

$B \to D\pi$
$B \to DK$
$B\overline{B}$
continuum

h is a pion candidate (KID<0.6) h is a kaon candidate (KID>0.6)

$B^- \to Dh^-$ $B^+ \to Dh^+$ $B^- \to Dh^-$ $B^+ \to Dh^+$



$\Rightarrow\ R_{D_{CP+}} = (7.56 \pm 0.51)\%,\ \ A_{D_{CP+}} = (28.7 \pm 6.0)\%$

large asymmetry !!

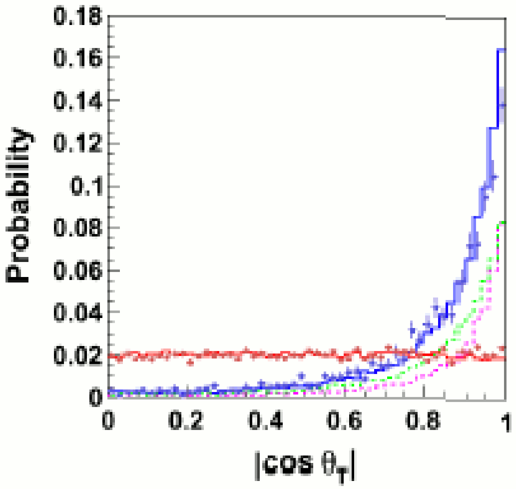
GLW Results

Yields	$B \to D\pi$	$B \to DK$
$D \to K\pi$	50432 ± 243	3692 ± 83
$D \to KK, \pi\pi$	7696 ± 106	582 ± 40
$D \to K_S\pi^0, K_S\eta$	5745 ± 91	476 ± 37

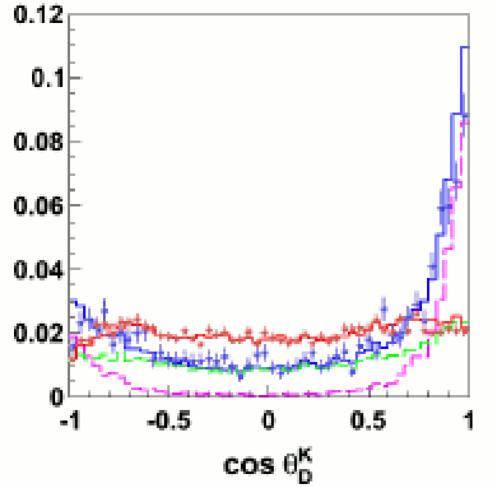
$$R_{CP+} = 1.03 \pm 0.07 \pm 0.03$$
$$R_{CP-} = 1.13 \pm 0.09 \pm 0.05$$

$$A_{CP+} = +0.29 \pm 0.06 \pm 0.02$$
$$A_{CP-} = -0.12 \pm 0.06 \pm 0.01$$

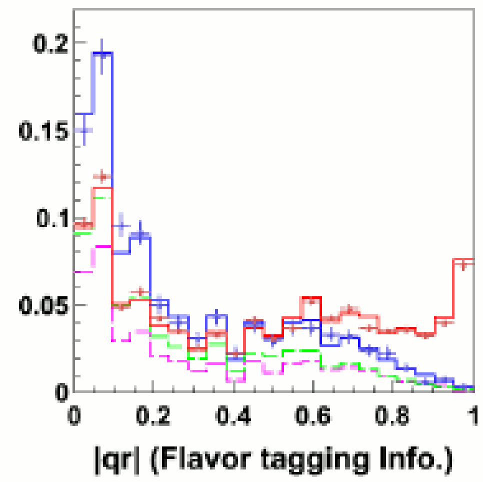
systematics dominated by peaking background,
double ratio approximation



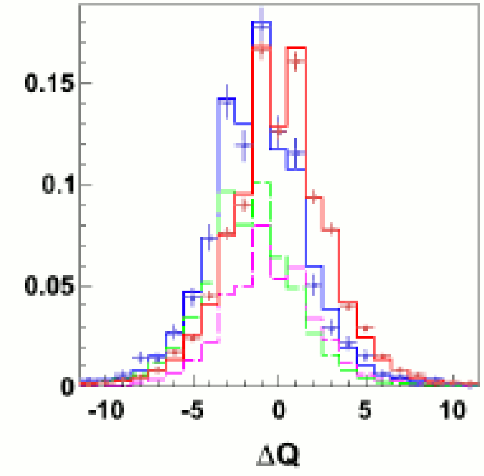
Angle between thrust axes of B decay and remainder.
No full correlation to LR(KSFW).



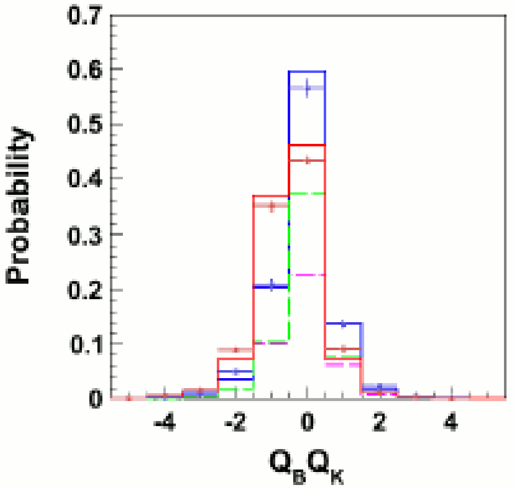
Decay angle of D → kπ.



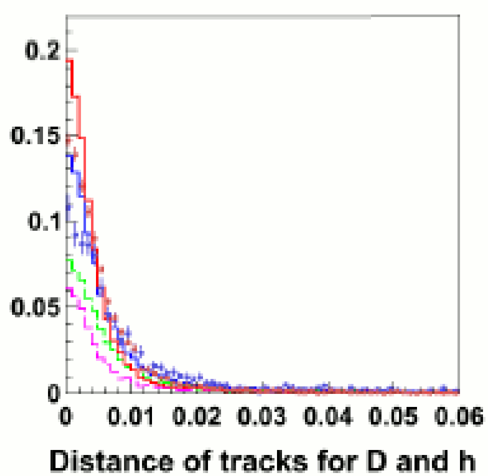
Flavor tagging Info. by MDLH. (NB possible.)



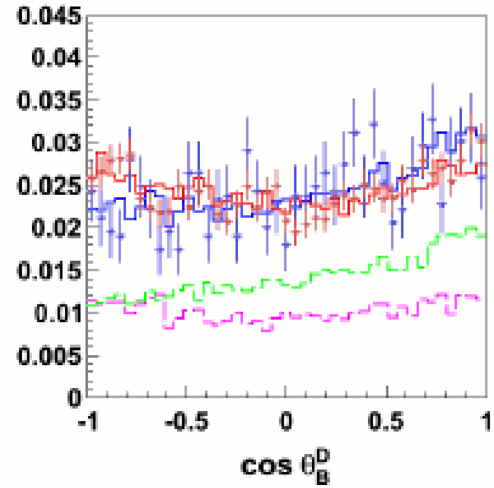
Difference of charges in D hemisphere and opposite hemisphere.



Product of charge of B and sum of charges for K not used in B reconstruction.



Distance of tracks for D and K.



Decay angle of B → DK.

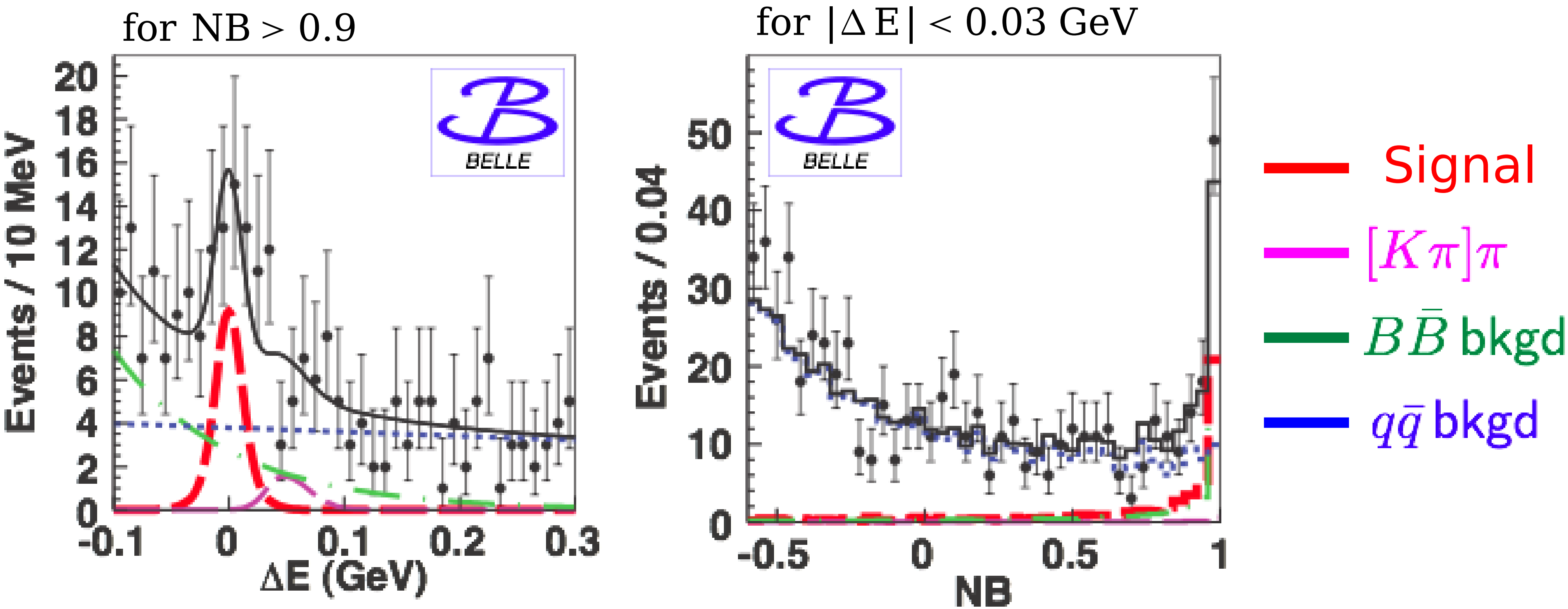
10 variables combined to obtain a single NN output (NB)

for example, at 99% bckg rej. signal eff. = 42% now becomes 60%

Yields for the ADS mode $B^- \to [K^+\pi^-]_D K^-$ from 772 million $B\overline{B}$ events

PRL 106, 231803 (2011)

Fit ΔE and NB distributions together to extract signal



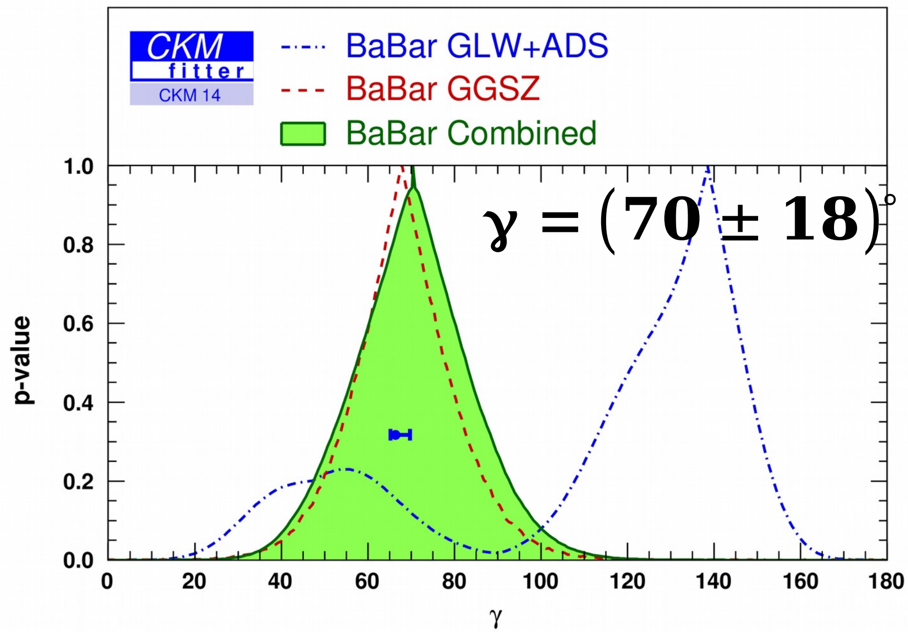
$56.0^{+15.1}_{-14.2}$ events

First evidence obtained with a significance of 3.8σ (including syst.)

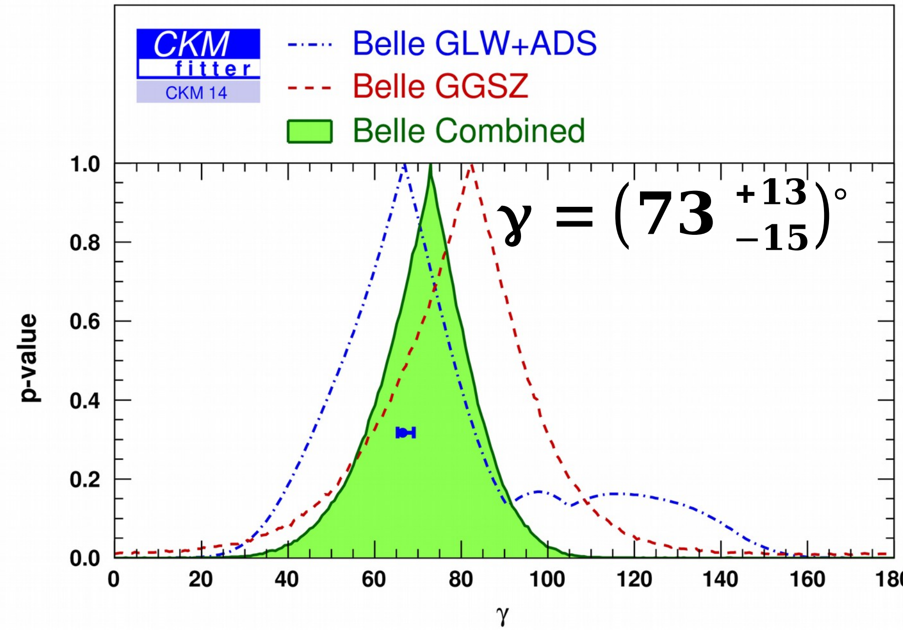
$$R_{DK} = (1.63\,^{+0.44}_{-0.41}\,^{+0.07}_{-0.13}) \times 10^{-2}$$

$$A_{DK} = -0.39\,^{+0.26}_{-0.28}\,^{+0.04}_{-0.03}$$

BaBar , Belle…



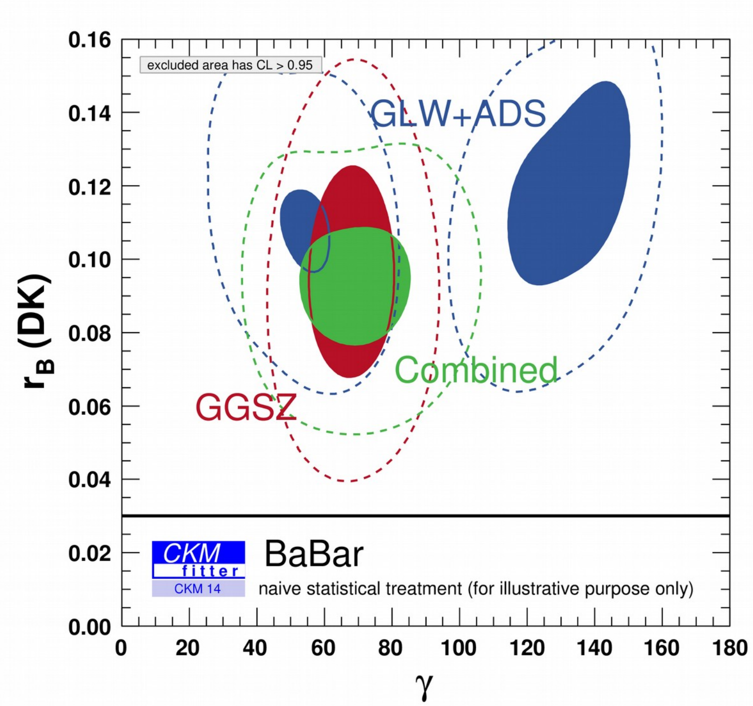
$$\gamma = (70 \pm 18)^{\circ}$$

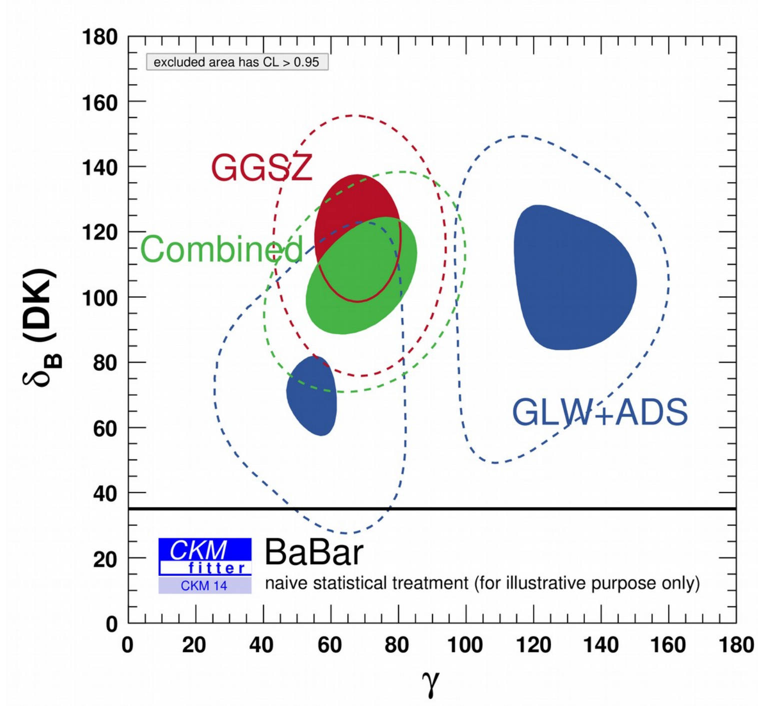


$$\gamma = \left(73\,^{+13}_{-15}\right)^{\circ}$$

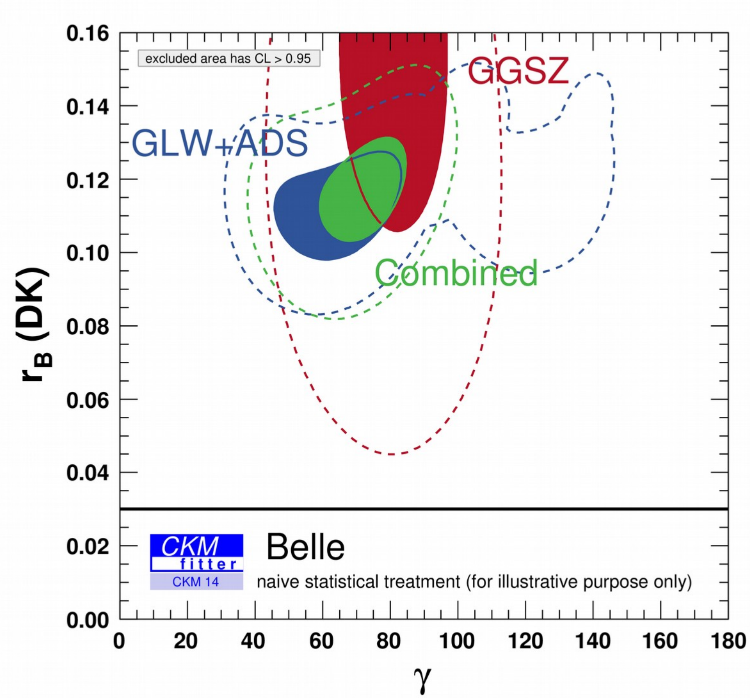
GGSZ versus GLW+ADS ($r_B(DK)$ vs γ, $\delta_B(DK)$ vs γ)

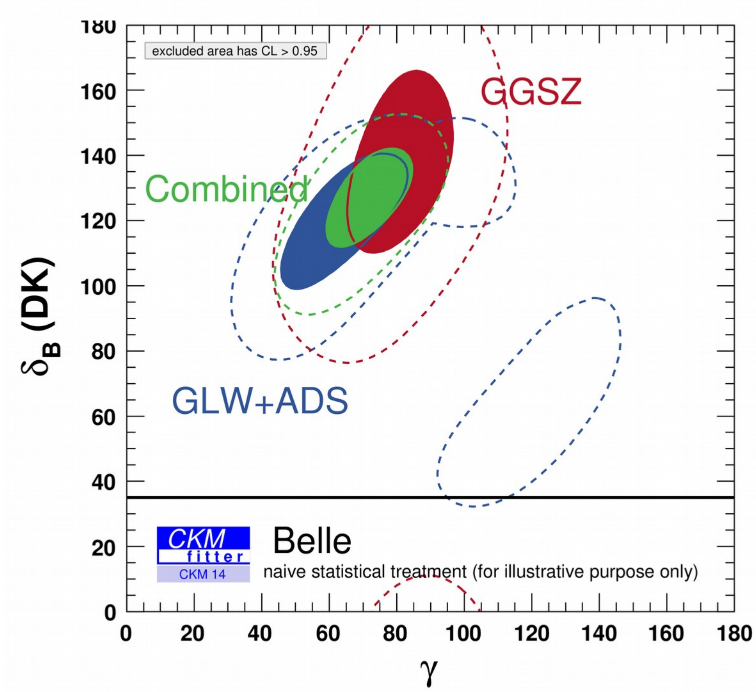
BaBar





Belle





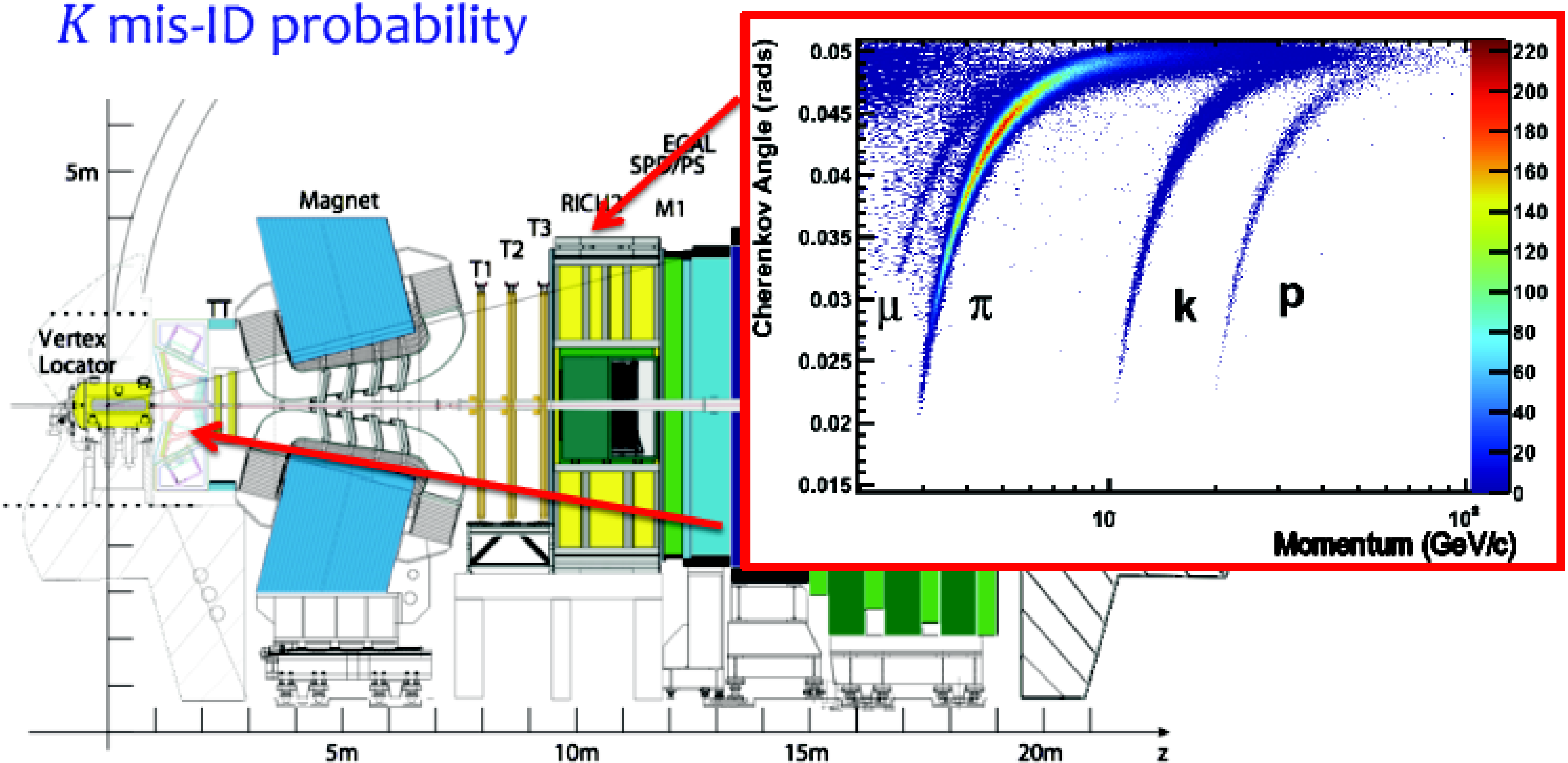
LHCb

The LHCb detector

Int. J. Mod. Phys. A30 (2015) 07

RICH DETECTORS

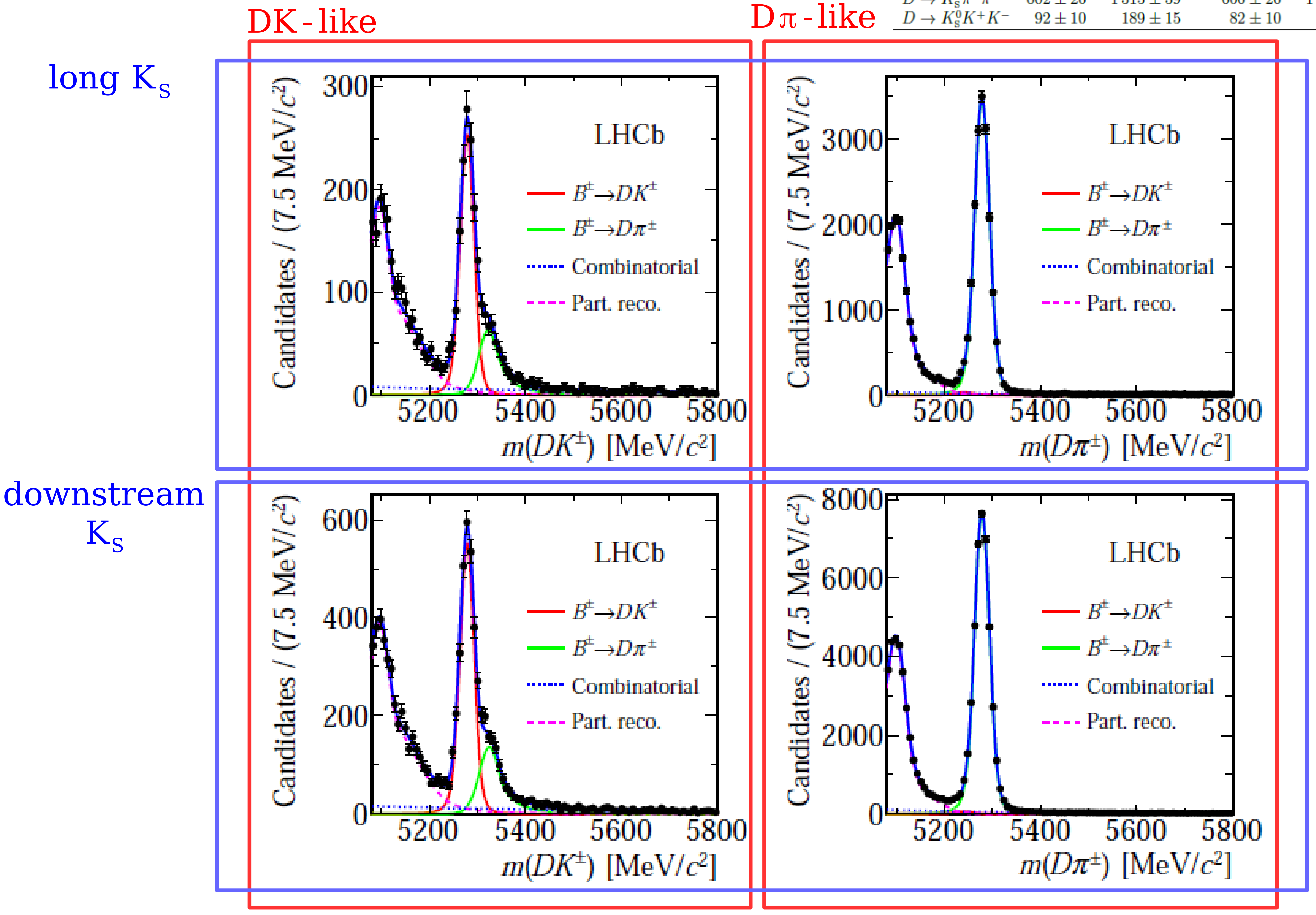
- Provide discrimination between kaons, pions and protons between 5 and 100 GeV/c. Typical kaon ID ~ 95 % for ~ 5 % $\pi \to K$ mis-ID probability



GGSZ, B→DK, D→$K_S\pi\pi$, K_SKK [arXiv:1806.01202]

shown for D→$K_S\pi\pi$ (last 2 fb^{-1})

	$B^- \to DK^-$		$B^+ \to DK^+$	
	Long	Downstream	Long	Downstream
$D \to K^0_S\pi^+\pi^-$	602 ± 26	$1\,315 \pm 39$	606 ± 26	$1\,334 \pm 39$
$D \to K^0_S K^+K^-$	92 ± 10	189 ± 15	82 ± 10	193 ± 15

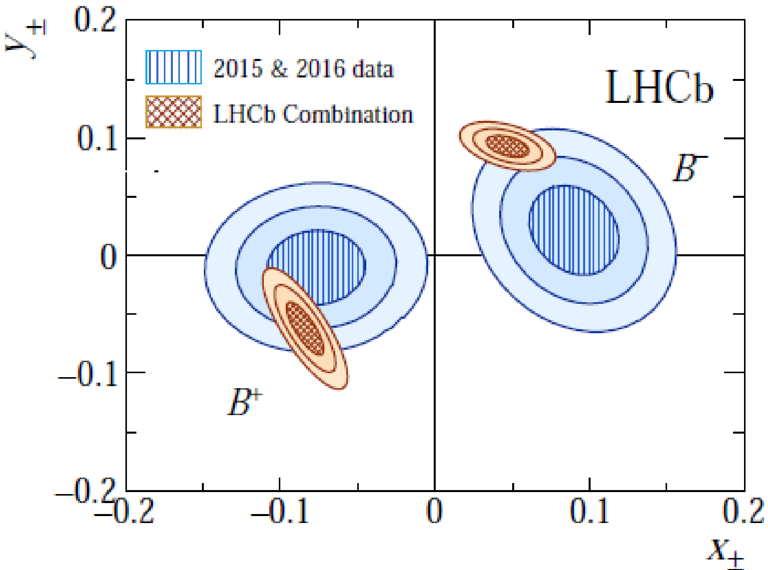


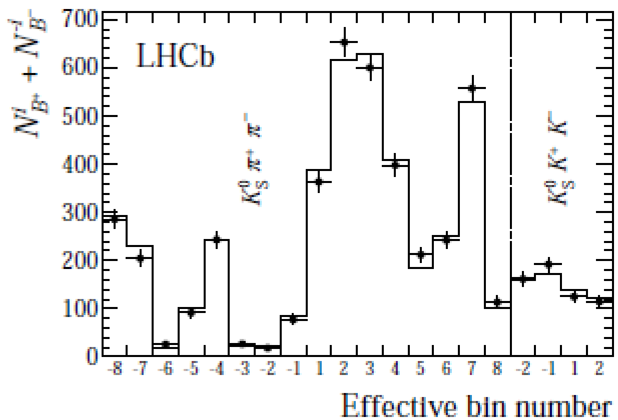
GGSZ, B→DK, D→$K_S\pi\pi$, $K_S KK$

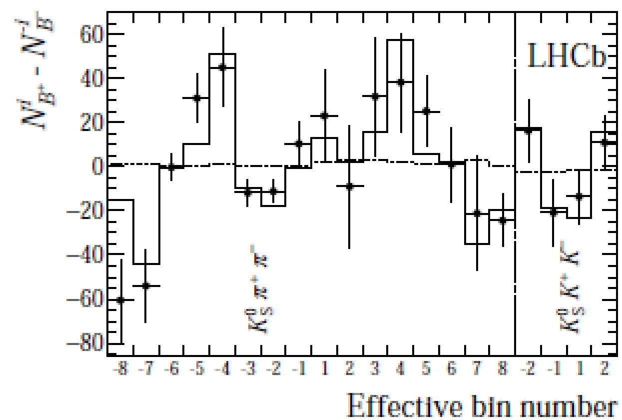
[arXiv:1806.01202]

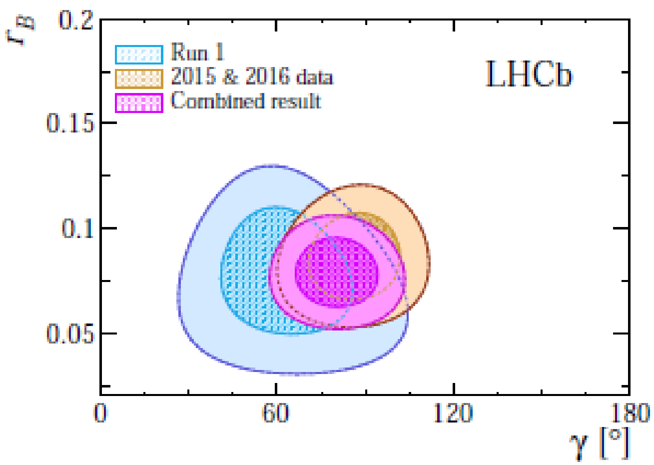
5 fb^{-1}

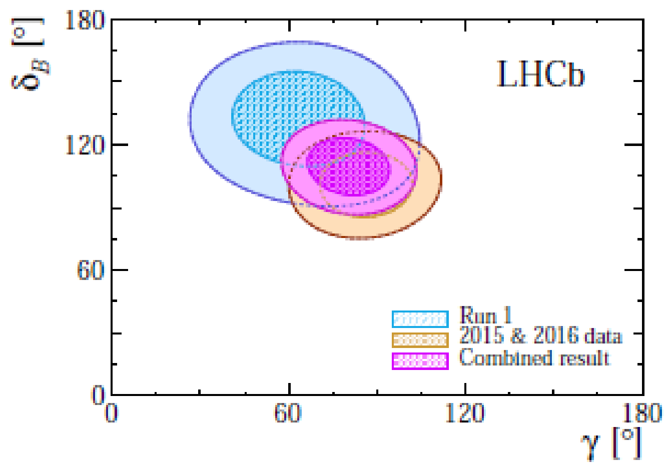
Cartesian coordinates combining data until 2016











$$\gamma = 80^\circ \,{}^{+10^\circ}_{-9^\circ} \left({}^{+19^\circ}_{-18^\circ}\right),$$

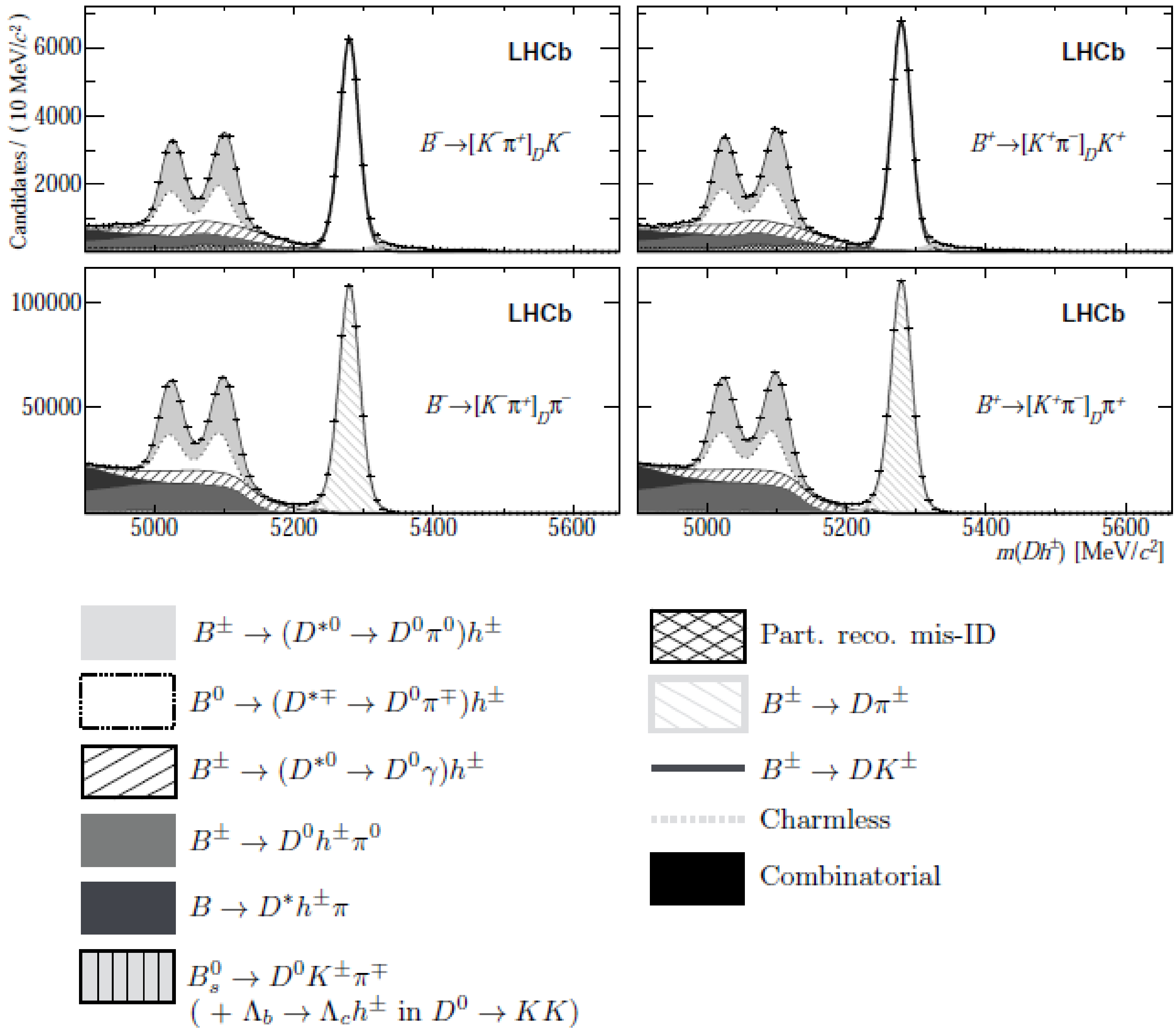
$$r_B = 0.080 \,{}^{+0.011}_{-0.011} \left({}^{+0.022}_{-0.023}\right),$$

$$\delta_B = 110^\circ \,{}^{+10^\circ}_{-10^\circ} \left({}^{+19^\circ}_{-20^\circ}\right).$$

GLW, $B \to DK$, $D \to K^+K^-$, $\pi^+\pi^-$

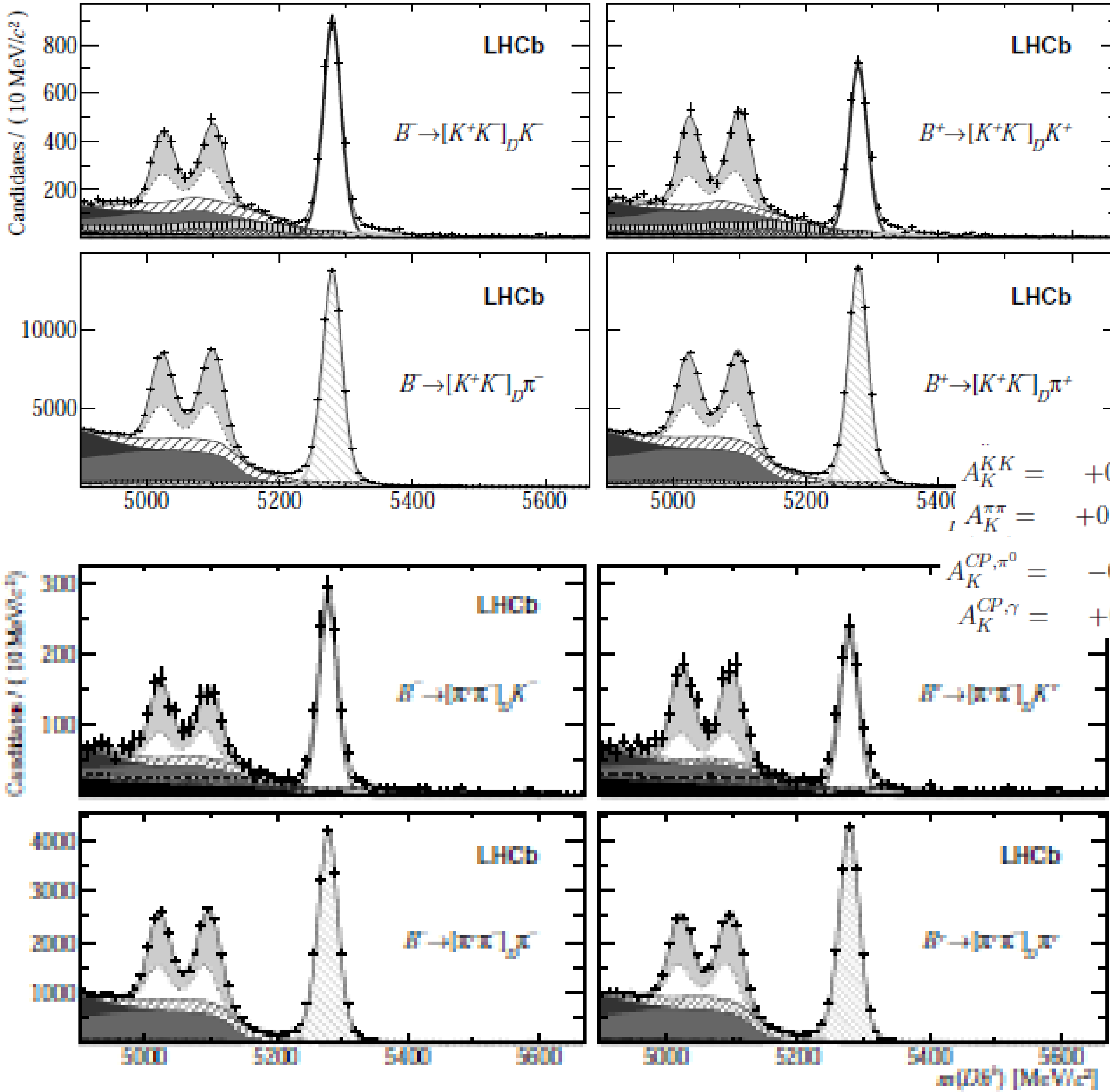
[arXiv:1708.06370]

5 fb^{-1}



GLW, B→DK, D→K^+K^-, $\pi^+\pi^-$

[arXiv:1708.06370]
5 fb^{-1}



$$A_K^{KK} = +0.126 \pm 0.014 \text{ (stat)} \pm 0.002 \text{ (syst)}$$
$$A_K^{\pi\pi} = +0.115 \pm 0.025 \text{ (stat)} \pm 0.007 \text{ (syst)}$$
$$A_K^{CP,\pi^0} = -0.151 \pm 0.033 \text{ (stat)} \pm 0.011 \text{ (syst)}$$
$$A_K^{CP,\gamma} = +0.276 \pm 0.094 \text{ (stat)} \pm 0.047 \text{ (syst)}$$

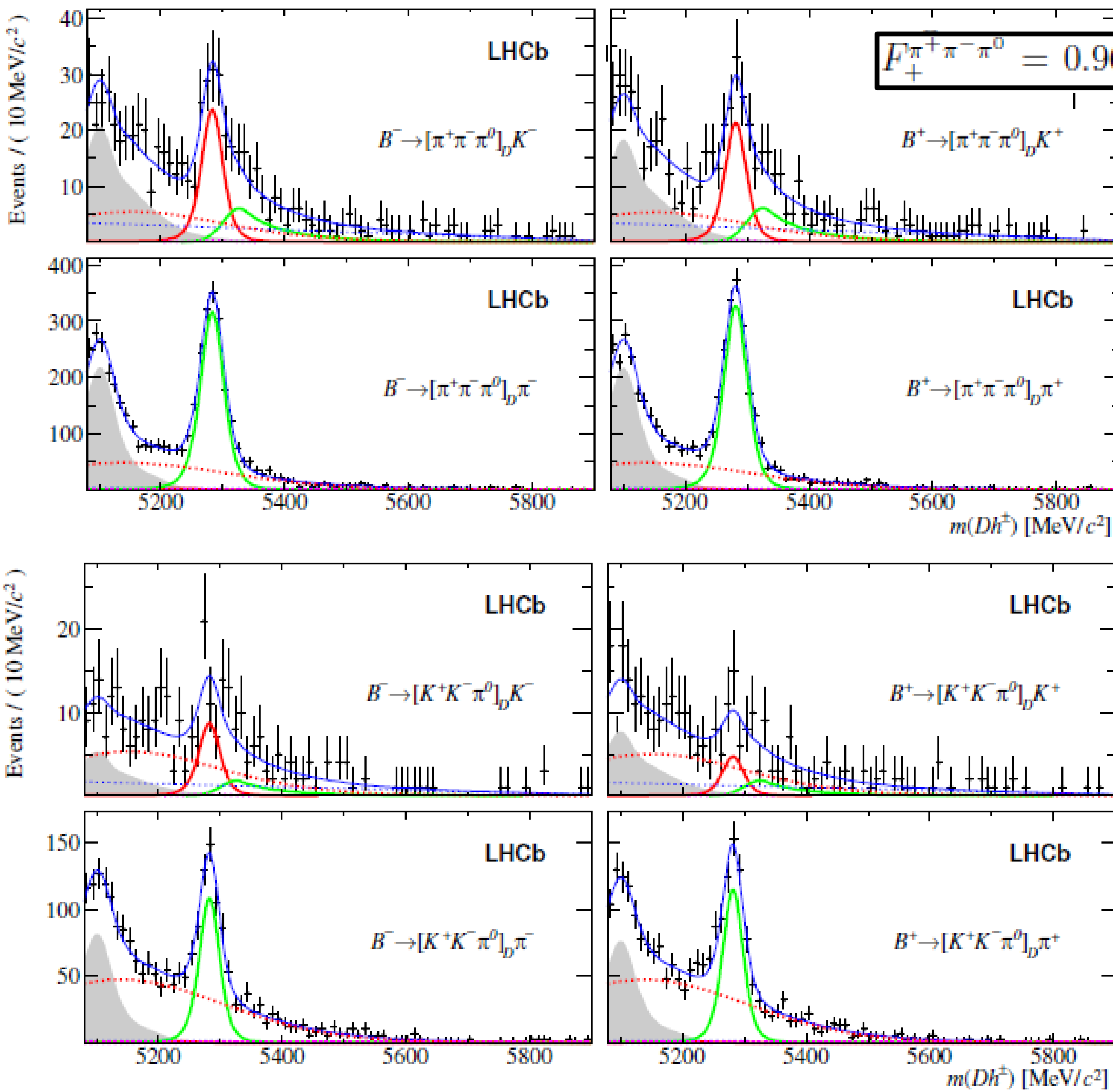
$B \to DK$, $D \to \pi^+\pi^-\pi^0$, $K^+K^-\pi^0$ (quasi GLW)

[arXiv:1504.05442]

3 fb^{-1}

$F_+^{\pi^+\pi^-\pi^0} = 0.968 \pm 0.018$ and $F_+^{K^+K^-\pi^0} = 0.731 \pm 0.062$

[arXiv:1410.3964]



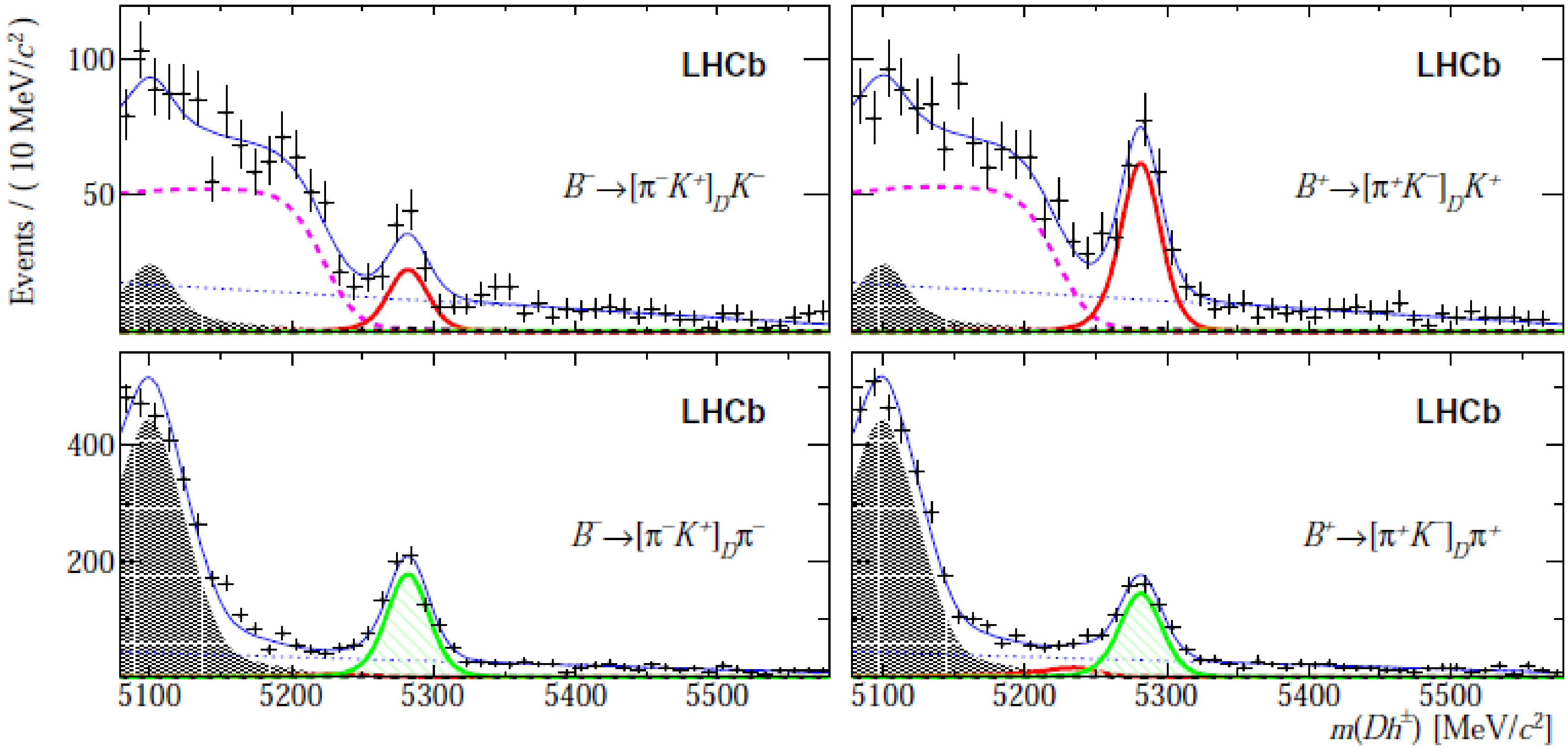
$$A_{\text{qGLW}(K)}^{KK\pi^0} = 0.30 \pm 0.20 \pm 0.02$$

$$A_{\text{qGLW}(K)}^{\pi\pi\pi^0} = 0.054 \pm 0.091 \pm 0.011$$

ADS , $B \to DK$, $D \to K^+ \pi^-$

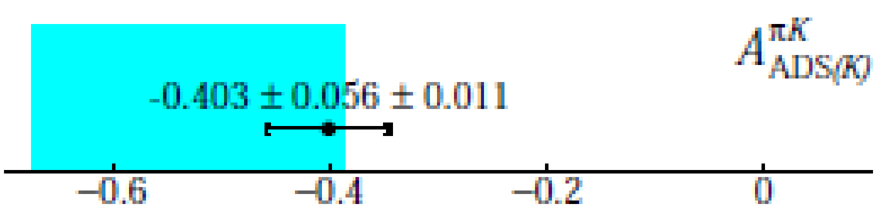
[arXiv:1603.08993]

3 fb^{-1}



$$A^{\pi K}_{\mathrm{ADS}(K)} = -0.403 \quad \pm 0.056 \quad \pm 0.011$$

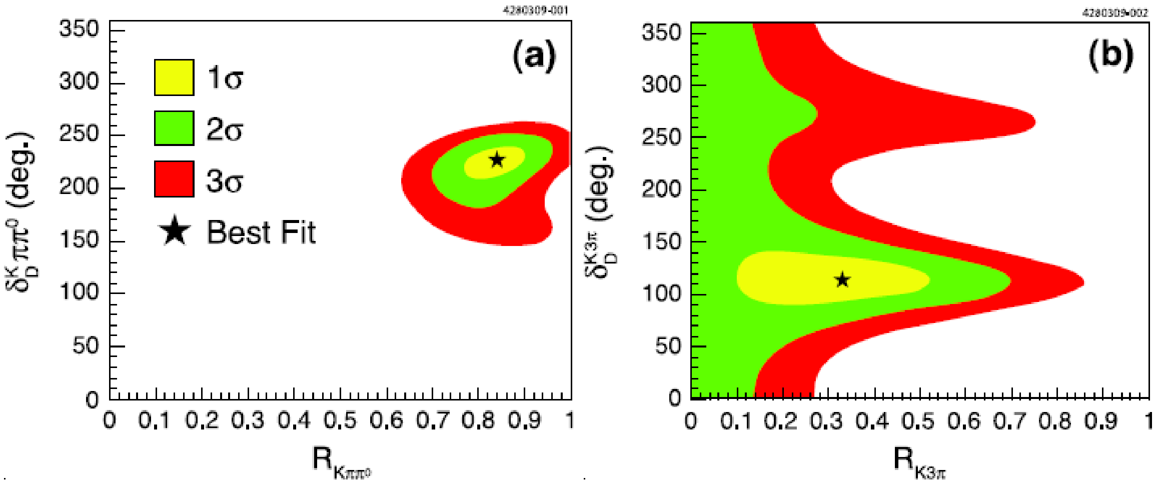
$$R^{\pi K}_{\mathrm{ADS}(K)} = \quad 0.0188 \quad \pm 0.0011 \quad \pm 0.0010$$



quasi-GLW, quasi-ADS...

certain multi-body decays are almost pure CP-eigenstates:
⇒ quasi-GLW, for example for $D \to 4\pi$, $2F_+ - 1 = 0.737 \pm 0.028$

other like ADS modes: for example $D \to K\pi\pi^0$, coherence factor ~ 1

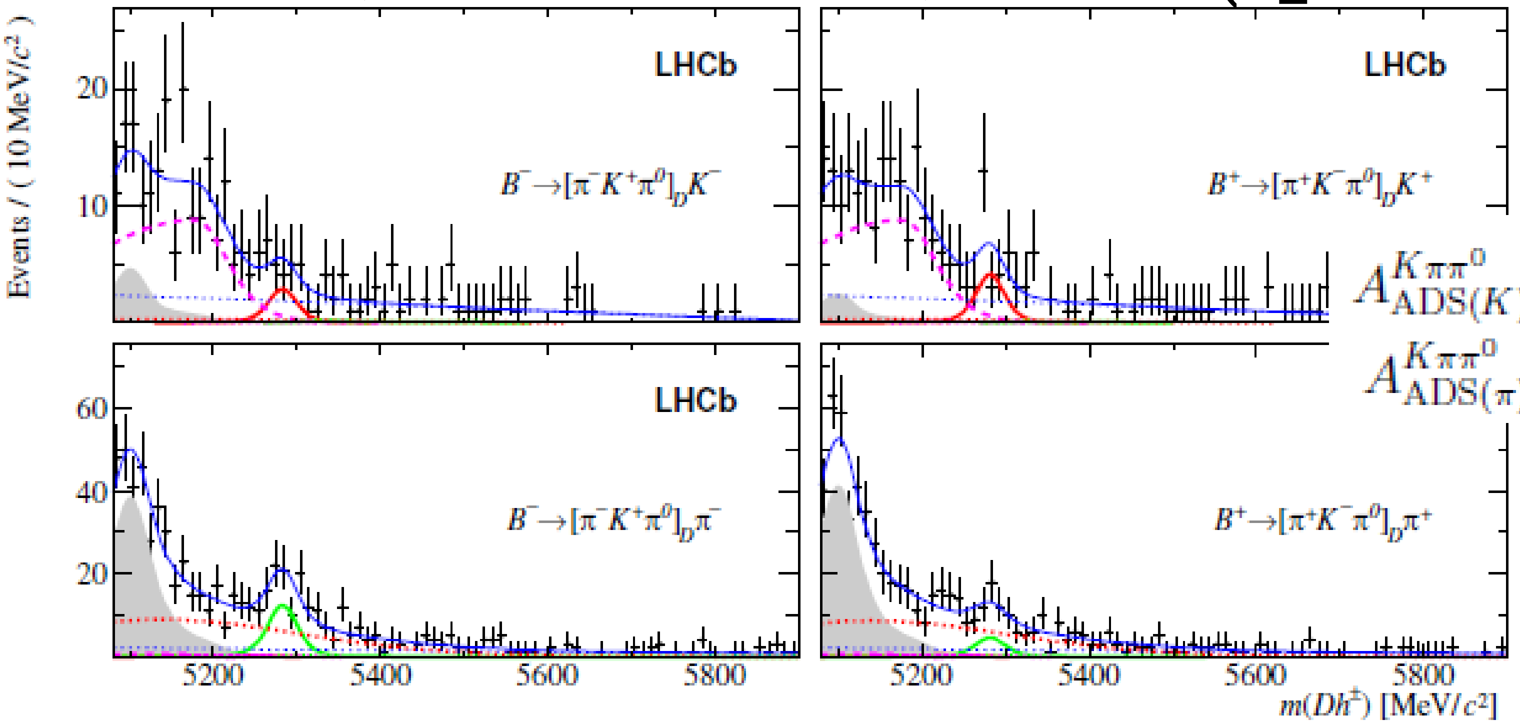


yields of double-tagged events where one meson decays into $K^-\pi^+\pi^0$ (or $K3\pi$), and the other meson decays into CP-odd, CP-even and $K\pi$

B→DK, D→K$^+\pi^-\pi^0$, K3π (quasi ADS)

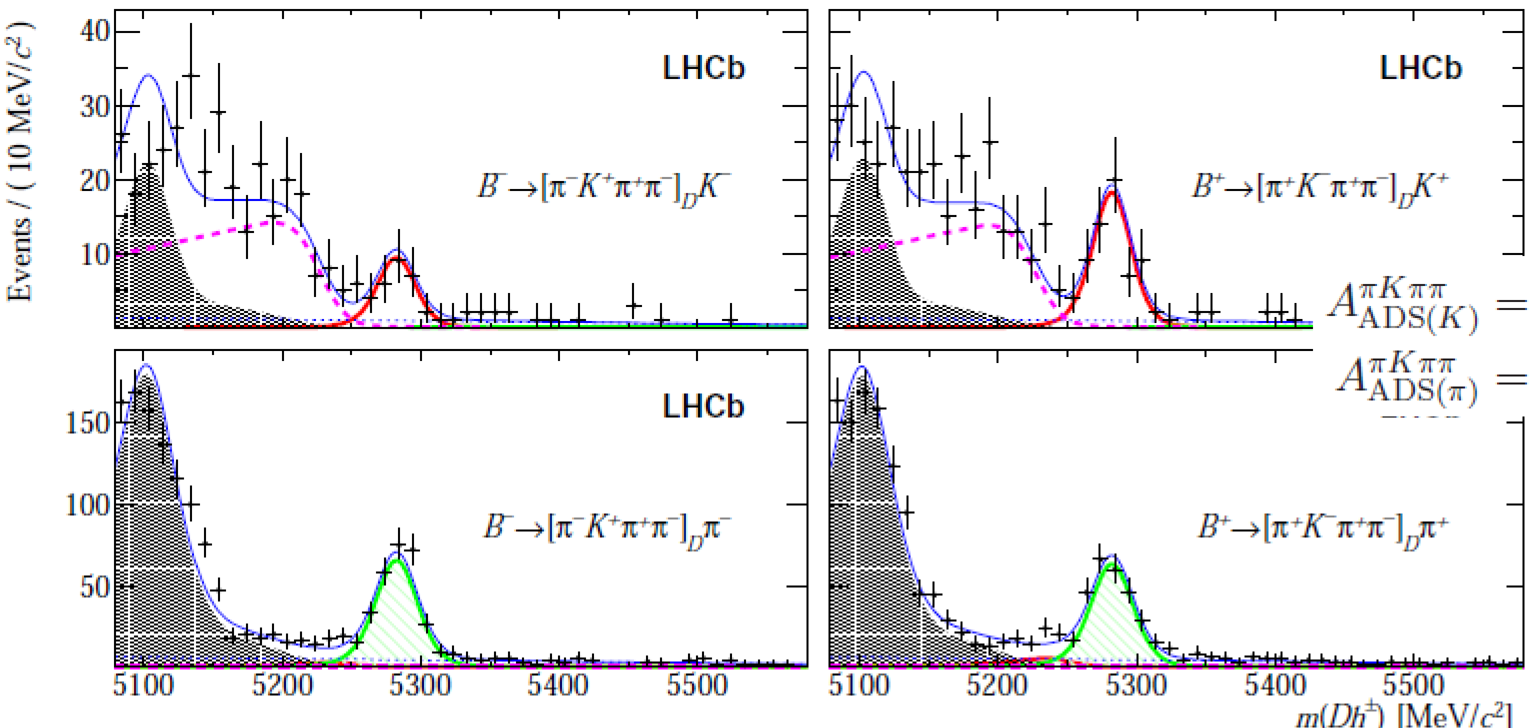
arXiv:1504.05442]

3 fb^{-1}



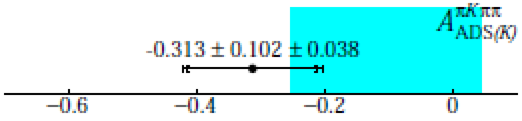
$$A^{K\pi\pi^0}_{\mathrm{ADS}(K)} = -0.20 \pm 0.27 \pm 0.04$$

$$A^{K\pi\pi^0}_{\mathrm{ADS}(\pi)} = 0.438 \pm 0.190 \pm 0.011$$



$$A^{\pi K\pi\pi}_{\mathrm{ADS}(K)} = -0.313 \pm 0.102 \pm 0.038$$

$$A^{\pi K\pi\pi}_{\mathrm{ADS}(\pi)} = 0.023 \pm 0.048 \pm 0.005$$



GGSZ, $B \to DK$, $D \to K_S \pi\pi$, $K_S KK$

GLW, $B \to DK$, $D \to K^+K^-$, $\pi^+\pi^-$

ADS, $B \to DK$, $D \to K^+\pi^-$

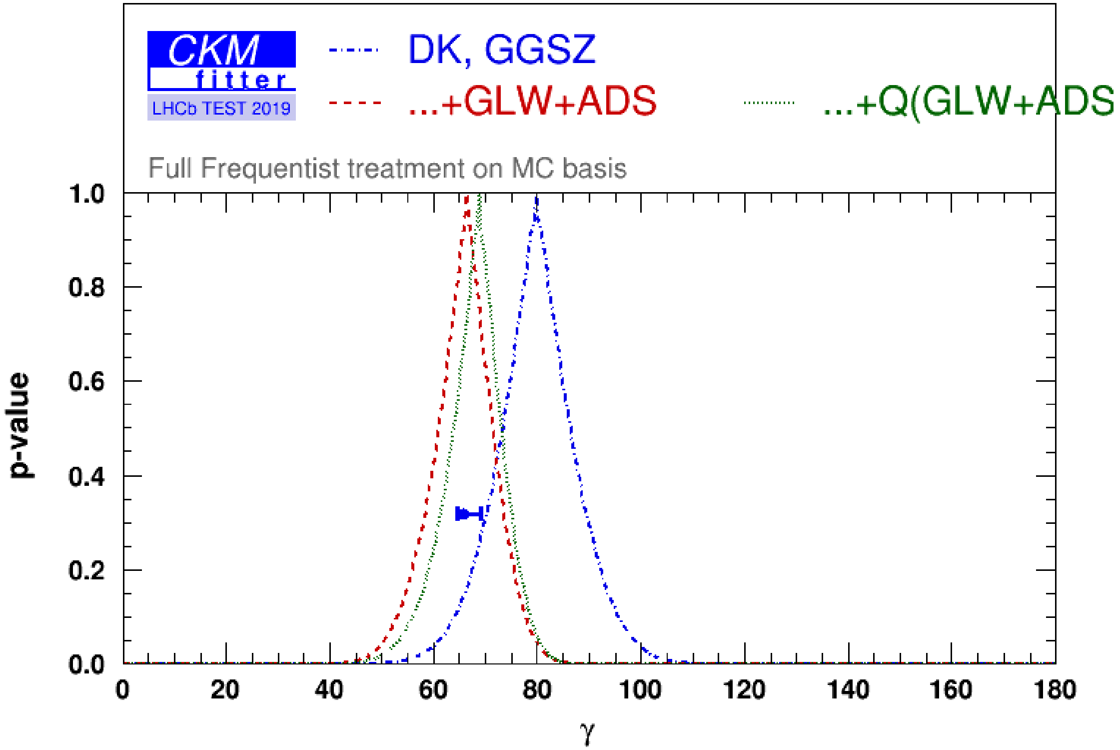
$B \to DK$, $D \to \pi^+\pi^-\pi^0$, $K^+K^-\pi^0$ (quasi GLW)

$B \to DK$, $D \to K^+\pi^-\pi^0$, $K3\pi$ (quasi ADS)

$\gamma(\mathrm{DK,\ GGSZ}) = (80 \pm 10)^\circ$

$\gamma(\mathrm{DK,\ GGSZ+GLW+ADS}) = (66.4^{+7.2}_{-8.2})^\circ$

$\gamma(\mathrm{DK,\ GGSZ+GLW+ADS+QGLW+QADS}) = (68.7^{+6.2}_{-7.4})^\circ$



D^*K, DK^*, $DK\pi\pi$

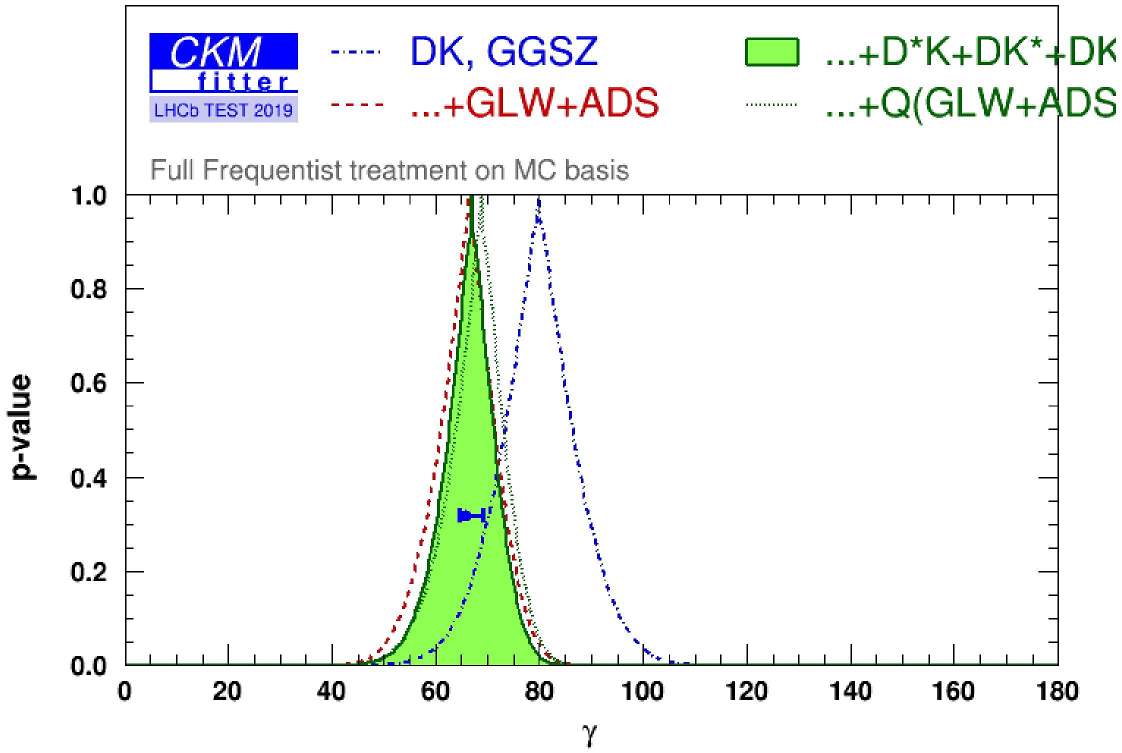
$D^*_{CP}K^-$	LHCb $\int\mathcal{L}dt$=5 fb^{-1}	−0.151 ± 0.033 ± 0.011	0.276 ± 0.094 ± 0.047	1.138 ± 0.029 ± 0.016	0.902 ± 0.087 ± 0.112	(stat) (syst)	PLB 777 (2018) 16
$D_{CP}K^{*-}$	LHCb KK $\int\mathcal{L}dt$=4.8 fb^{-1}	0.06 ± 0.07 ± 0.01	-	1.22 ± 0.09 ± 0.01	-	-	JHEP 11 (2017) 156
	LHCb pipi $\int\mathcal{L}dt$=4.8 fb^{-1}	0.15 ± 0.13 ± 0.02	-	1.08 ± 0.14 ± 0.03	-	-	JHEP 11 (2017) 156
$D_{CP}K^-\pi^+\pi^-$	LHCb KK $\int\mathcal{L}dt$=3 fb^{-1}	−0.045 ± 0.064 ± 0.011	-	1.043 ± 0.069 ± 0.034	-	-	PRD 92 (2015) 112005
	LHCb ππ $\int\mathcal{L}dt$=3 fb^{-1}	−0.054 ± 0.101 ± 0.011	-	1.035 ± 0.108 ± 0.038	-	-	
$D_{\pi\pi\pi\pi}K^{*-}$	LHCb $\int\mathcal{L}dt$=4.8 fb^{-1}	0.02 ± 0.11 ± 0.01		1.08 ± 0.13 ± 0.03		JHEP 1711 (2017) 156	
DK^{*-} $D\to K\pi$	LHCb $\int\mathcal{L}dt$=4.8 fb^{-1}	−0.81 ± 0.17 ± 0.04		0.011 ± 0.004 ± 0.001		JHEP 1711 (2017) 156	
DK^{*-} $D\to K3\pi$	LHCb $\int\mathcal{L}dt$=4.8 fb^{-1}	−0.45 ± 0.21 ± 0.14		0.011 ± 0.005 ± 0.003		JHEP 1711 (2017) 156	
$DK^-\pi^+\pi^-$ $D\to K\pi$	LHCb $\int\mathcal{L}dt$=3 fb^{-1}	$-0.32\ ^{+0.27}_{-0.34}$		$0.0082\ ^{+0.0038}_{-0.0030}$		PRD 92 (2015) 112005	

$$\gamma(DK,\ GGSZ) = (80 \pm 10)^\circ$$

$$\gamma(DK,\ GGSZ+GLW+ADS) = (66.4^{+7.2}_{-8.2})^\circ$$

$$\gamma(DK,\ GGSZ+GLW+ADS+QGLW+QADS) = (68.7^{+6.2}_{-7.4})^\circ$$

$$\gamma(DK,\ GGSZ+GLW+ADS+QGLW+QADS;\ D^*K,\ DK^*,\ DK\pi\pi) = (67.0^{+5.9}_{-6.7})^\circ$$



Experiment	A_{CP+}	R_{CP+}	Reference
LHCb KK $\int L dt = 3\ fb^{-1}$	$-0.20 \pm 0.15 \pm 0.02$	$1.05\ ^{+0.17}_{-0.15} \pm 0.04$	PRD 90 (2014) 112002
LHCb pipi $\int L dt = 3\ fb^{-1}$	$-0.09 \pm 0.22 \pm 0.02$	$1.21\ ^{+0.28}_{-0.25} \pm 0.05$	PRD 90 (2014) 112002

Experiment	R_+	R_-	Reference
LHCb $\int L dt = 3\ fb^{-1}$	$0.06 \pm 0.03 \pm 0.01$	$0.06 \pm 0.03 \pm 0.01$	PRD 90 (2014) 112002

Experiment	x+	y+	x−	y−	Correlation	Reference
LHCb $\int L dt = 3\ fb^{-1}$	$0.04 \pm 0.16 \pm 0.11$	$-0.47 \pm 0.28 \pm 0.22$	$-0.02 \pm 0.13 \pm 0.14$	$-0.35 \pm 0.26 \pm 0.41$	(stat) (syst)	PR D93 (2016) 112018

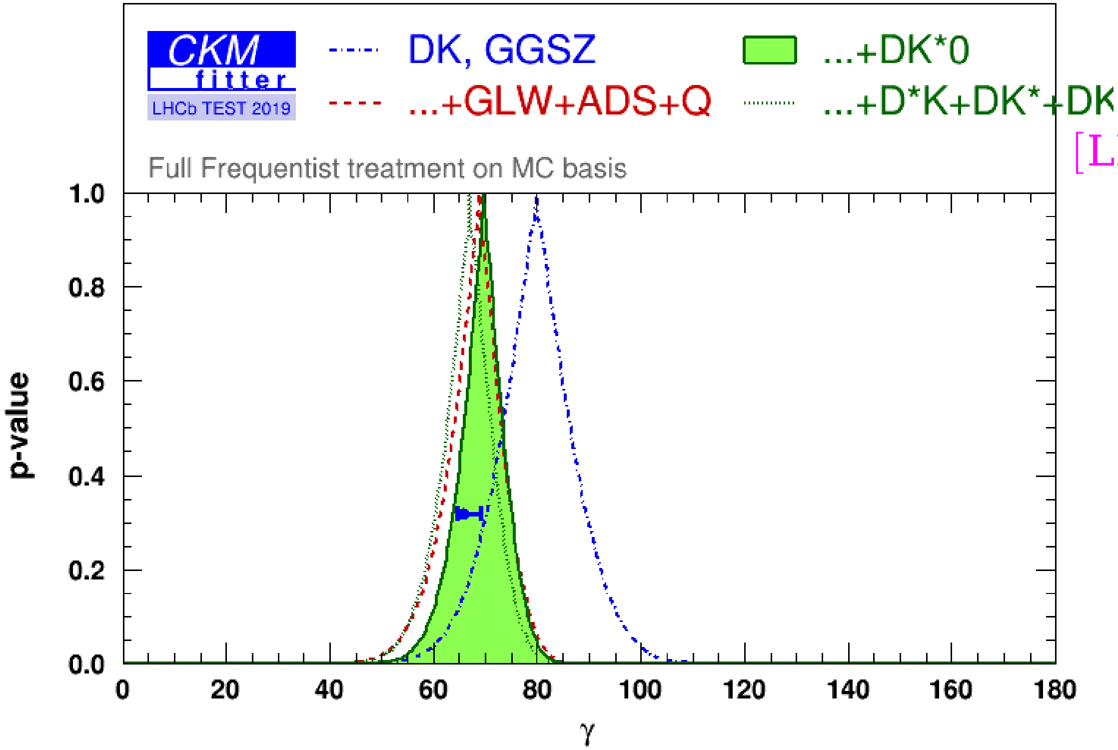
$\gamma(DK, GGSZ) = (80 \pm 10)^\circ$

$\gamma(DK, GGSZ+GLW+ADS) = (66.4^{+7.2}_{-8.2})^\circ$

$\gamma(DK, GGSZ+GLW+ADS+QGLW+QADS) = (68.7^{+6.2}_{-7.4})^\circ$

$\gamma(DK, GGSZ+GLW+ADS+QGLW+QADS; D^*K, DK^*, DK\pi\pi) = (67.0^{+5.9}_{-6.7})^\circ$

$\gamma(DK, D^*K, DK^*, DK\pi\pi + DK^{*0}) = (69.7^{+5.3}_{-5.9})^\circ$



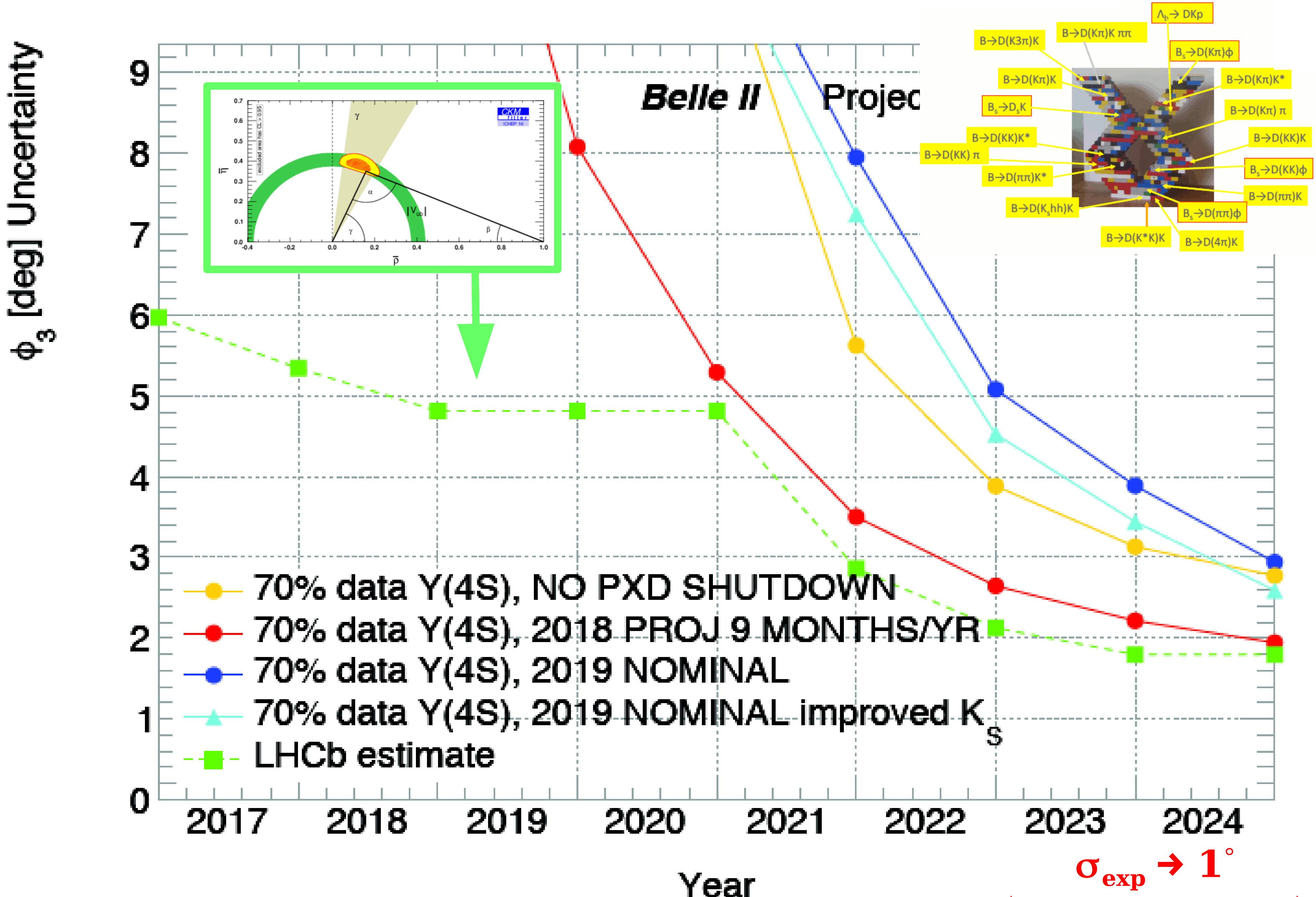
[LHCb−CONF−2018−002]

$\gamma_{LHCb} = (74.0^{+5.0}_{-5.8})^\circ$

$\gamma_{UT} = (65.6^{+1.0}_{-3.4})^\circ$

Ultimate γ-from-tree decays

precision will be reached through many individual measurements



$\sigma_{exp} \rightarrow 1^{\circ}$

$(\sigma_{theory}$ **negligible**$)$