What do we know about γ/φ$_3$ today?

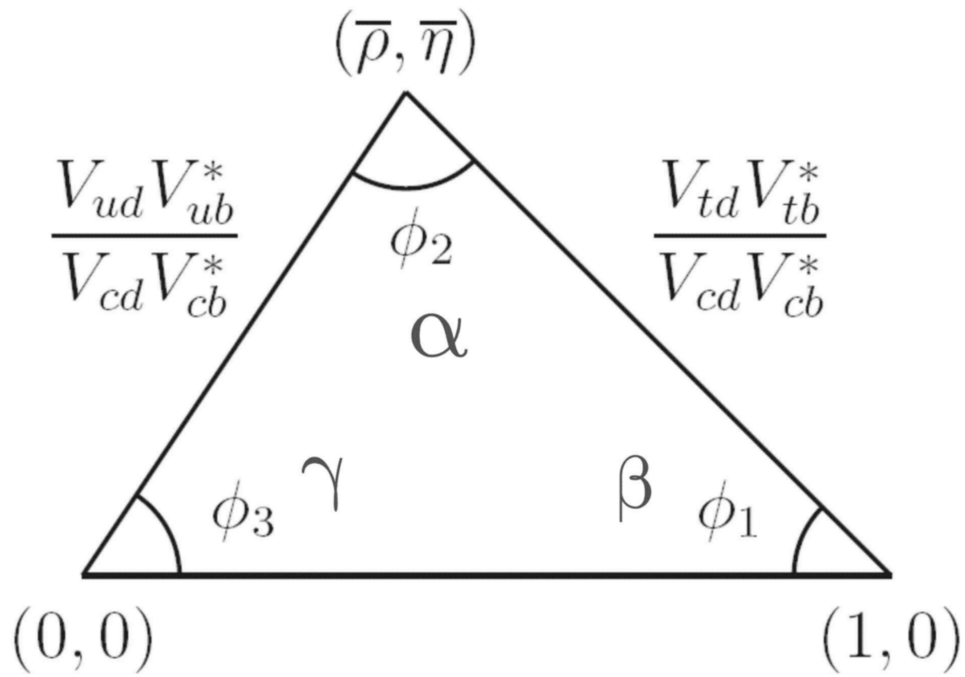
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$\mathbf{V_{CKM}} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \sum_{n=4}^{N} O(\lambda^n)$$

V. Gligorov, CERN

3rd December 2012

What do we know about γ/φ$_3$ today?

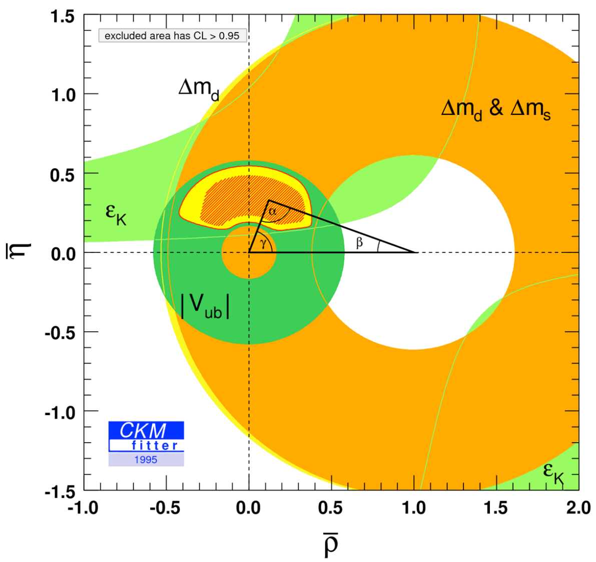


V. Gligorov, CERN

3rd December 2012

What do we know about γ/φ_3 today?

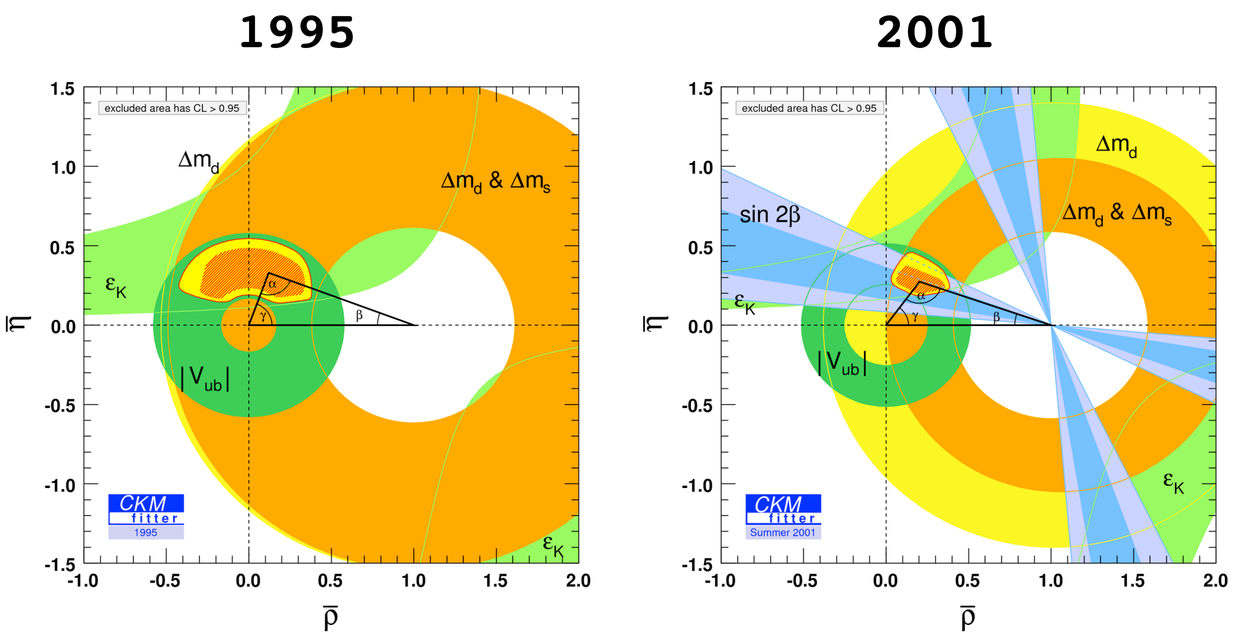
1995



V. Gligorov, CERN

3rd December 2012

What do we know about γ/φ₃ today?

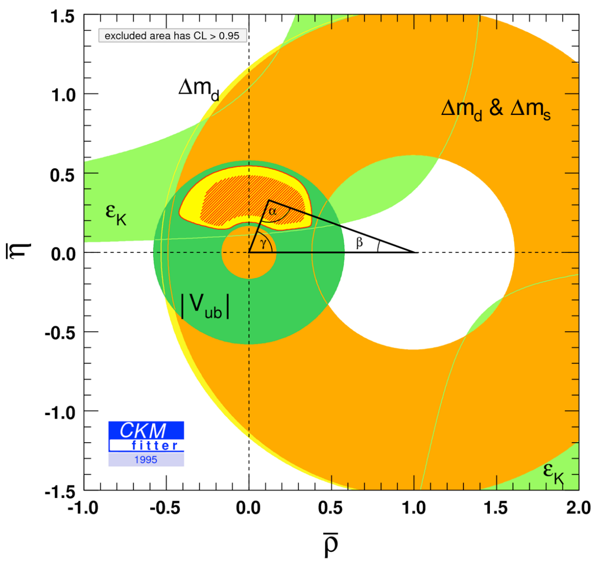


V. Gligorov, CERN

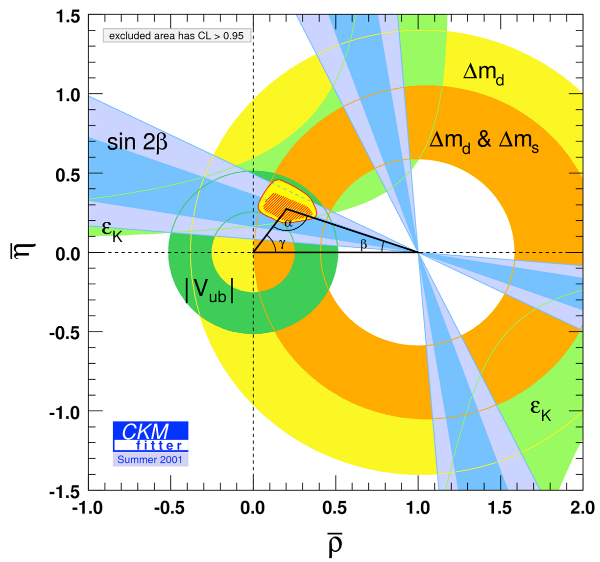
3rd December 2012

What do we know about γ/φ_3 today?

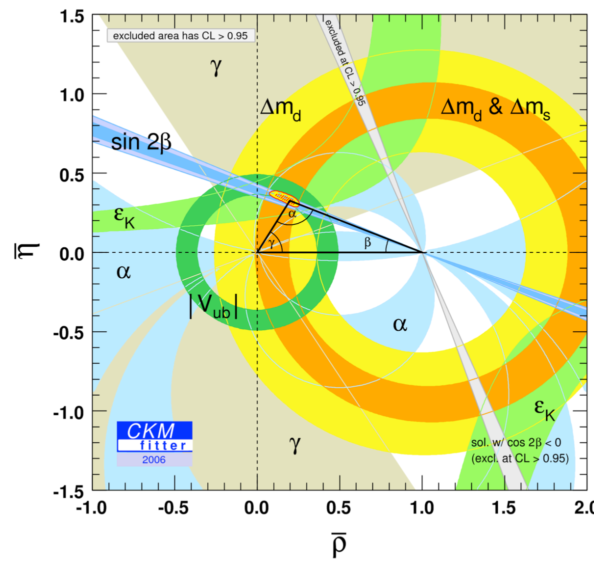
1995



2001



2006

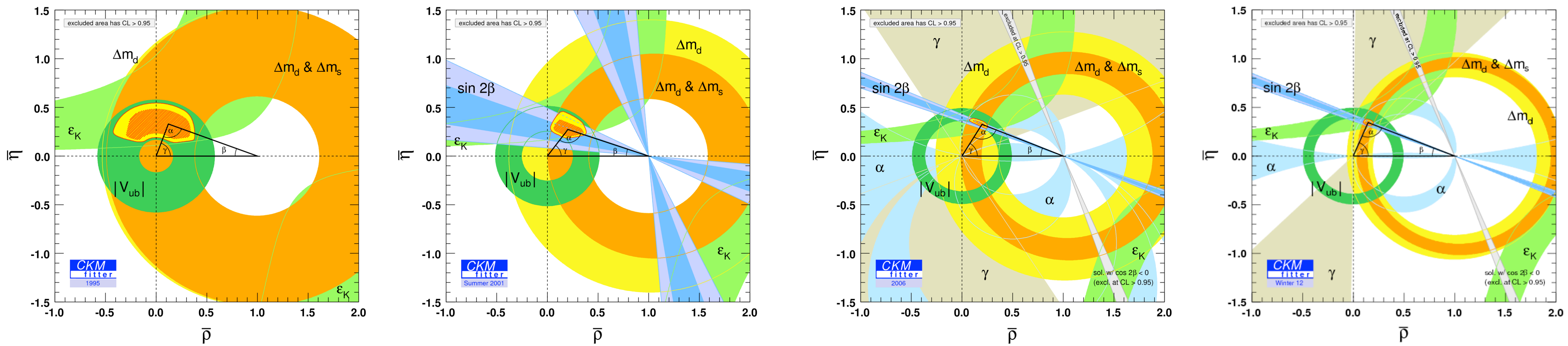


V. Gligorov, CERN

3rd December 2012

What do we know about γ/φ_3 today?

1995 **2001** **2006** **2012**

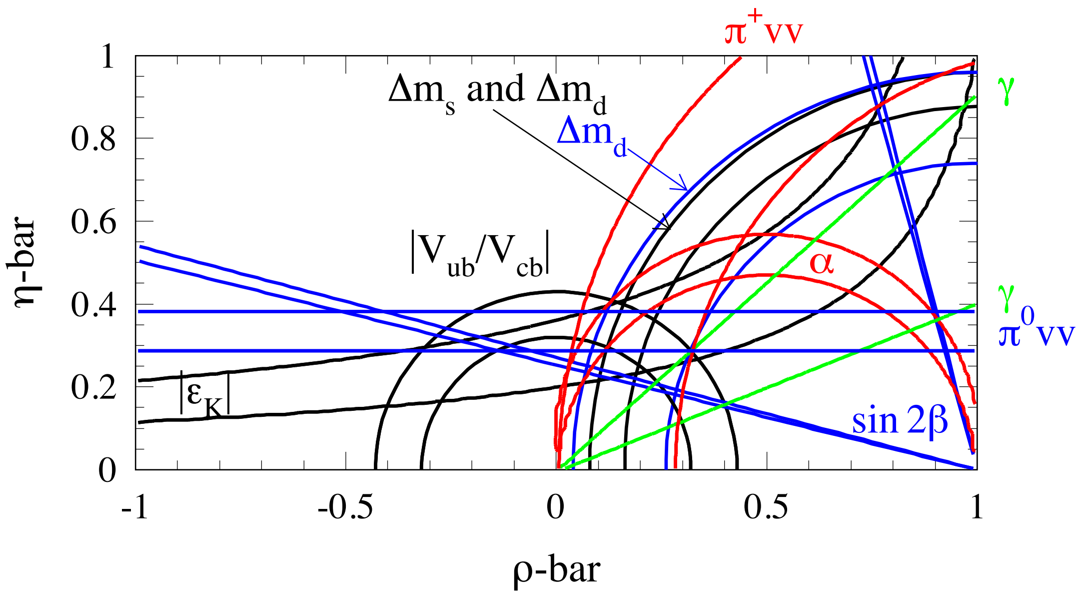


V. Gligorov, CERN

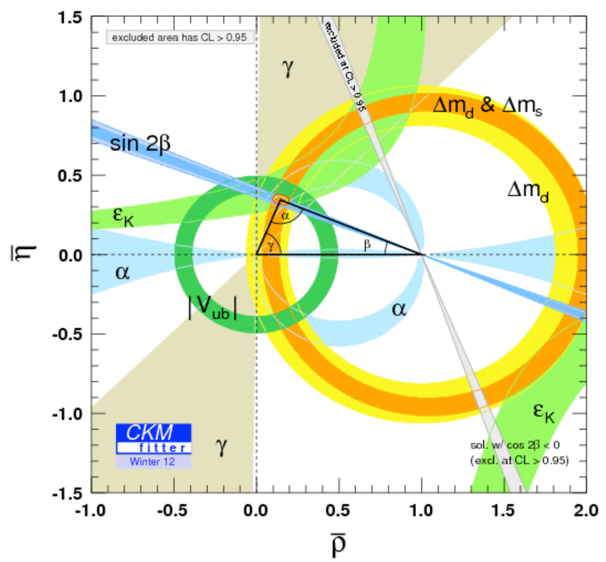
3rd December 2012

What do we know about γ/φ3 today?

Prophecy for 2010 -- clearly a bit optimistic!



2012

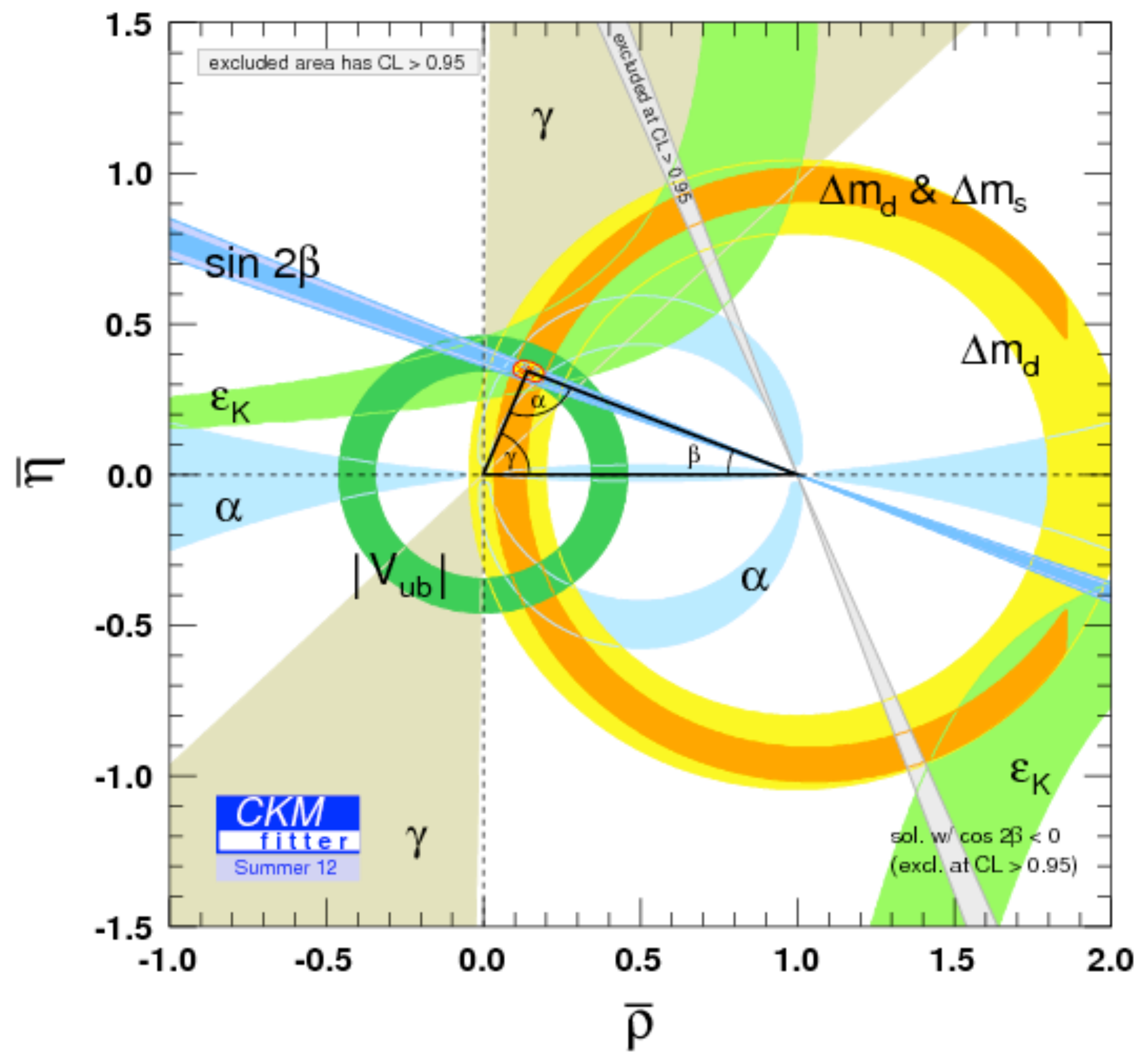


V. Gligorov, CERN

3rd December 2012

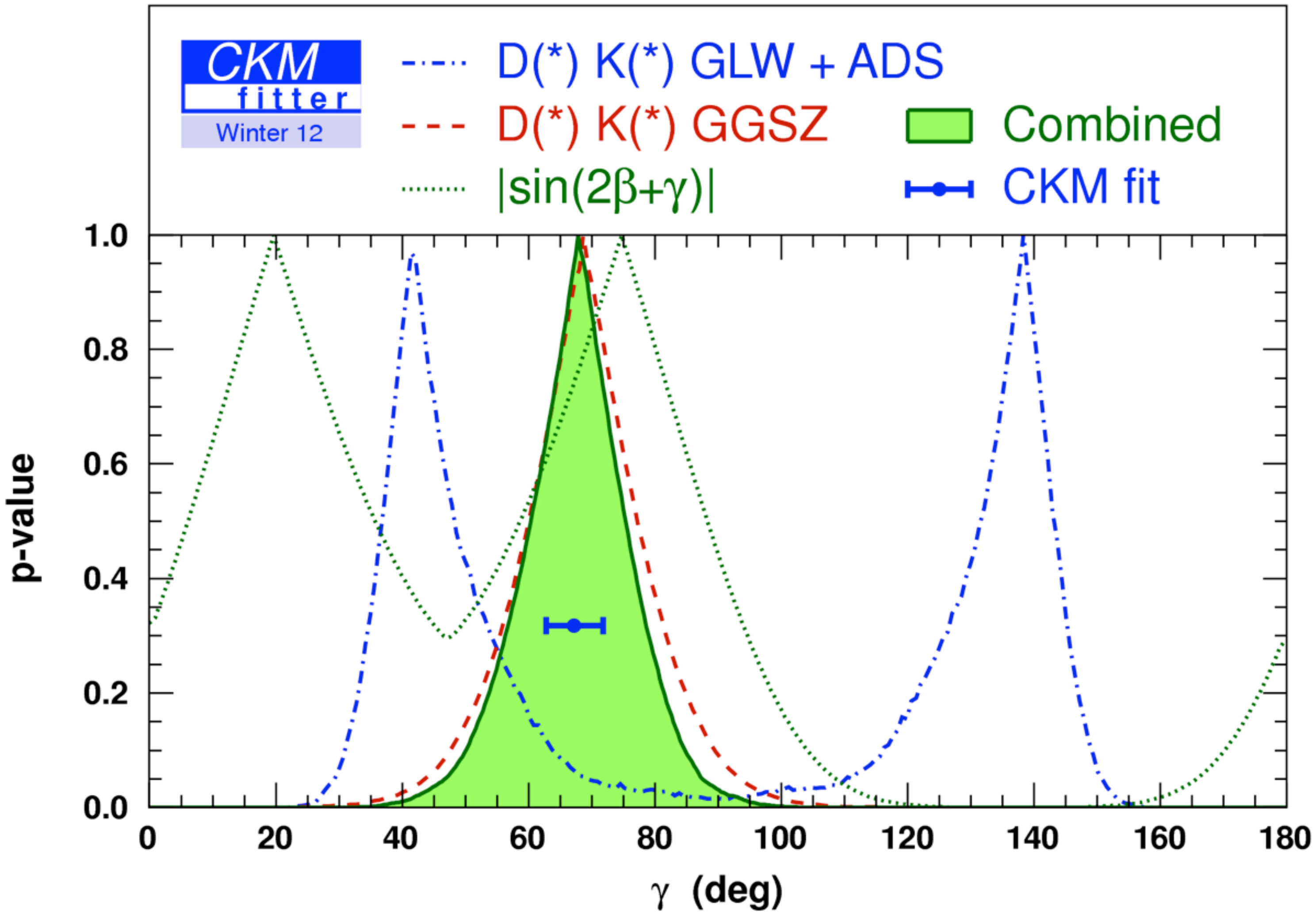
But seriously...

γ is still the least precisely measured of the UT angles...



But seriously...

...though the number of ways in which it is being measured is growing...



But seriously…

...and it is still probably the theoretically cleanest CKM parameter

We first review the methods for determining γ from $B \to DK$ decays that appeared after CKM 2008. We then discuss the theoretical errors in γ extraction. The errors due to neglected $D-\overline{D}$ and $B_{d,s}-\overline{B}_{d,s}$ mixing can be avoided by including their effects in the fits. The ultimate theoretical error is then given by electroweak corrections that we estimate to give a shift $\delta\gamma/\gamma \sim \mathcal{O}(10^{-6})$.

Zupan, http://arxiv.org/pdf/1101.0134.pdf

But seriously…

...and it is still probably the theoretically cleanest CKM parameter

Probe	Λ_{NP} for (N)MFV NP	Λ_{NP} for gen. FV NP	$B\overline{B}$ pairs
γ from $B \to DK^{1)}$	$\Lambda \sim \mathcal{O}(10^2$ TeV)	$\Lambda \sim \mathcal{O}(10^3$ TeV)	$\sim 10^{18}$
$B \to \tau\nu^{2)}$	$\Lambda \sim \mathcal{O}($ TeV)	$\Lambda \sim \mathcal{O}(30$ TeV)	$\sim 10^{13}$
$b \to ss\bar{d}^{3)}$	$\Lambda \sim \mathcal{O}($ TeV)	$\Lambda \sim \mathcal{O}(10^3$ TeV)	$\sim 10^{13}$
β from $B \to J/\psi K_S^{4)}$	$\Lambda \sim \mathcal{O}(50$ TeV)	$\Lambda \sim \mathcal{O}(200$ TeV)	$\sim 10^{12}$
$K - \overline{K}$ mixing$^{5)}$	$\Lambda > 0.4$ TeV (6 TeV)	$\Lambda > 10^{3(4)}$ TeV	now

Table 1: *The ultimate NP scales that can be probed using different observables listed in the first column. They are given by saturating the theoretical errors given respectively by 1) $\delta\gamma/\gamma = 10^{-6}$, 2) optimistically assuming no error on f_B, so that ultimate theoretical error just from electroweak corrections, 3) using SM predictions in [20], 4) optimistically assuming perturbative error estimates $\delta\beta/\beta$ 0.1% [21], and 5) from bounds for* ReC_1(ImC_1) *from UTfitter [23].*

Zupan, http://arxiv.org/pdf/1101.0134.pdf

A decade of overachievement…

BELLE ADS

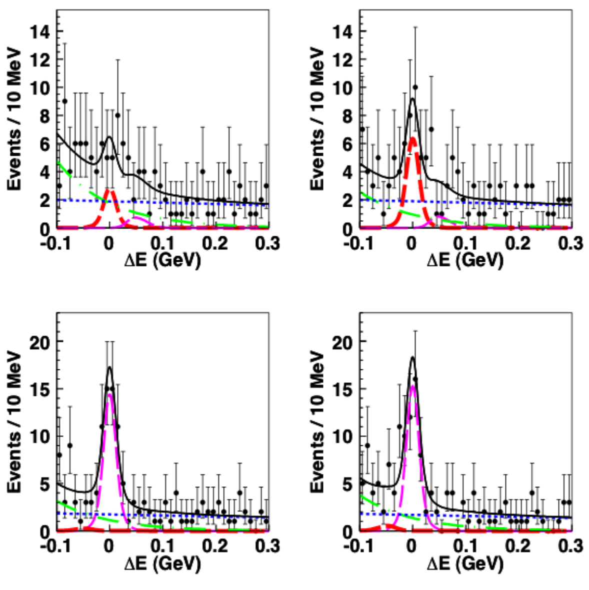


FIG. 2: ΔE distributions ($NB > 0.9$) for $[K^+\pi^-]_D K^-$ (left upper), $[K^-\pi^+]_D K^+$ (right upper), $[K^+\pi^-]_D \pi^-$ (left lower), and $[K^-\pi^+]_D \pi^+$ (right lower). The curves show the same components as in Fig. 1.

BABAR ADS

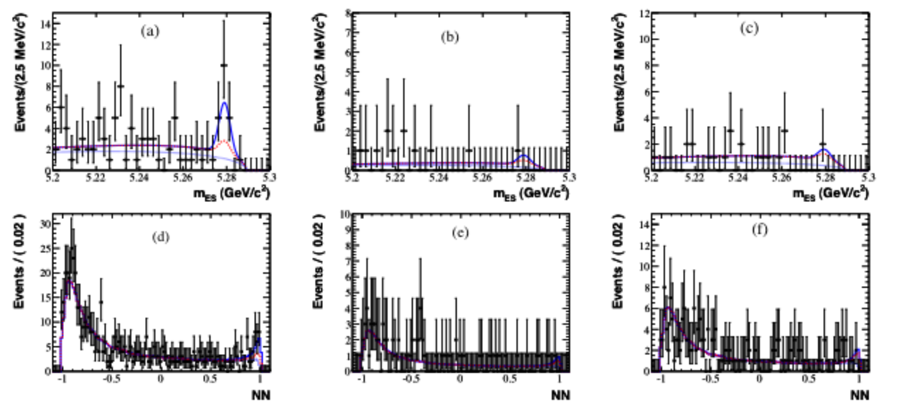


FIG. 8: (color online). Projections on $m_{\rm ES}$ (a, b, c) and NN (d, e, f) of the fit results for DK^+ (a, d), $D^*_{D\pi^0}K^+$ (b, e) and $D^*_{D\gamma}K^+$ (c, f) WS decays, for samples enriched in signal with the requirements $NN > 0.94$ ($m_{\rm ES}$ projections) or $5.2725 < m_{\rm ES} < 5.2875$ GeV/c^2 (NN projections). The points with error bars are data. The curves represent the fit projections for signal plus background (solid), the sum of all background components (dashed), and $q\bar{q}$ background only (dotted).

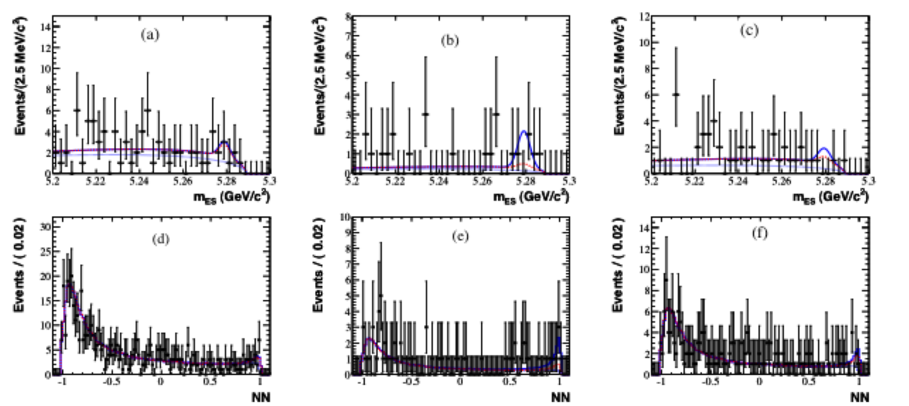


FIG. 9: (color online). Projections on $m_{\rm ES}$ (a, b, c) and NN (d, e, f) of the fit results for DK^- (a, d), $D^*_{D\pi^0}K^-$ (b, e) and $D^*_{D\gamma}K^-$ (c, f) WS decays, for samples enriched in signal with the requirements $NN > 0.94$ ($m_{\rm ES}$ projections) or $5.2725 < m_{\rm ES} < 5.2875$ GeV/c^2 (NN projections). The points with error bars are data. The curves represent the fit projections for signal plus background (solid), the sum of all background components (dashed), and $q\bar{q}$ background only (dotted).

CDF ADS

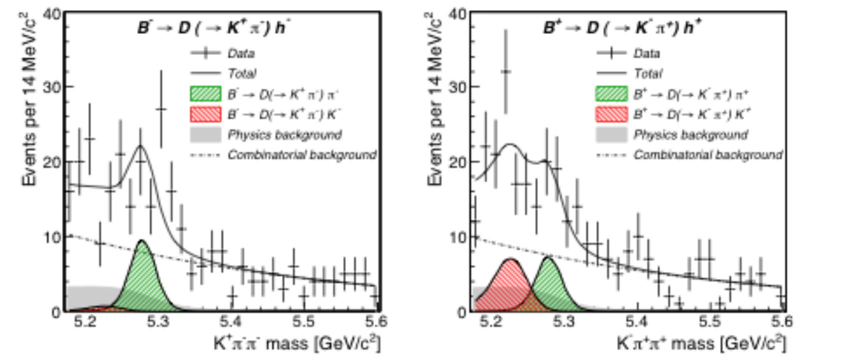


FIG. 1: Invariant mass distributions of $B^\pm \to Dh^\pm$ for the suppressed mode (bottom meson on the left and antibottom on the right). The pion mass is assigned to the charged track from the B candidate decay vertex. The projections of the common likelihood fit (see text) are overlaid.

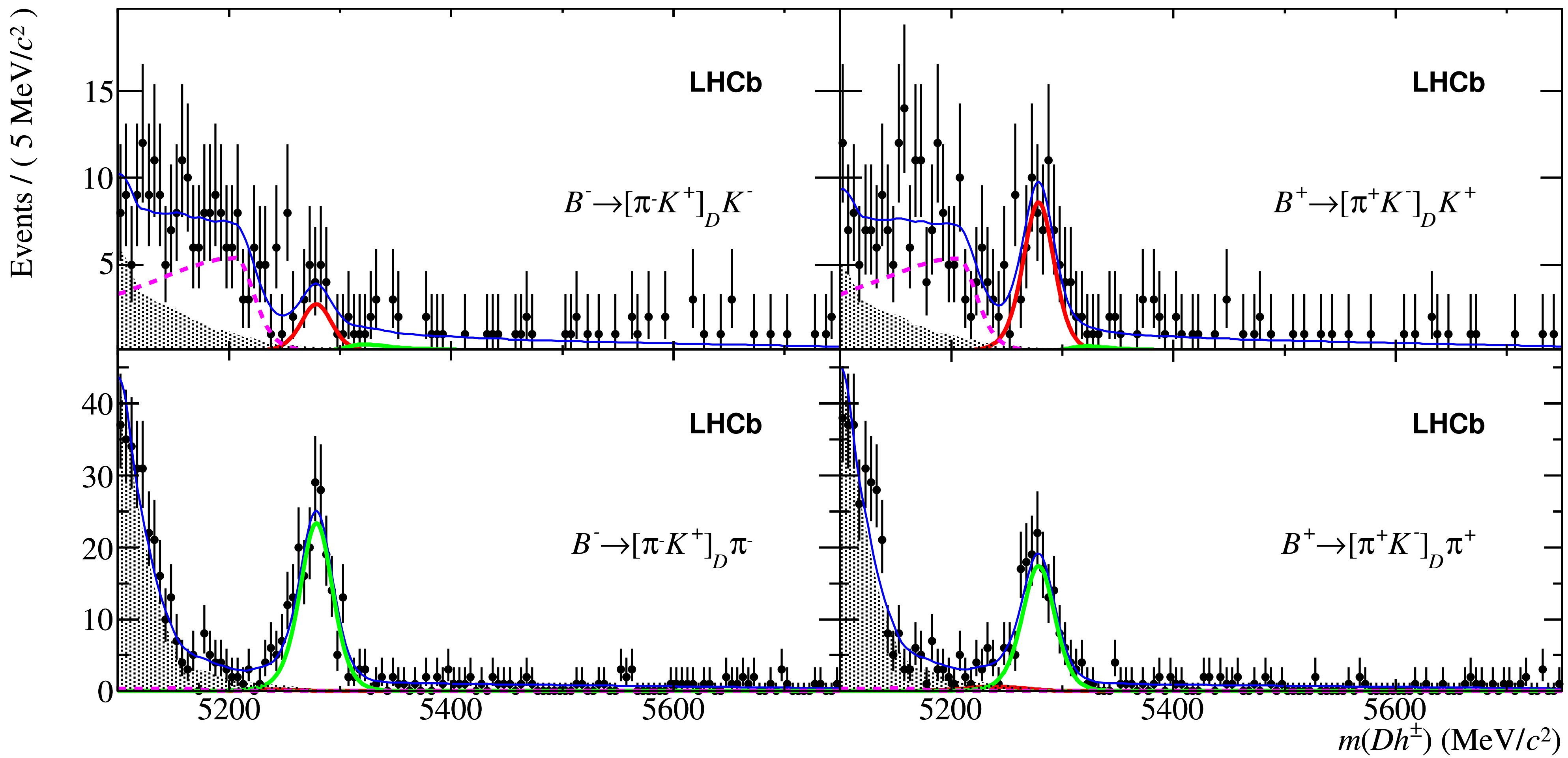
Left to right :

arXiv:1103.5951v2

PRD 82 072006 (2010)

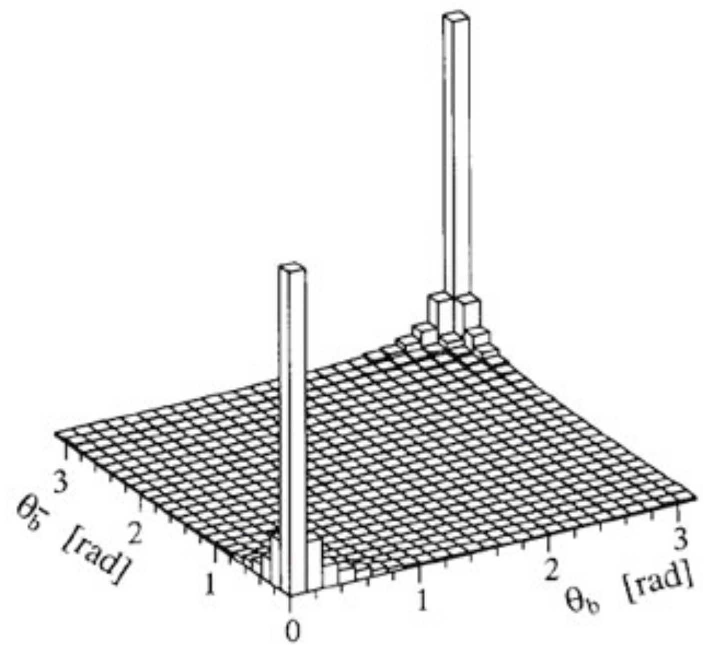
arXiv:1108.5765v2

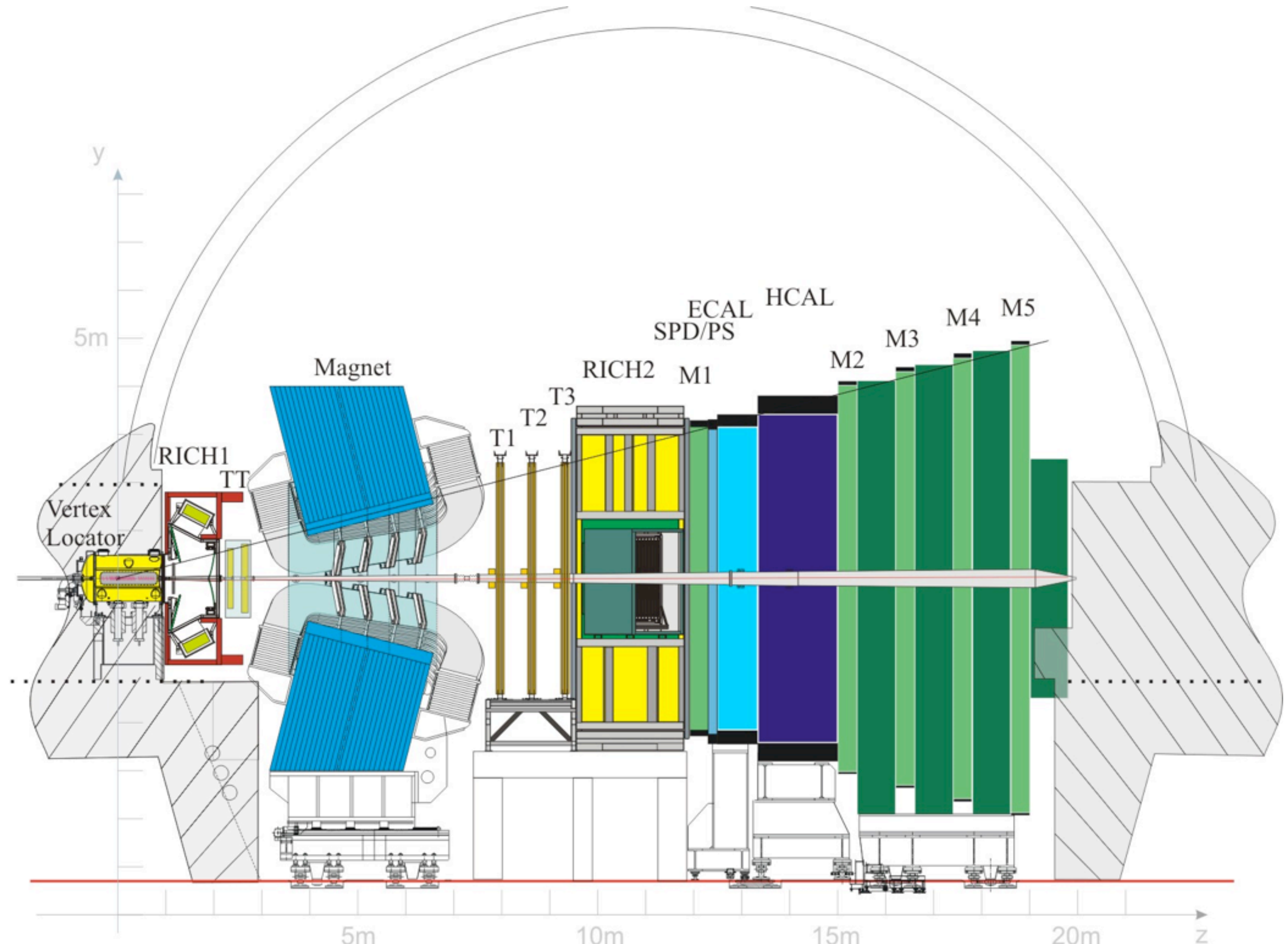
…and the start of a new era



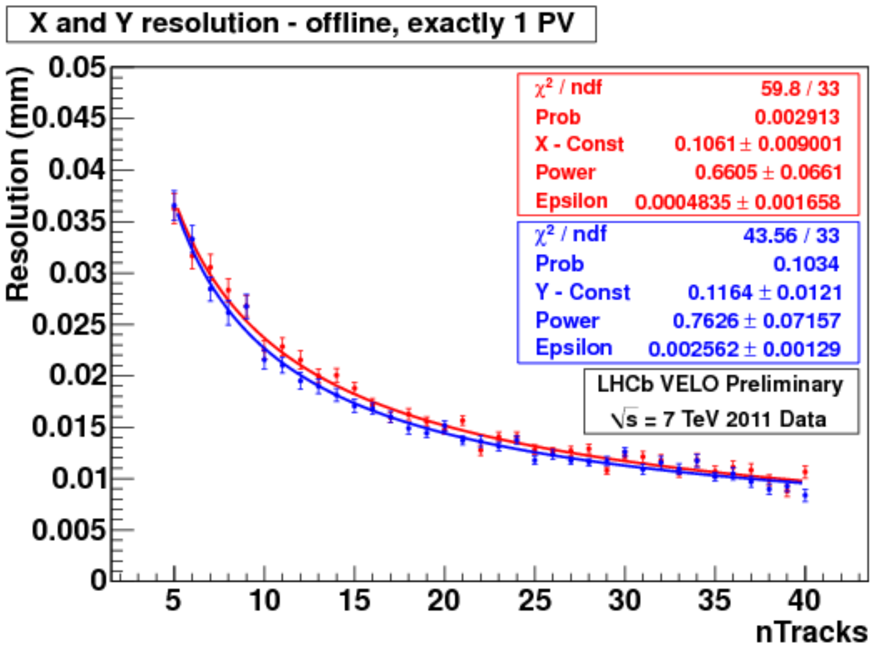
LHCB-PAPER-2012-001

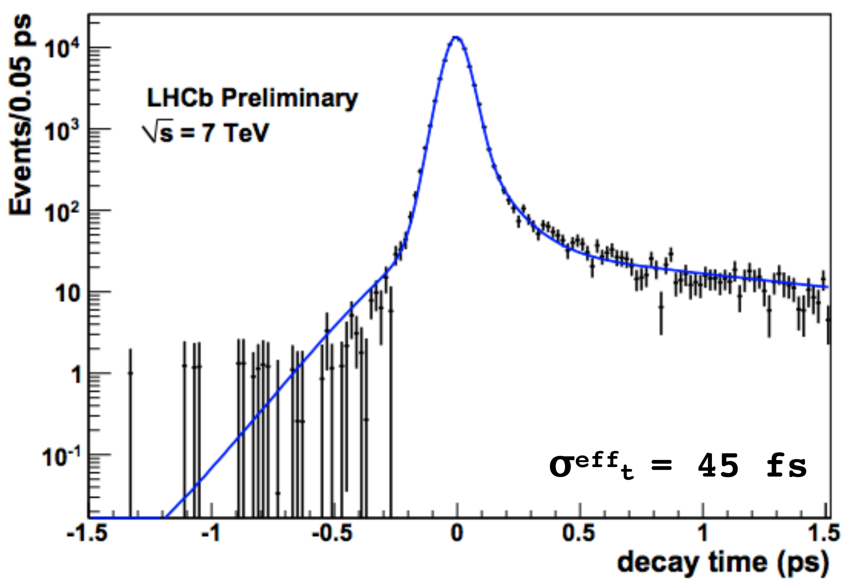
So who is this new kid in town?

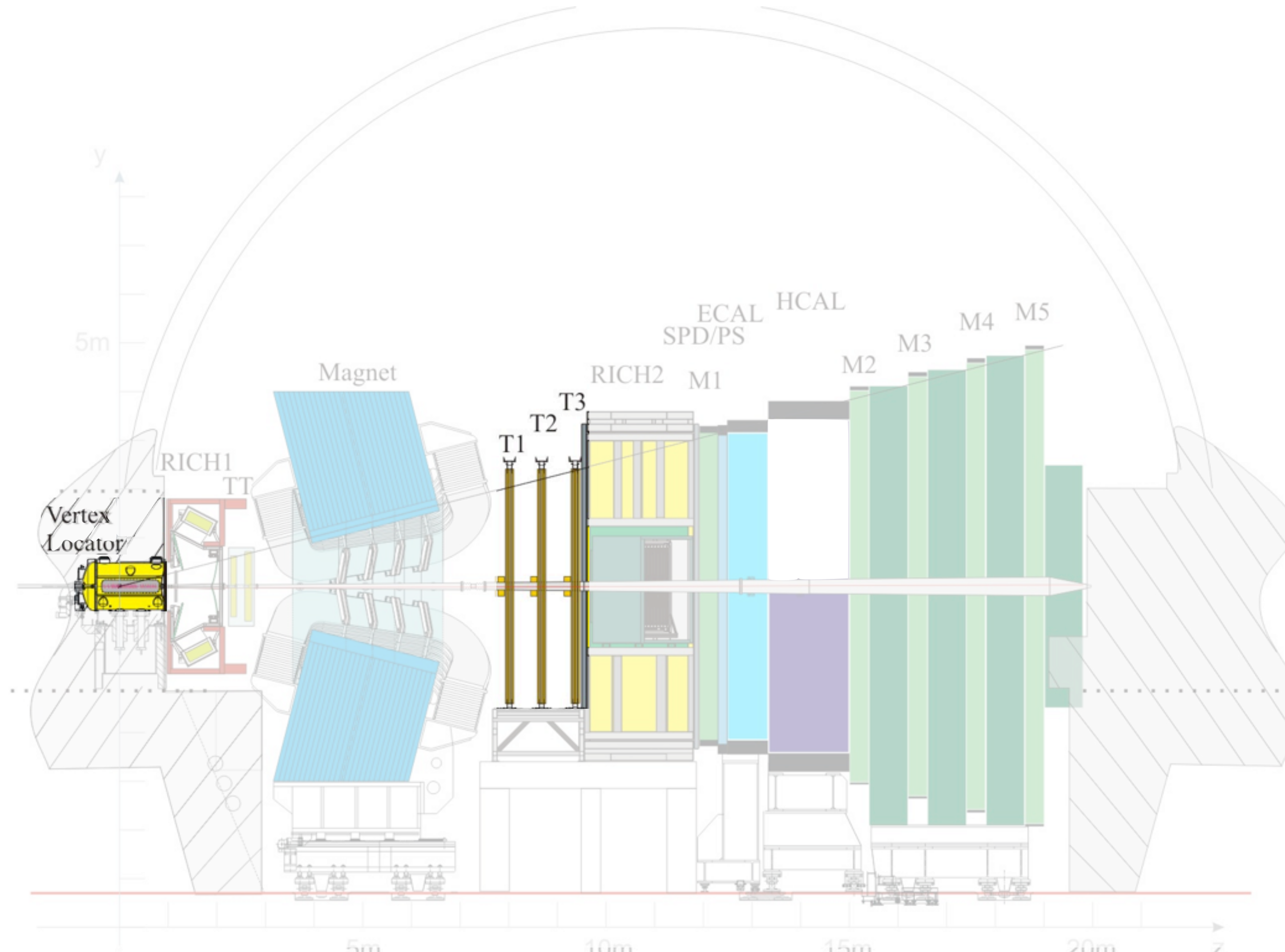




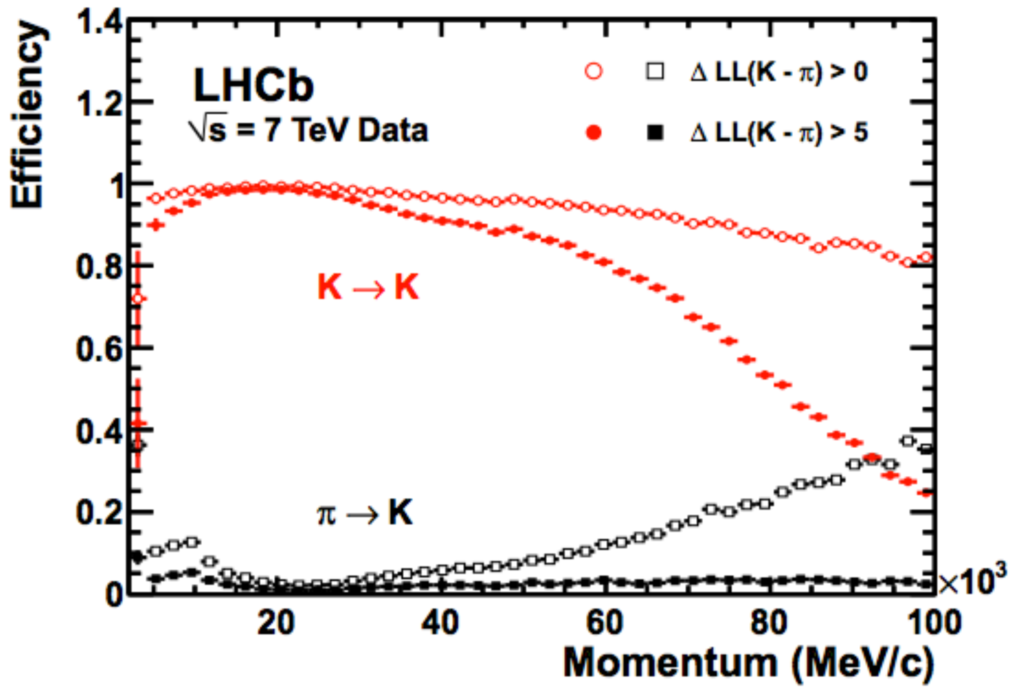
So who is this new kid in town?

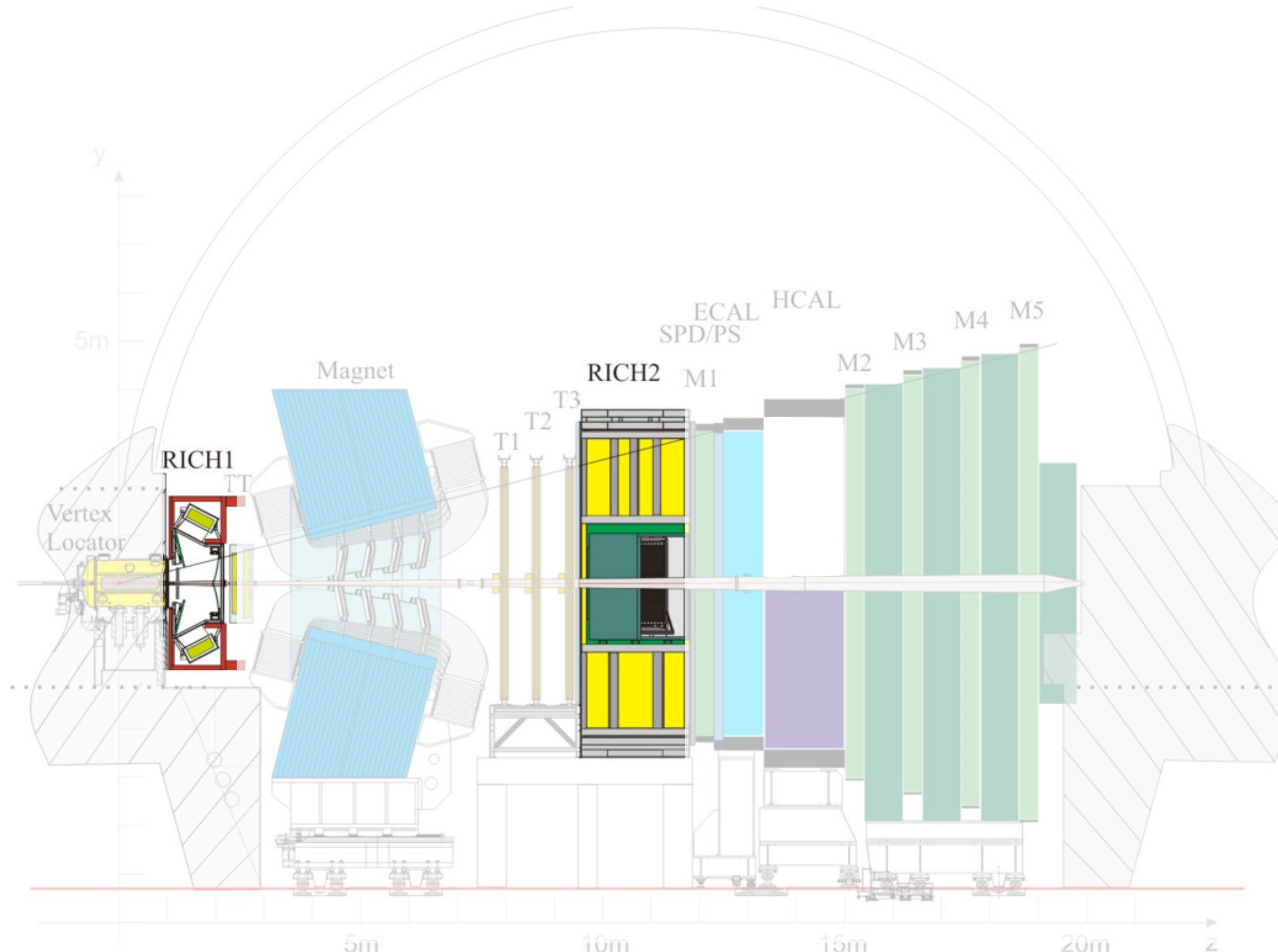






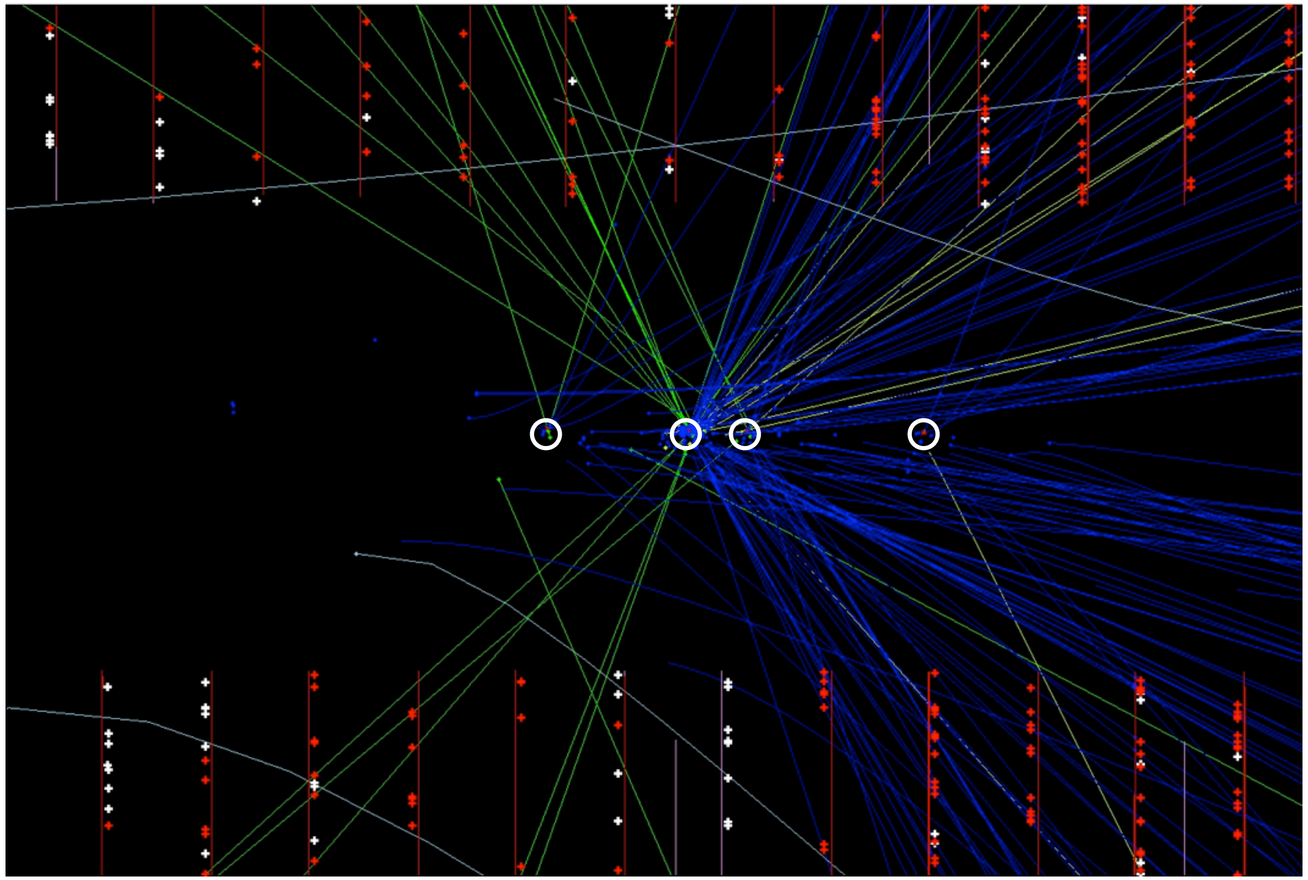
So who is this new kid in town?





The LHC environment

VELO rz view



The LHC produces 15 MHz of proton-proton (pp) collisions

In order to maximize integrated luminosity, it is necessary to accept events with multiple pp interactions in a single bunch crossing

Event with four interactions is shown on the left

We have been running with an average of ~1.5 interactions per bunch crossing in 2011/12

75-100% above design instantaneous luminosity!

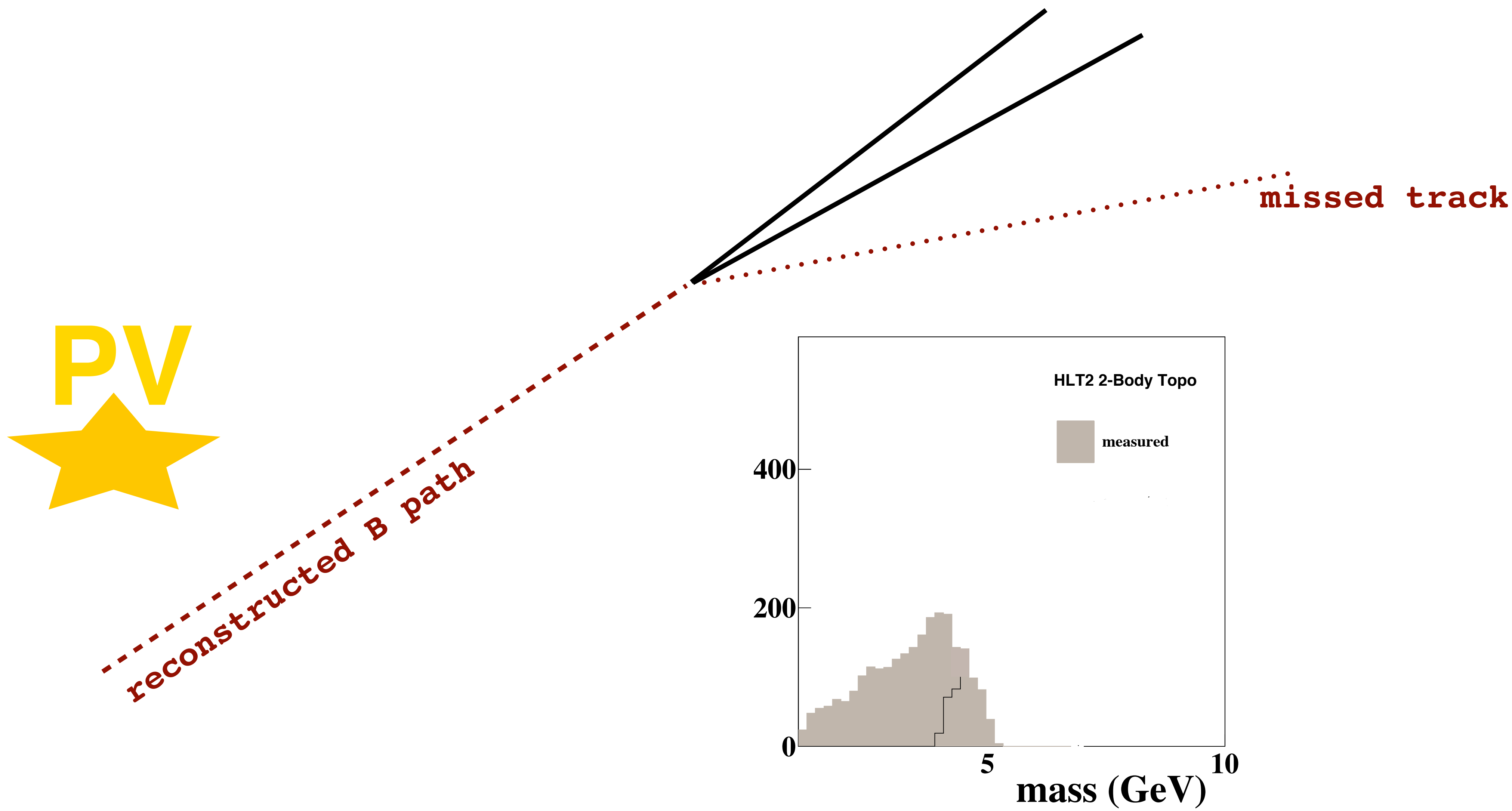
Multivariate selections from the start

Question : How is LHCb achieving clean signals in a much dirtier environment than either the B-factories or CDF?

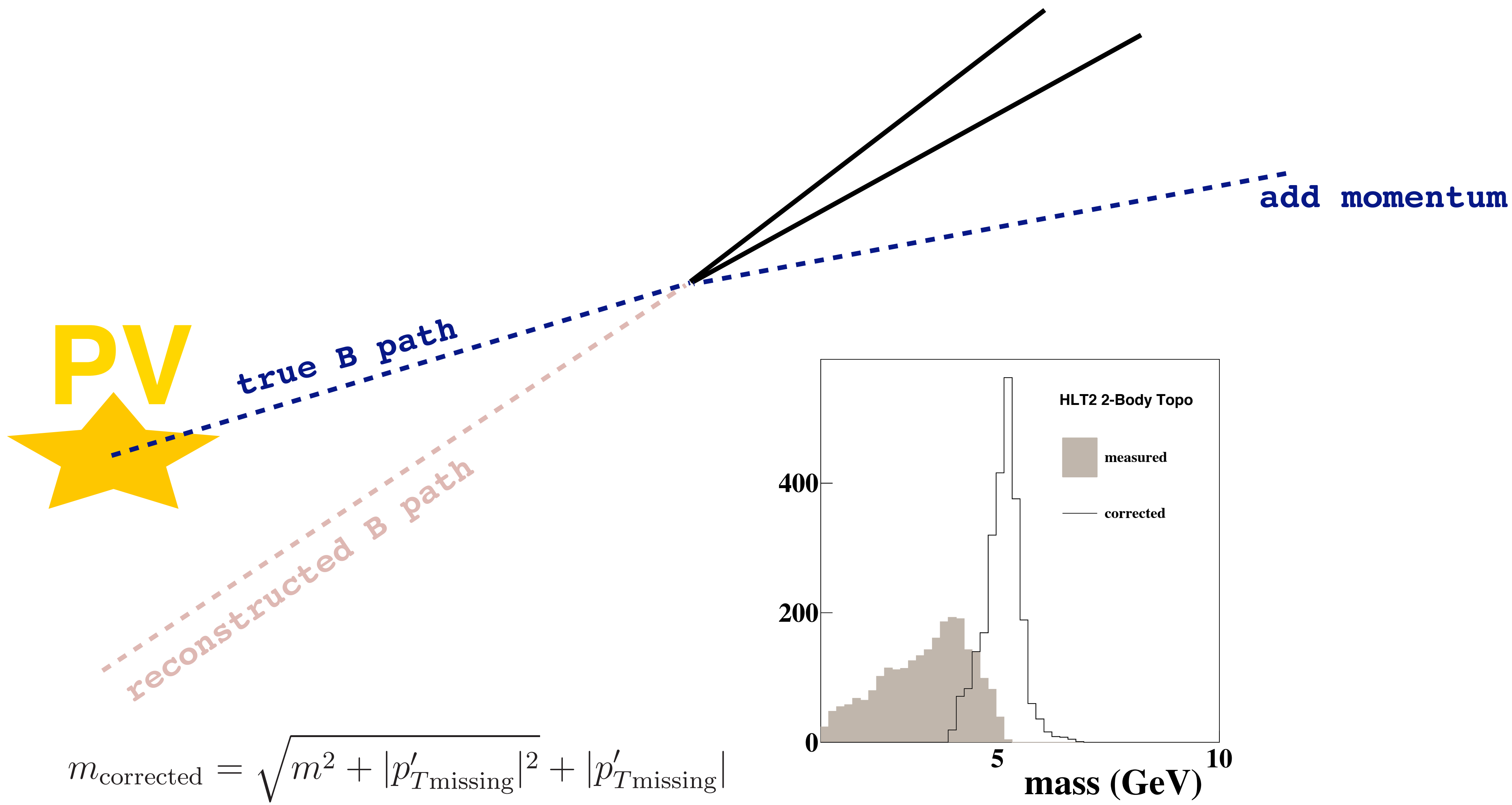
Answer 1 : A state of the art detector with ~0.5% momentum resolution and powerful particle identification.

Answer 2 : An aggressive use of multivariate selections from the very first stage of the datataking process, the trigger.

A topological decision tree trigger



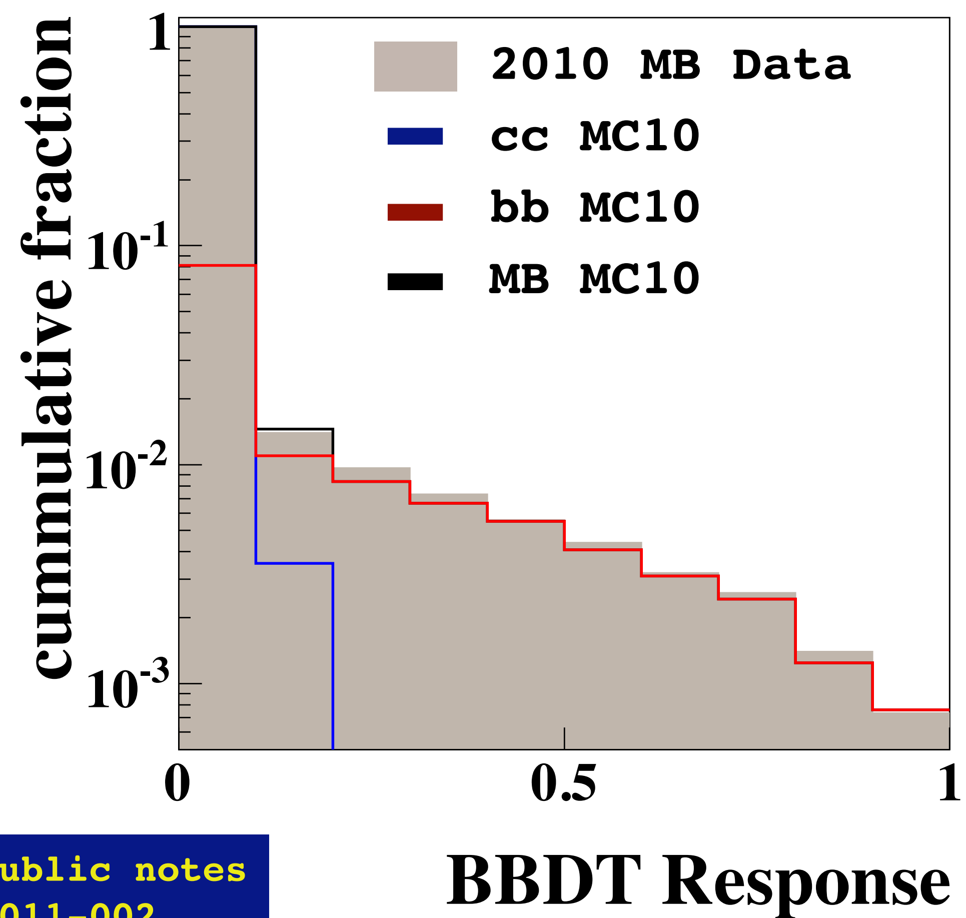
A topological decision tree trigger

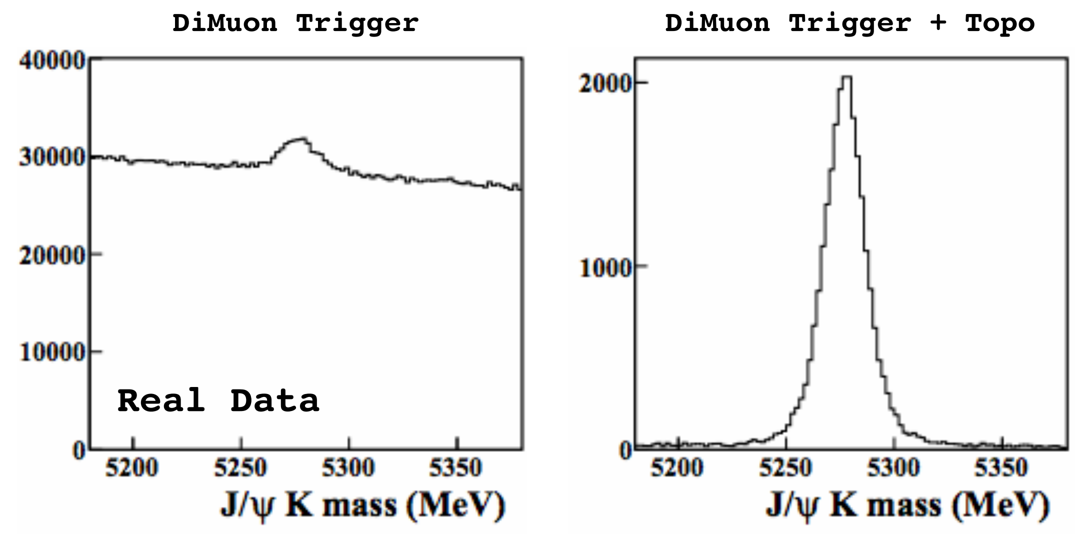


$$m_{\text{corrected}} = \sqrt{m^2 + |p'_{T\text{missing}}|^2} + |p'_{T\text{missing}}|$$

A topological decision tree trigger

The corrected mass is a good variable, but not good enough to deal with pileup on its own : deploy a boosted decision tree to discriminate between signal and background displaced vertices.





Left : J/ψK candidates with a dimuon trigger and no detachment required

Right : the subset of these candidates which pass the topological trigger

See LHCb public notes
LHCb-PUB-2011-002
LHCb-PUB-2011-003
LHCb-PUB-2011-016

Gligorov&Williams http://arxiv.org/abs/1210.6861

What has this enabled LHCb to produce?

GLW/ADS in $B \to DK, D\pi$ with $D \to hh$

ADS in $B \to DK, D\pi$ with $D \to hhhh$

GGSZ in $B \to DK$ with $D \to K_S hh$

GLW in $B \to DK^{0*}$

GLW in $B \to Dhhh$

Time dependent CPV in $B_S \to D_S K$

What has this enabled us to produce?

GLW/ADS in $B \to DK, D\pi$ with $D \to hh$

ADS in $B \to DK, D\pi$ with $D \to hhhh$

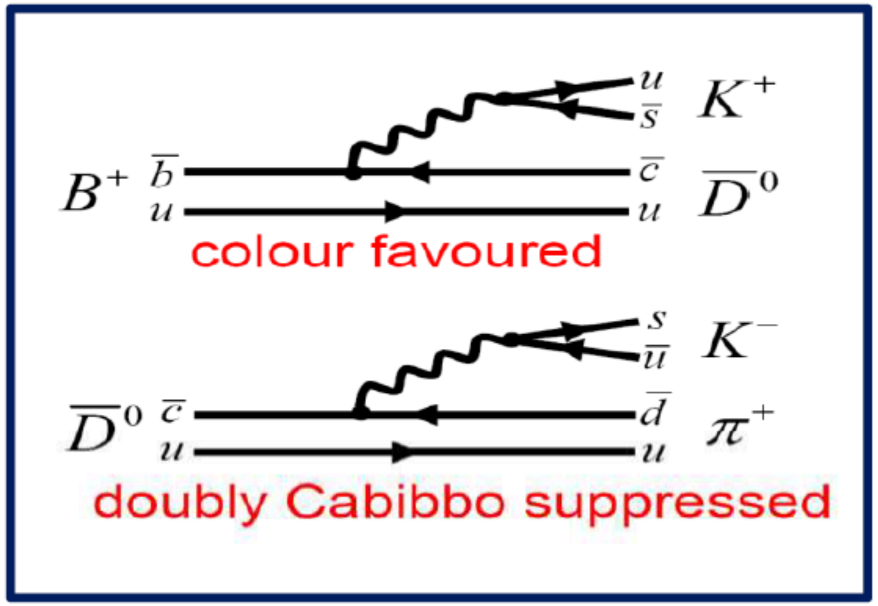
GGSZ in $B \to DK$ with $D \to K_S hh$

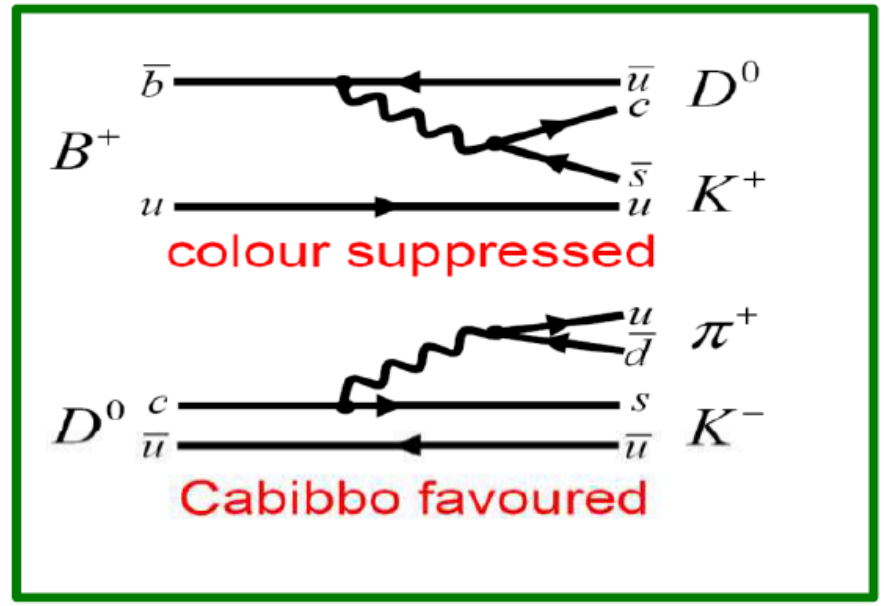
GLW in $B \to DK^{0*}$

GLW in $B \to Dhhh$

Time dependent CPV in $B_S \to D_S K$

Observables ⇔ physics parameters





GLW : D^0 decays to singly Cabbibo-suppressed final states (KK,$\pi\pi$), higher absolute yields but lower interference due to colour suppression

ADS : Combine colour-suppressed B decays with Cabbibo-favoured D decays in order to increase interference and hence sensitivity to γ

In both cases measure branching fractions and charge asymmetries

Same principle applies to Dπ decays but interference smaller

Observables ⇔ physics parameters

$$
\begin{aligned}
R^{K\pi}_{K/\pi} &= R\,\frac{1+(r_B r_D)^2+2r_B r_D\cos(\delta_B-\delta_D)\cos\gamma}{1+(r^\pi_B r_D)^2+2r^\pi_B r_D\cos(\delta^\pi_B-\delta_D)\cos\gamma} \\
R^{KK}_{K/\pi} = R^{\pi\pi}_{K/\pi} &= R\,\frac{1+{r_B}^2+2r_B\cos\delta_B\cos\gamma}{1+{r^\pi_B}^2+2r^\pi_B\cos\delta^\pi_B\cos\gamma} \\
A^{Fav} &= \frac{2r_B r_D\sin(\delta_B-\delta_D)\sin\gamma}{1+(r_B r_D)^2+r_B r_D\cos(\delta_B-\delta_D)\cos\gamma} \\
A^{Fav}_\pi &= \frac{2r^\pi_B r_D\sin(\delta^\pi_B-\delta_D)\sin\gamma}{1+(r^\pi_B r_D)^2+r^\pi_B r_D\cos(\delta^\pi_B-\delta_D)\cos\gamma} \\
A^{KK} = A^{\pi\pi} &= \frac{2r_B\sin\delta_B\sin\gamma}{1+{r_B}^2+r_B\cos\delta_B\cos\gamma} \\
A^{KK}_\pi = A^{\pi\pi}_\pi &= \frac{2r^\pi_B\sin\delta^\pi_B\sin\gamma}{1+{r^\pi_B}^2+r^\pi_B\cos\delta^\pi_B\cos\gamma} \\
R^{ADS} &= \frac{{r_B}^2+{r_D}^2+2r_B r_D\cos(\delta_B+\delta_D)\cos\gamma}{1+(r_B r_D)^2+2r_B r_D\cos(\delta_B-\delta_D)\cos\gamma} \\
A^{ADS} &= \frac{2r_B r_D\sin(\delta_B+\delta_D)\sin\gamma}{{r_B}^2+{r_D}^2+2r_B r_D\cos(\delta_B+\delta_D)\cos\gamma} \\
R^{ADS}_\pi &= \frac{{r^\pi_B}^2+{r_D}^2+2r^\pi_B r_D\cos(\delta^\pi_B+\delta_D)\cos\gamma}{1+(r^\pi_B r_D)^2+2r^\pi_B r_D\cos(\delta^\pi_B-\delta_D)\cos\gamma} \\
A^{ADS}_\pi &= \frac{2r^\pi_B r_D\sin(\delta^\pi_B+\delta_D)\sin\gamma}{{r^\pi_B}^2+{r_D}^2+2r^\pi_B r_D\cos(\delta^\pi_B+\delta_D)\cos\gamma}
\end{aligned}
$$

Observables ⇔ physics parameters

r_B,δ_B are the amplitude ratio and relative strong phase of the interfering B decays

$$
\begin{aligned}
R^{K\pi}_{K/\pi} &= R\,\frac{1+(r_B r_D)^2+2r_B r_D\cos(\delta_B-\delta_D)\cos\gamma}{1+(r^\pi_B r_D)^2+2r^\pi_B r_D\cos(\delta^\pi_B-\delta_D)\cos\gamma}\\
R^{KK}_{K/\pi} = R^{\pi\pi}_{K/\pi} &= R\,\frac{1+{r_B}^2+2r_B\cos\delta_B\cos\gamma}{1+{r^\pi_B}^2+2r^\pi_B\cos\delta^\pi_B\cos\gamma}\\
A^{Fav} &= \frac{2r_B r_D\sin(\delta_B-\delta_D)\sin\gamma}{1+(r_B r_D)^2+r_B r_D\cos(\delta_B-\delta_D)\cos\gamma}\\
A^{Fav}_\pi &= \frac{2r^\pi_B r_D\sin(\delta^\pi_B-\delta_D)\sin\gamma}{1+(r^\pi_B r_D)^2+r^\pi_B r_D\cos(\delta^\pi_B-\delta_D)\cos\gamma}\\
A^{KK} = A^{\pi\pi} &= \frac{2r_B\sin\delta_B\sin\gamma}{1+{r_B}^2+r_B\cos\delta_B\cos\gamma}\\
A^{KK}_\pi = A^{\pi\pi}_\pi &= \frac{2r^\pi_B\sin\delta^\pi_B\sin\gamma}{1+{r^\pi_B}^2+r^\pi_B\cos\delta^\pi_B\cos\gamma}\\
R^{ADS} &= \frac{{r_B}^2+{r_D}^2+2r_B r_D\cos(\delta_B+\delta_D)\cos\gamma}{1+(r_B r_D)^2+2r_B r_D\cos(\delta_B-\delta_D)\cos\gamma}\\
A^{ADS} &= \frac{2r_B r_D\sin(\delta_B+\delta_D)\sin\gamma}{{r_B}^2+{r_D}^2+2r_B r_D\cos(\delta_B+\delta_D)\cos\gamma}\\
R^{ADS}_\pi &= \frac{{r^\pi_B}^2+{r_D}^2+2r^\pi_B r_D\cos(\delta^\pi_B+\delta_D)\cos\gamma}{1+(r^\pi_B r_D)^2+2r^\pi_B r_D\cos(\delta^\pi_B-\delta_D)\cos\gamma}\\
A^{ADS}_\pi &= \frac{2r^\pi_B r_D\sin(\delta^\pi_B+\delta_D)\sin\gamma}{{r^\pi_B}^2+{r_D}^2+2r^\pi_B r_D\cos(\delta^\pi_B+\delta_D)\cos\gamma}
\end{aligned}
$$

Observables ⇔ physics parameters

r_B, δ_B are the amplitude ratio and relative strong phase of the interfering B decays

r_D, δ_D are hadronic parameters describing the $D^0 \to K\pi(\pi K)$ decays

- **r_D is the amplitude ratio of the CF to DCS D^0 decays**

- **δ_D is the relative strong phase between the CF and DCS decays**

Both are taken from CLEO measurements

$$
\begin{aligned}
R^{K\pi}_{K/\pi} &= R\,\frac{1+(r_B r_D)^2+2r_B r_D\cos(\delta_B-\delta_D)\cos\gamma}{1+(r_B^\pi r_D)^2+2r_B^\pi r_D\cos(\delta_B^\pi-\delta_D)\cos\gamma} \\
R^{KK}_{K/\pi} = R^{\pi\pi}_{K/\pi} &= R\,\frac{1+{r_B}^2+2r_B\cos\delta_B\cos\gamma}{1+{r_B^\pi}^2+2r_B^\pi\cos\delta_B^\pi\cos\gamma} \\
A^{Fav} &= \frac{2r_B r_D\sin(\delta_B-\delta_D)\sin\gamma}{1+(r_B r_D)^2+r_B r_D\cos(\delta_B-\delta_D)\cos\gamma} \\
A^{Fav}_\pi &= \frac{2r_B^\pi r_D\sin(\delta_B^\pi-\delta_D)\sin\gamma}{1+(r_B^\pi r_D)^2+r_B^\pi r_D\cos(\delta_B^\pi-\delta_D)\cos\gamma} \\
A^{KK} = A^{\pi\pi} &= \frac{2r_B\sin\delta_B\sin\gamma}{1+{r_B}^2+r_B\cos\delta_B\cos\gamma} \\
A^{KK}_\pi = A^{\pi\pi}_\pi &= \frac{2r_B^\pi\sin\delta_B^\pi\sin\gamma}{1+{r_B^\pi}^2+r_B^\pi\cos\delta_B^\pi\cos\gamma} \\
R^{ADS} &= \frac{{r_B}^2+{r_D}^2+2r_B r_D\cos(\delta_B+\delta_D)\cos\gamma}{1+(r_B r_D)^2+2r_B r_D\cos(\delta_B-\delta_D)\cos\gamma} \\
A^{ADS} &= \frac{2r_B r_D\sin(\delta_B+\delta_D)\sin\gamma}{{r_B}^2+{r_D}^2+2r_B r_D\cos(\delta_B+\delta_D)\cos\gamma} \\
R^{ADS}_\pi &= \frac{{r_B^\pi}^2+{r_D}^2+2r_B^\pi r_D\cos(\delta_B^\pi+\delta_D)\cos\gamma}{1+(r_B^\pi r_D)^2+2r_B^\pi r_D\cos(\delta_B^\pi-\delta_D)\cos\gamma} \\
A^{ADS}_\pi &= \frac{2r_B^\pi r_D\sin(\delta_B^\pi+\delta_D)\sin\gamma}{{r_B^\pi}^2+{r_D}^2+2r_B^\pi r_D\cos(\delta_B^\pi+\delta_D)\cos\gamma}
\end{aligned}
$$

Observables ⇔ physics parameters

r_B, δ_B are the amplitude ratio and relative strong phase of the interfering B decays

r_D, δ_D are hadronic parameters describing the $D^0 \to K\pi(\pi K)$ decays

- **r_D is the amplitude ratio of the CF to DCS D^0 decays**

- **δ_D is the relative strong phase between the CF and DCS decays**

Both are taken from CLEO measurements

Notice that ADS asymmetries are enhanced by the absence of a "1 +" term in the denominator compared to the GLW ones

$$R^{K\pi}_{K/\pi} = R\,\frac{1+(r_B r_D)^2 + 2 r_B r_D \cos(\delta_B - \delta_D)\cos\gamma}{1+(r_B^\pi r_D)^2 + 2 r_B^\pi r_D \cos(\delta_B^\pi - \delta_D)\cos\gamma}$$

$$R^{KK}_{K/\pi} = R^{\pi\pi}_{K/\pi} = R\,\frac{1+{r_B}^2 + 2 r_B \cos\delta_B \cos\gamma}{1+{r_B^\pi}^2 + 2 r_B^\pi \cos\delta_B^\pi \cos\gamma}$$

$$A^{Fav} = \frac{2 r_B r_D \sin(\delta_B - \delta_D)\sin\gamma}{1+(r_B r_D)^2 + r_B r_D \cos(\delta_B - \delta_D)\cos\gamma}$$

$$A^{Fav}_\pi = \frac{2 r_B^\pi r_D \sin(\delta_B^\pi - \delta_D)\sin\gamma}{1+(r_B^\pi r_D)^2 + r_B^\pi r_D \cos(\delta_B^\pi - \delta_D)\cos\gamma}$$

$$\boxed{A^{KK} = A^{\pi\pi} = \frac{2 r_B \sin\delta_B \sin\gamma}{1+{r_B}^2 + r_B \cos\delta_B \cos\gamma}}$$

$$A^{KK}_\pi = A^{\pi\pi}_\pi = \frac{2 r_B^\pi \sin\delta_B^\pi \sin\gamma}{1+{r_B^\pi}^2 + r_B^\pi \cos\delta_B^\pi \cos\gamma}$$

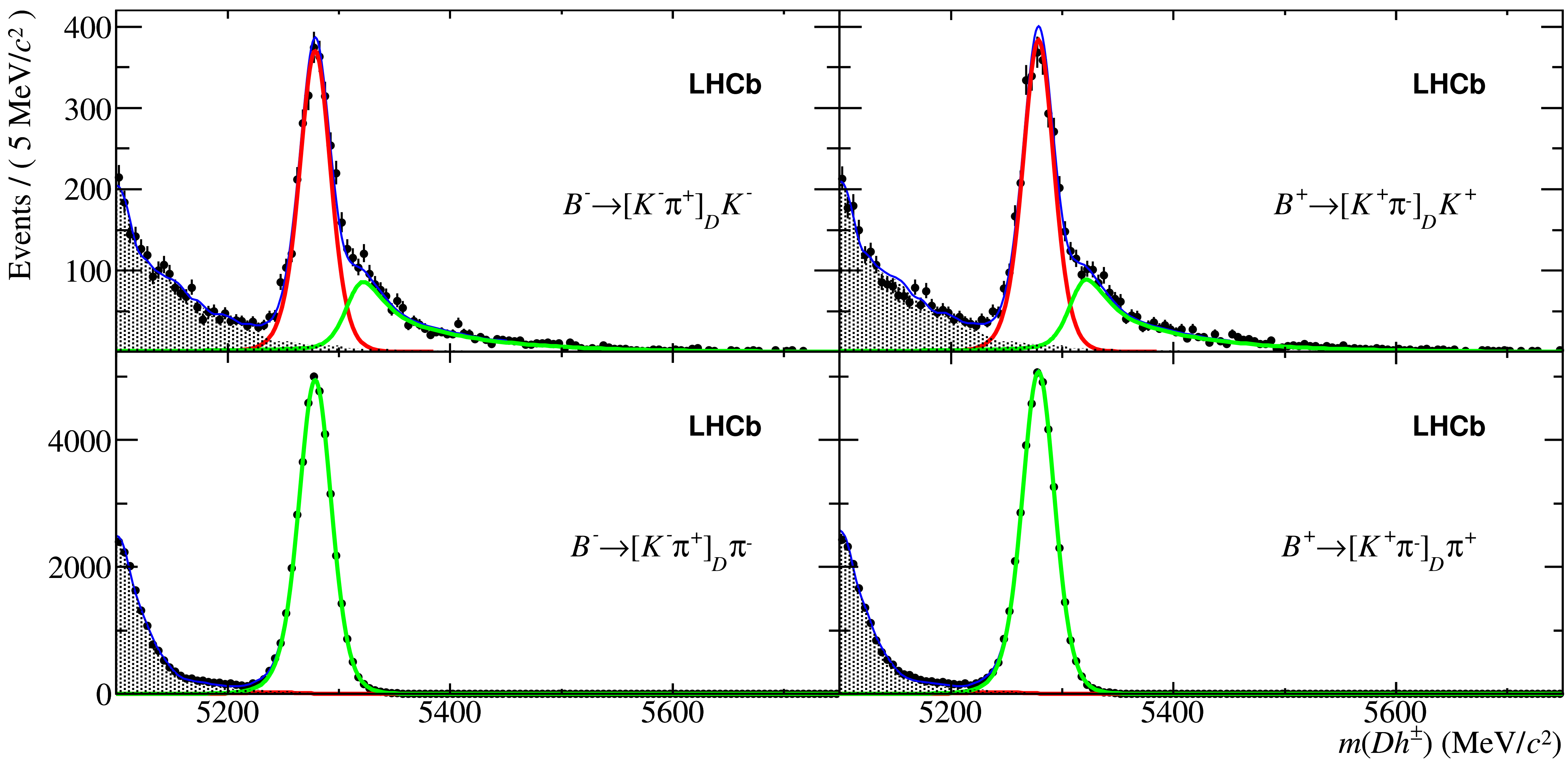
$$R^{ADS} = \frac{{r_B}^2 + {r_D}^2 + 2 r_B r_D \cos(\delta_B + \delta_D)\cos\gamma}{1+(r_B r_D)^2 + 2 r_B r_D \cos(\delta_B - \delta_D)\cos\gamma}$$

$$\boxed{A^{ADS} = \frac{2 r_B r_D \sin(\delta_B + \delta_D)\sin\gamma}{{r_B}^2 + {r_D}^2 + 2 r_B r_D \cos(\delta_B + \delta_D)\cos\gamma}}$$

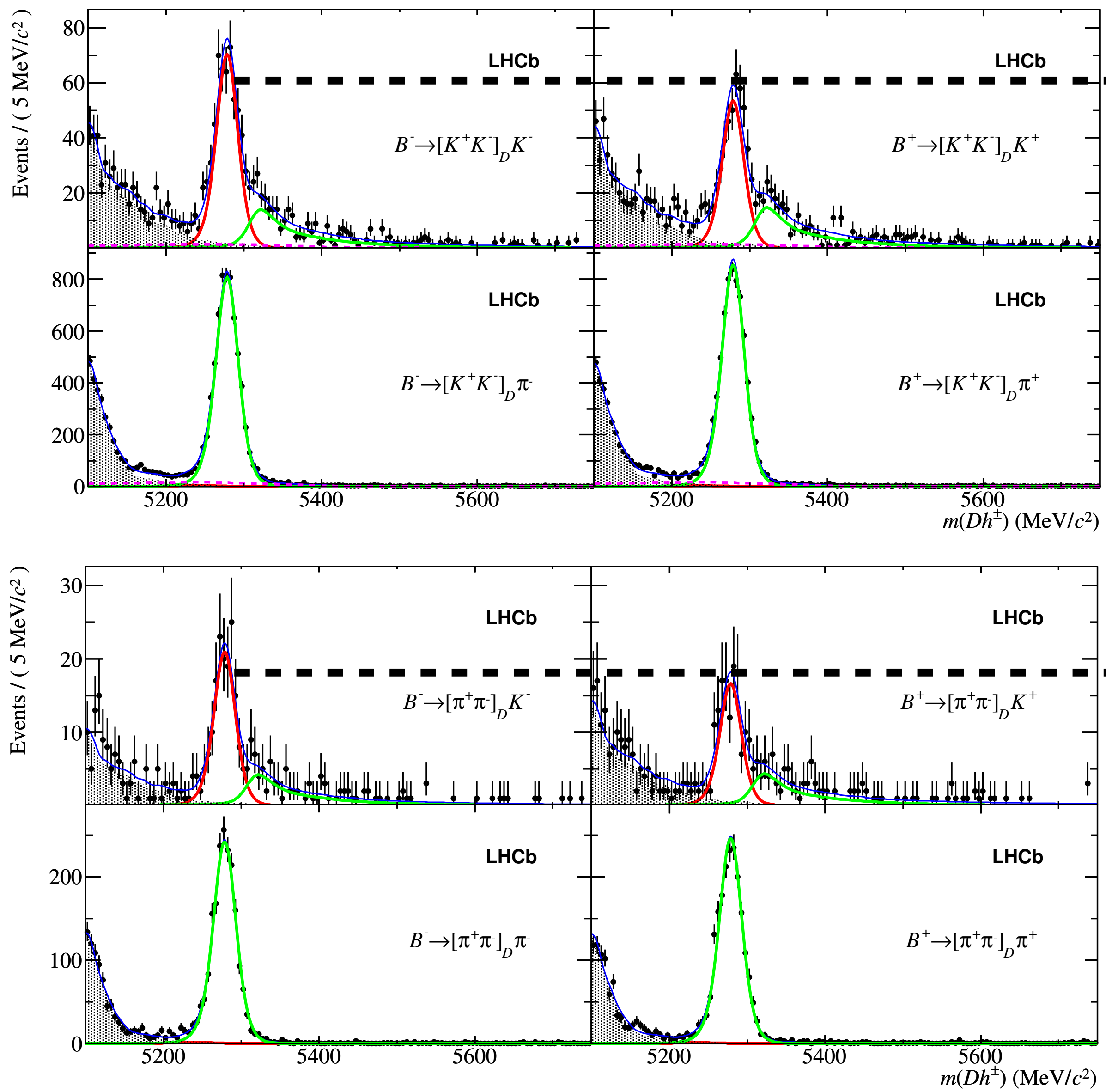
$$R^{ADS}_\pi = \frac{{r_B^\pi}^2 + {r_D}^2 + 2 r_B^\pi r_D \cos(\delta_B^\pi + \delta_D)\cos\gamma}{1+(r_B^\pi r_D)^2 + 2 r_B^\pi r_D \cos(\delta_B^\pi - \delta_D)\cos\gamma}$$

$$A^{ADS}_\pi = \frac{2 r_B^\pi r_D \sin(\delta_B^\pi + \delta_D)\sin\gamma}{{r_B^\pi}^2 + {r_D}^2 + 2 r_B^\pi r_D \cos(\delta_B^\pi + \delta_D)\cos\gamma}$$

The Cabbibo-favoured signals



The singly Cabbibo-Suppressed signals



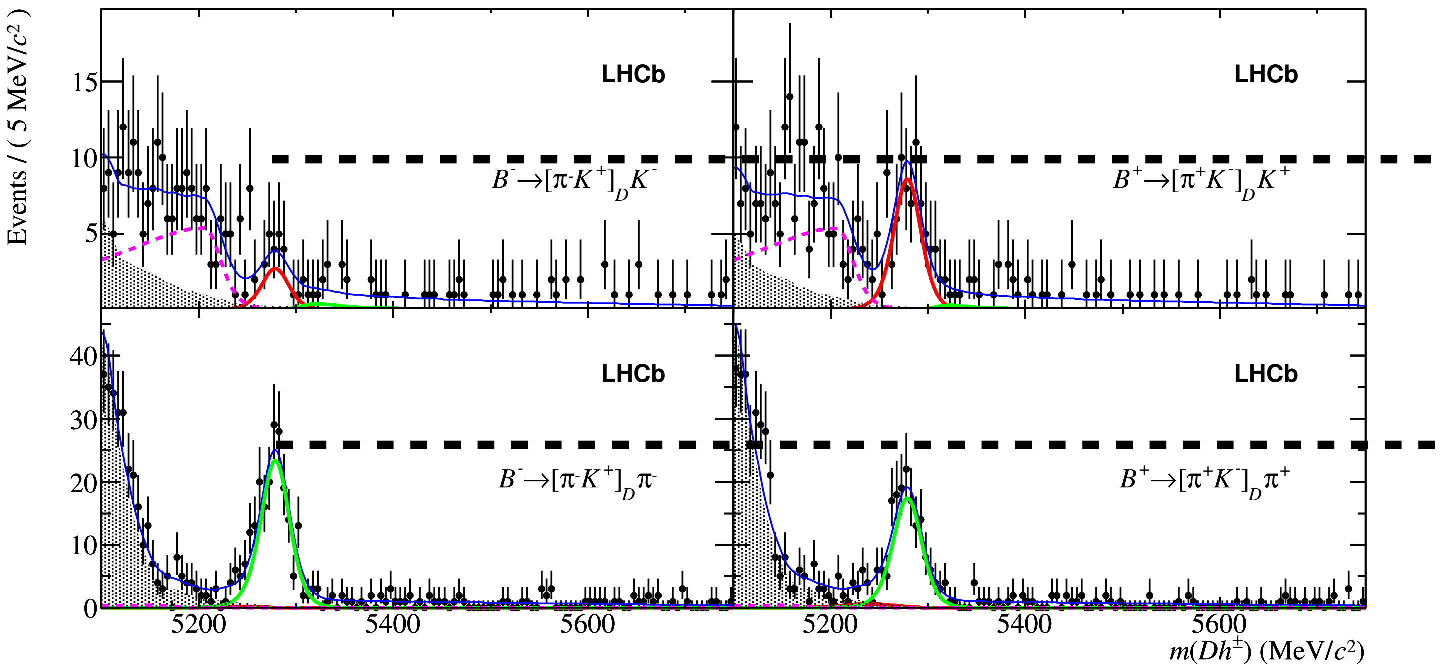
KK and $\pi\pi$ show similar-sized CP asymmetries, in the same direction

$$A_{CP+} = < A_K^{KK}, A_K^{\pi\pi} > \quad = \quad 0.145 \pm 0.032 \pm 0.010$$

Branching fraction ratios consistent with CF D^0 decay mode

$$R_{CP+} = \frac{< R_{K/\pi}^{KK}, R_{K/\pi}^{\pi\pi} >}{R_{K/\pi}^{Kpi}} \quad = \quad 1.007 \pm 0.038 \pm 0.012$$

The ADS signals



The Kaon mode shows a large CP asymmetery

$$A_{ADS(K)} = \frac{R_K^- - R_K^+}{R_K^- + R_K^+} = -0.520 \pm 0.150 \pm 0.021$$

And there is also a hint of something in the pion mode!

$$A_{ADS(\pi)} = \frac{R_\pi^- - R_\pi^+}{R_\pi^- + R_\pi^+} = 0.1426 \pm 0.0621 \pm 0.0110$$

ADS modes established at >5σ significance

Combining all two body modes, direct CPV is observed at 5.8σ significance

LHCb-PAPER-2012-001

What has this enabled us to produce?

GLW/ADS in B→DK,Dπ with D→hh

ADS in B→DK,Dπ with D→hhhh

GGSZ in B→DK with D→$K_S$hh

GLW in B→DK^{0*}

GLW in B→Dhhh

Time dependent CPV in B_S→D_SK

Observables ⇔ physics parameters

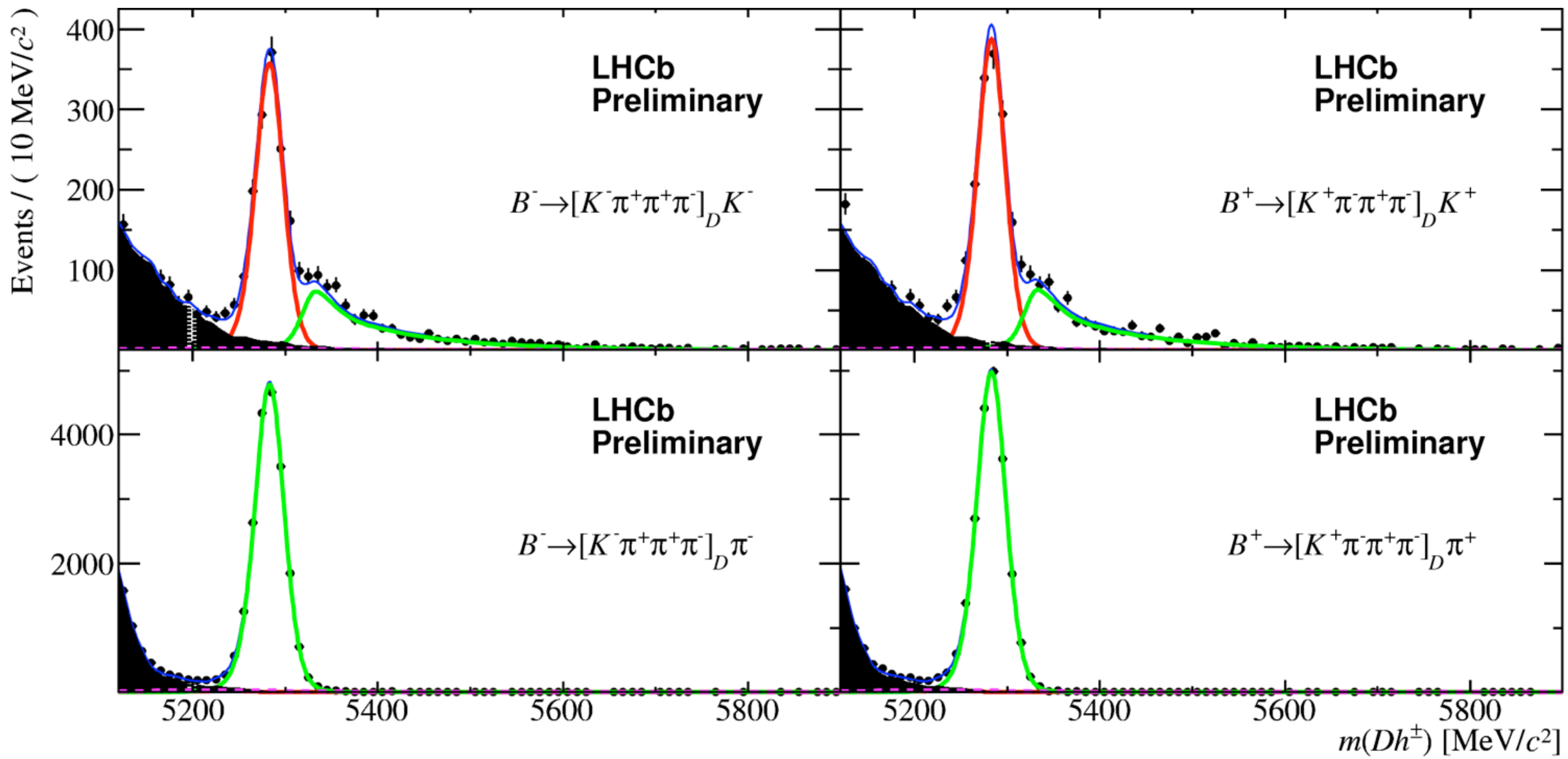
$$\Gamma(B^{\pm} \to D(K^{\pm}\pi^{\mp}\pi^{+}\pi^{-})K^{\pm}) \propto 1 + (r_B r_D^{K3\pi})^2 + 2\boxed{R_{K3\pi}}\, r_B r_D^{K3\pi} \cos(\delta_B - \delta_D^{K3\pi} \pm \gamma),$$

$$\Gamma(B^{\pm} \to D(K^{\mp}\pi^{\pm}\pi^{+}\pi^{-})K^{\pm}) \propto r_B^2 + (r_D^{K3\pi})^2 + 2\boxed{R_{K3\pi}}\, r_B r_D^{K3\pi} \cos(\delta_B + \delta_D^{K3\pi} \pm \gamma),$$

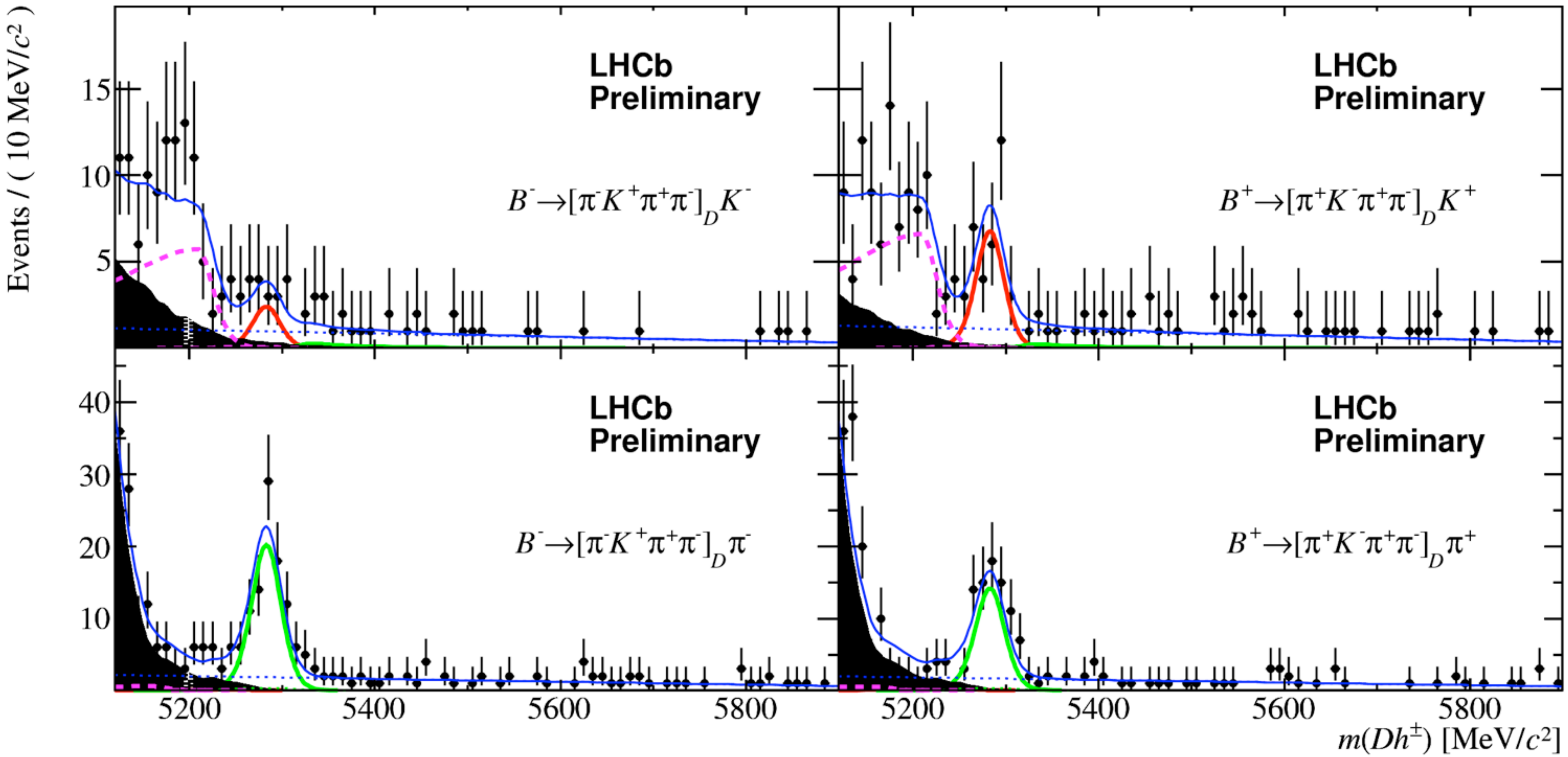
Same formalism as for the two-body case, except for the coherence factor $R_{K3\pi}$. This is necessary because the D^0 decay is a sum of amplitudes varying across the Dalitz plot; when we perform an analysis integrating over these amplitudes, we lose sensitivity from the way in which they interfere.

$R_{K3\pi}$ has been measured at CLEO and is small (~0.33) which indicates that these modes have a smaller sensitivity to γ when treated in this integrated manner than the two-body modes. However, they can still provide a good constraint on r_B.

The Cabbibo-favoured signals



The ADS signals



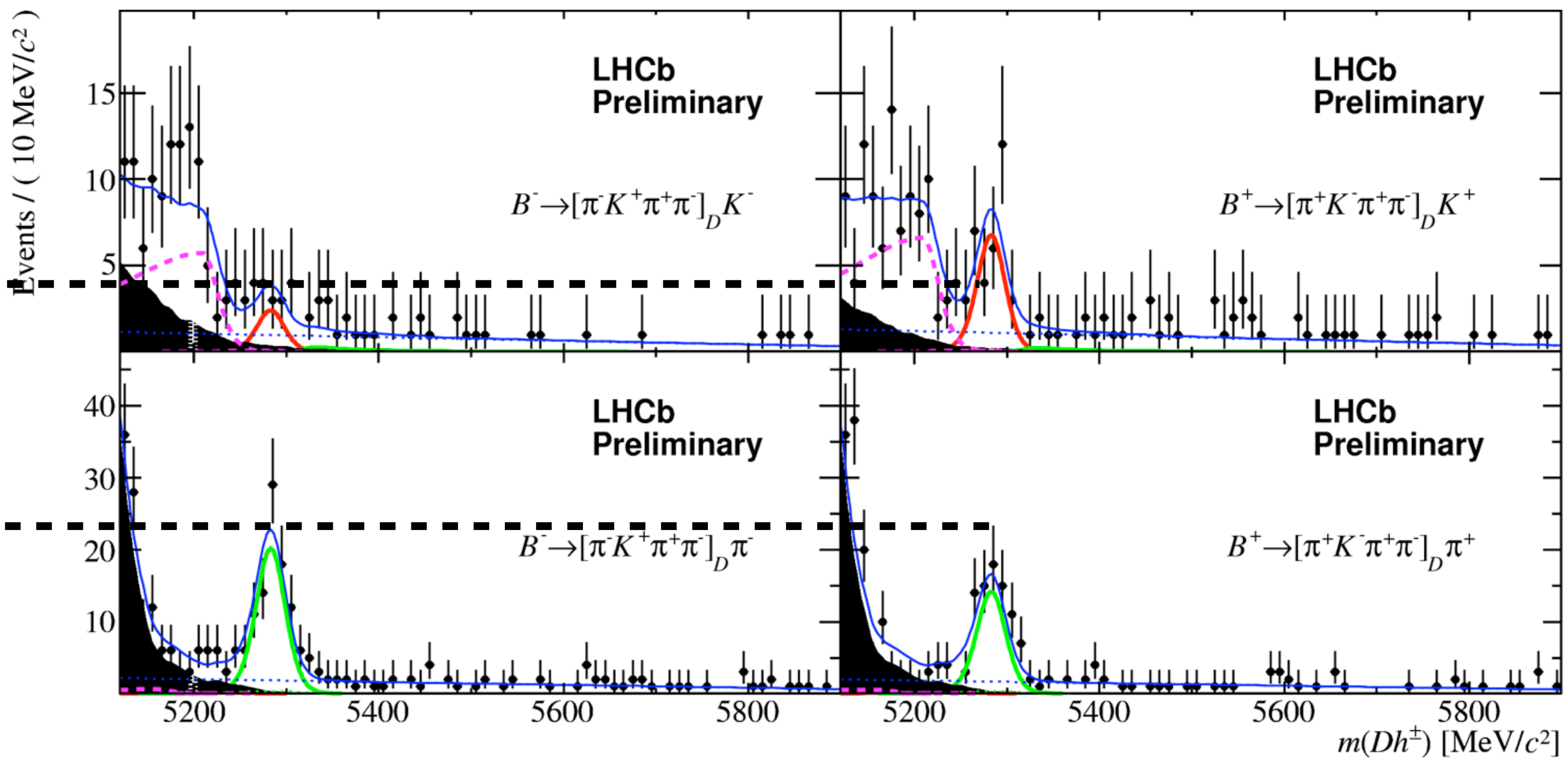
The ADS signals

Once again, indications of CP asymmetries in both the Kaon and the Pion modes

And again, going in the same direction as for the two-body modes. Keep this in mind... we'll come back to it when we extract γ.

$$A^{K3\pi}_{\mathrm{ADS}(K)} = (R^{K3\pi,-}_K - R^{K3\pi,+}_K)/(R^{K3\pi,-}_K + R^{K3\pi,+}_K) = -0.42 \pm 0.22$$

$$A^{K3\pi}_{\mathrm{ADS}(\pi)} = (R^{K3\pi,-}_\pi - R^{K3\pi,+}_\pi)/(R^{K3\pi,-}_\pi + R^{K3\pi,+}_\pi) = +0.13 \pm 0.10,$$



ADS modes established at >5σ significance!

LHCb-CONF-2012-030

What has this enabled us to produce?

GLW/ADS in $B \to DK, D\pi$ with $D \to hh$

ADS in $B \to DK, D\pi$ with $D \to hhhh$

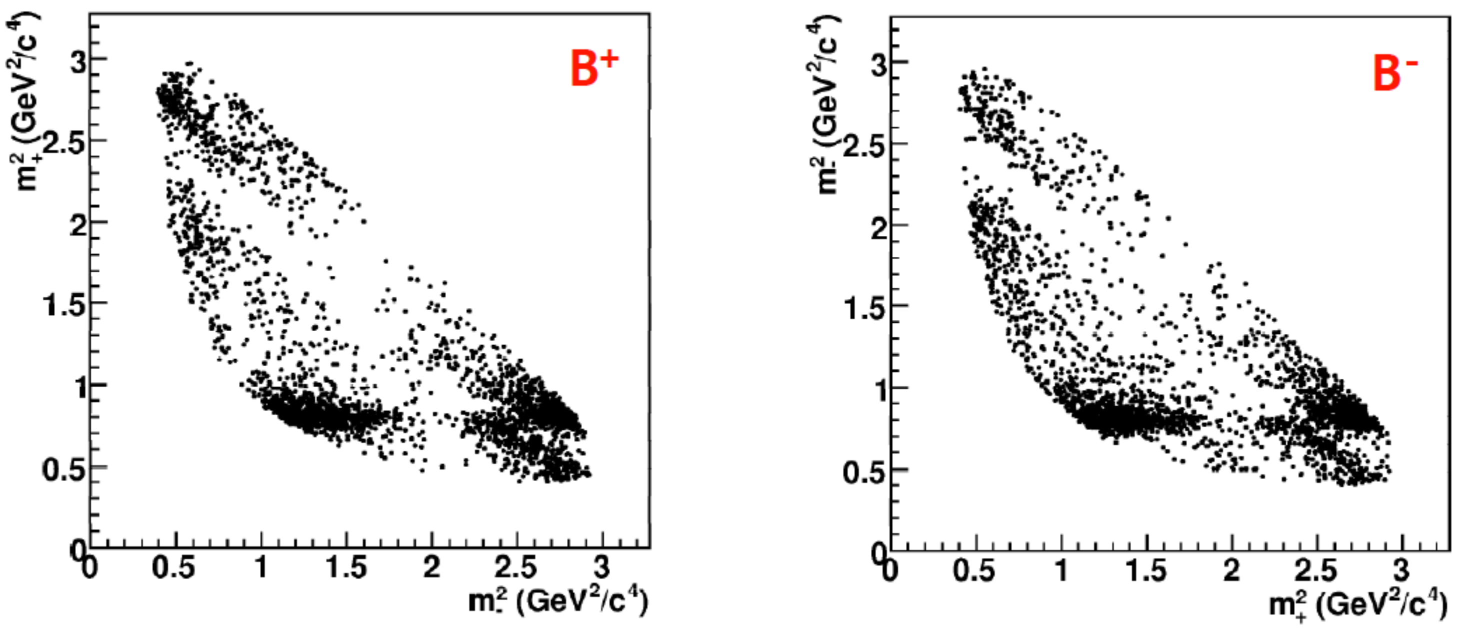
GGSZ in $B \to DK$ with $D \to K_S hh$

GLW in $B \to DK^{0*}$

GLW in $B \to Dhhh$

Time dependent CPV in $B_S \to D_S K$

Observables ⇔ physics parameters

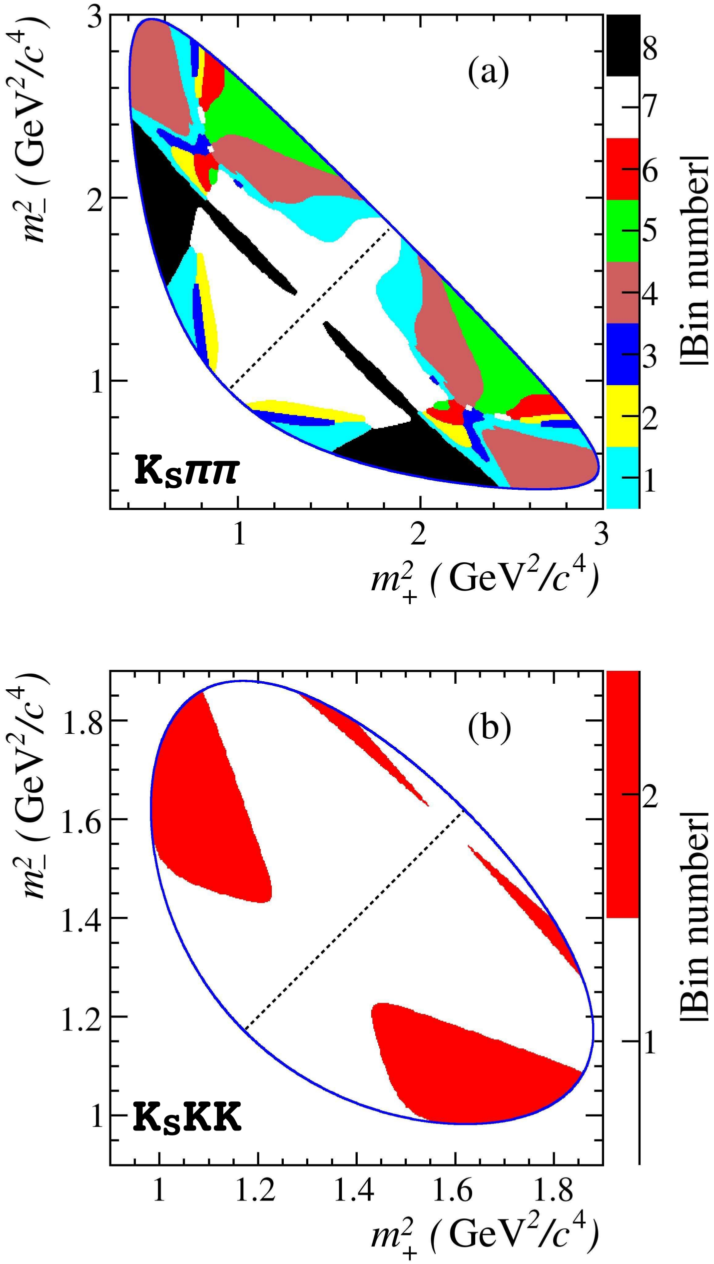


Here the decay chain is $B \to D^0 K$, with $D^0 \to K_S \pi\pi / K_S KK$

The D^0 decays proceed through many interfering amplitudes, some of which are Cabbibo-favoured, some singly Cabbibo-suppressed, and some doubly Cabbibo-suppressed

Effectively this means you are doing a simultaneous ADS/GLW analysis, as long as you understand how the amplitudes and their phases vary across the Dalitz plot.

Observables ⇔ physics parameters



Historically two approaches :

"Model-dependent" : Use a model to describe the interfering amplitudes, fitting for the amplitudes and strong phases of each component.

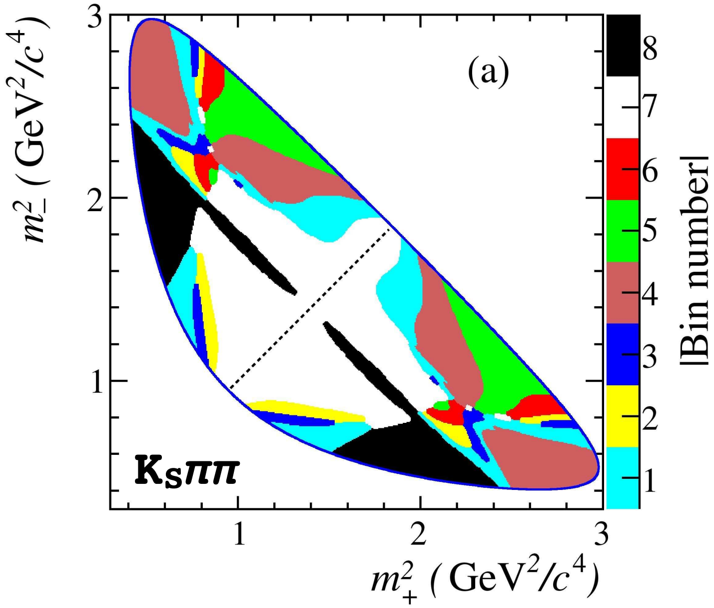
"Model-independent" : Bin the Dalitz plot and plug in the strong phase in each bin from a CLEO measurement.

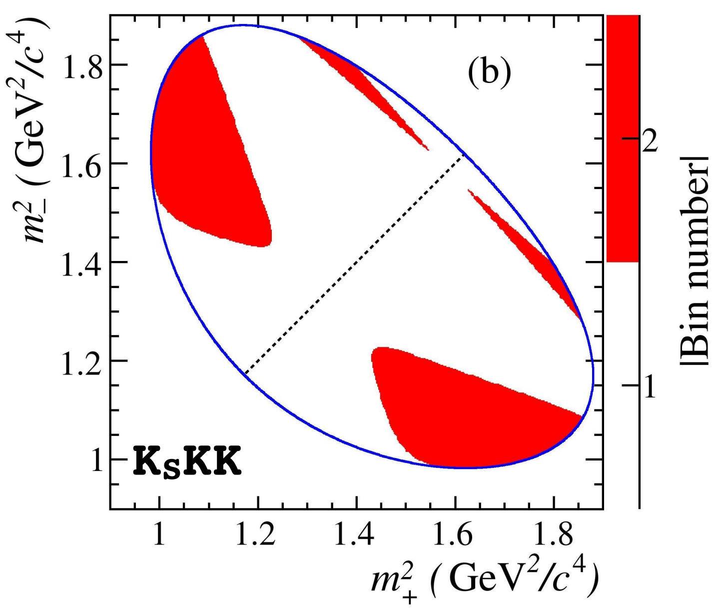
LHCb has published the model independent analysis now, though we are also pursuing the model dependent.

The model independent is effectively a binned counting experiment, so intrinsically faster to perform.

The model dependent approach has better statistical precision (as binning loses information) but harder to evaluate systematic effects.

Observables ⇔ physics parameters





Model independent : fit for yield of B^+ and B^- in each bin of the Dalitz plot

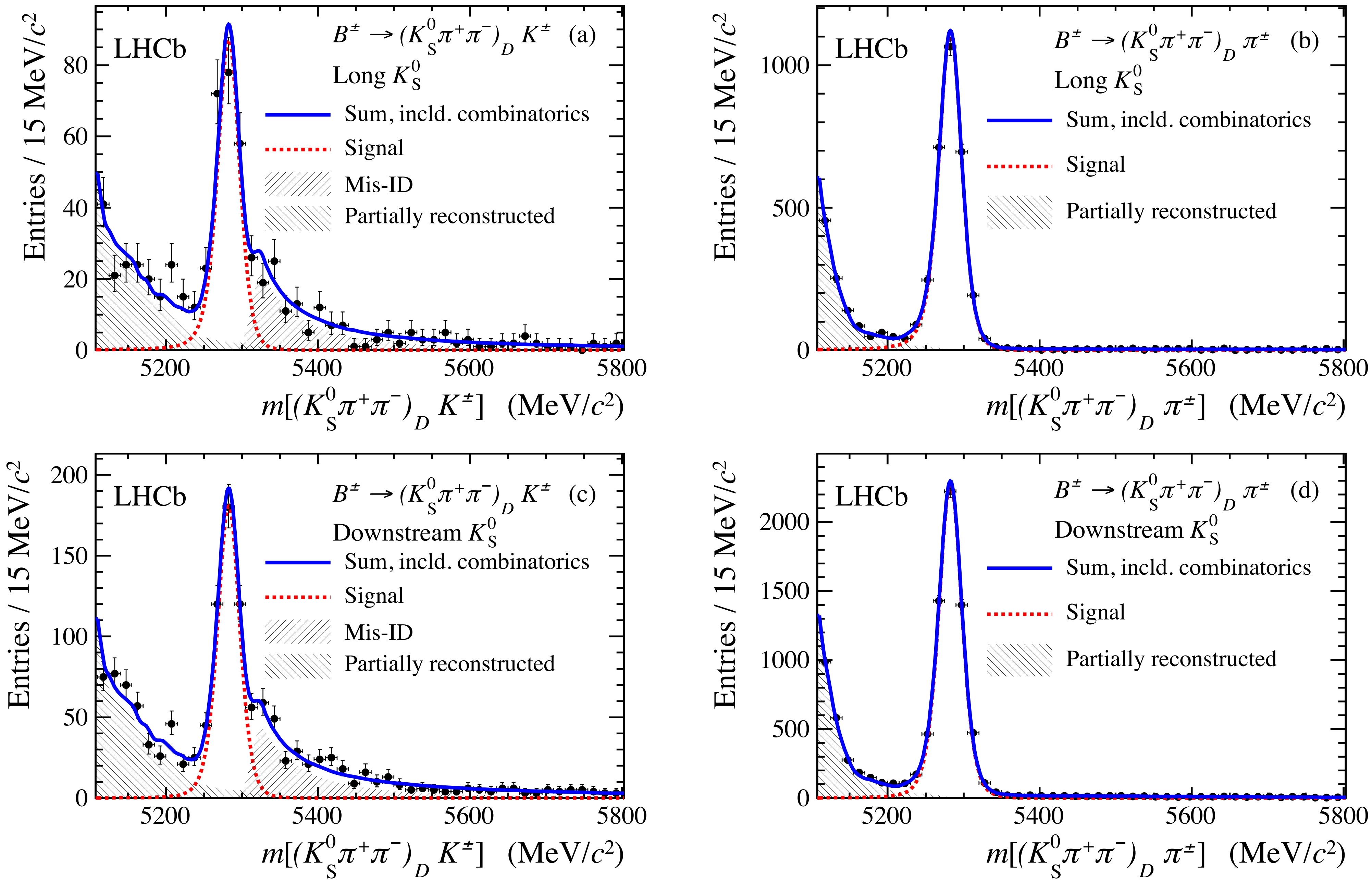
$$N_{+i}^{+} = n_{B^+}[K_{-i} + (x_+^2 + y_+^2)K_{+i} + 2\sqrt{K_{+i}K_{-i}}(x_+c_{+i} - y_+s_{+i})]$$

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

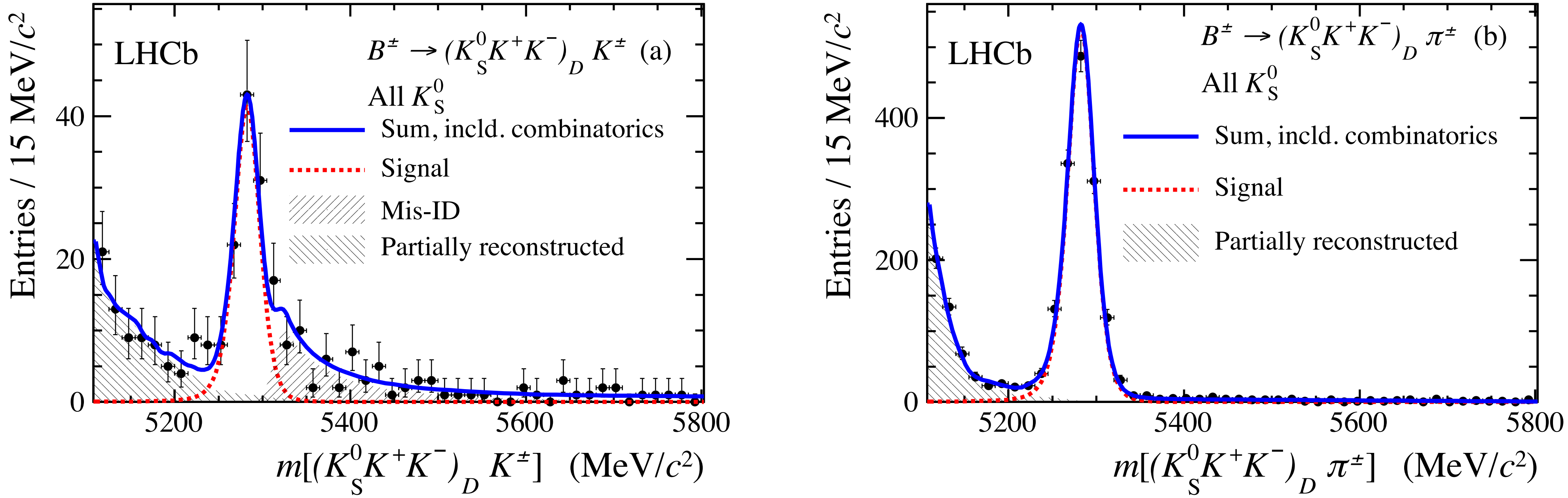
c_i, s_i are the CLEO inputs

K_i are the yields of tagged D^0 decays in each bin

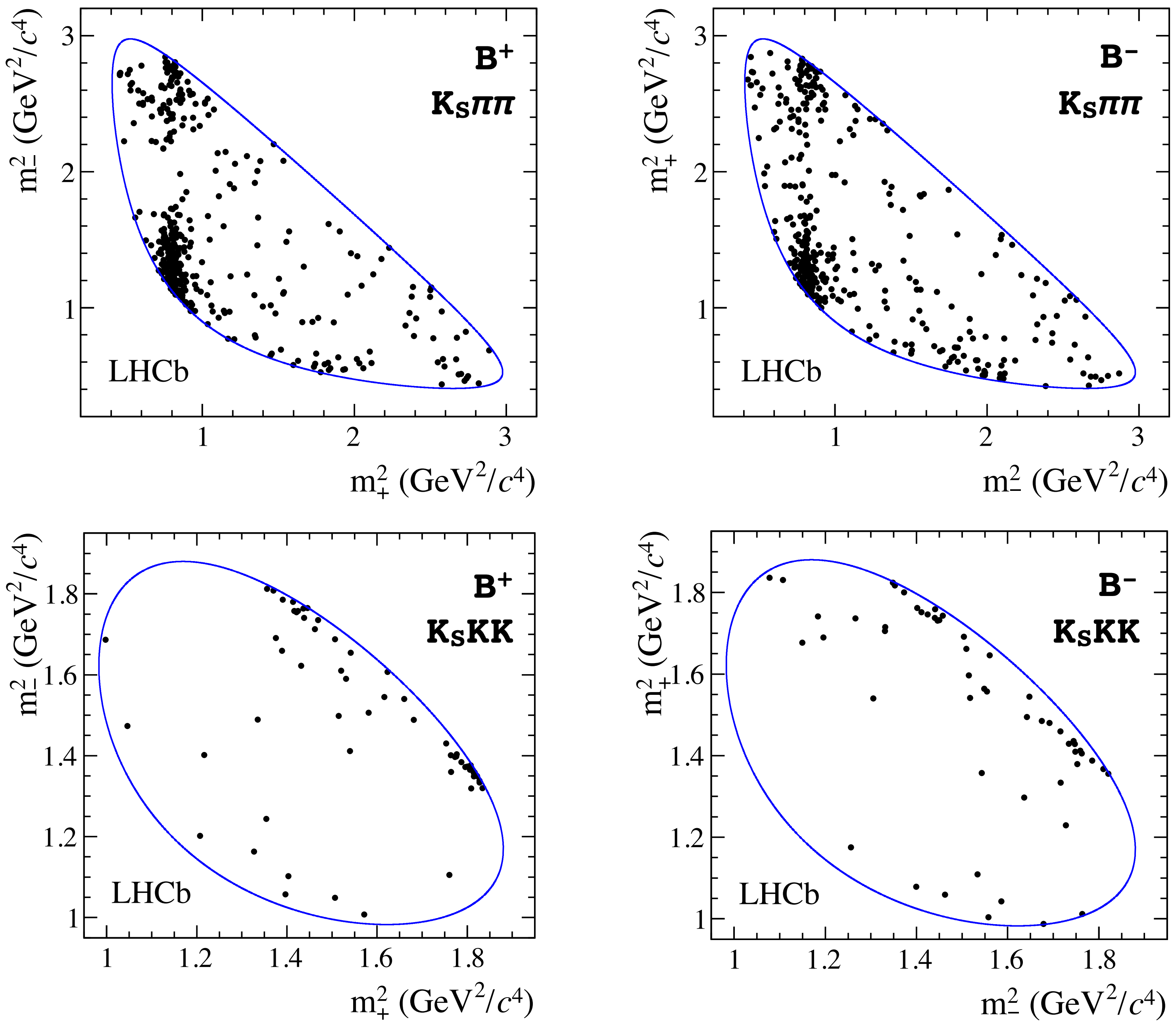
$K_S\pi\pi$ yields



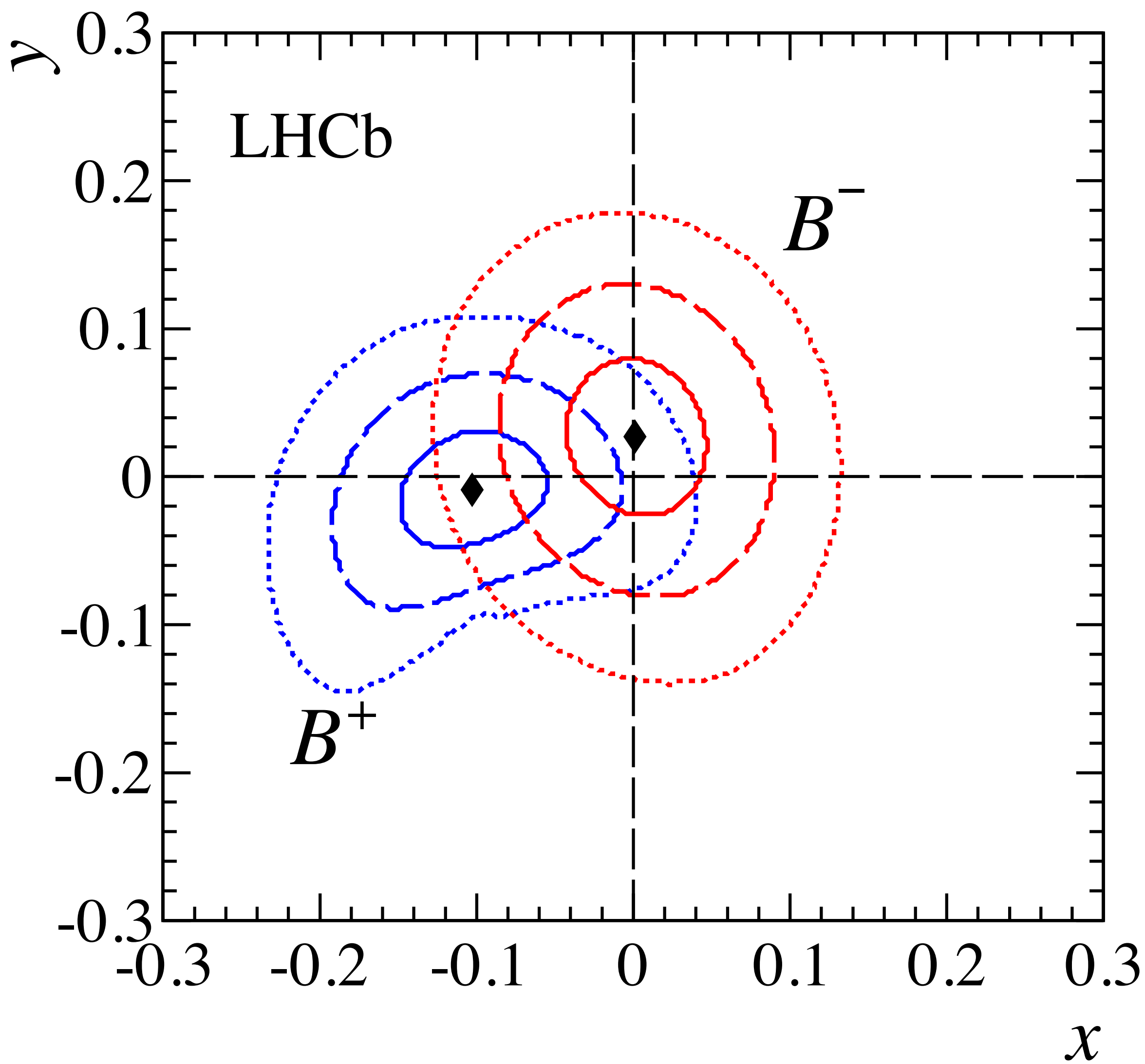
K_SKK yields


LHCb
$B^{\pm} \to (K^0_S K^+ K^-)_D K^{\pm}$ (a)
All K^0_S
Sum, incld. combinatorics
Signal
Mis-ID
Partially reconstructed
Entries / 15 MeV/c^2
$m[(K^0_S K^+ K^-)_D K^{\pm}]$ (MeV/c^2)
LHCb
$B^{\pm} \to (K^0_S K^+ K^-)_D \pi^{\pm}$ (b)
All K^0_S
Sum, incld. combinatorics
Signal
Partially reconstructed
Entries / 15 MeV/c^2
$m[(K^0_S K^+ K^-)_D \pi^{\pm}]$ (MeV/c^2)

Dalitz distributions for signal



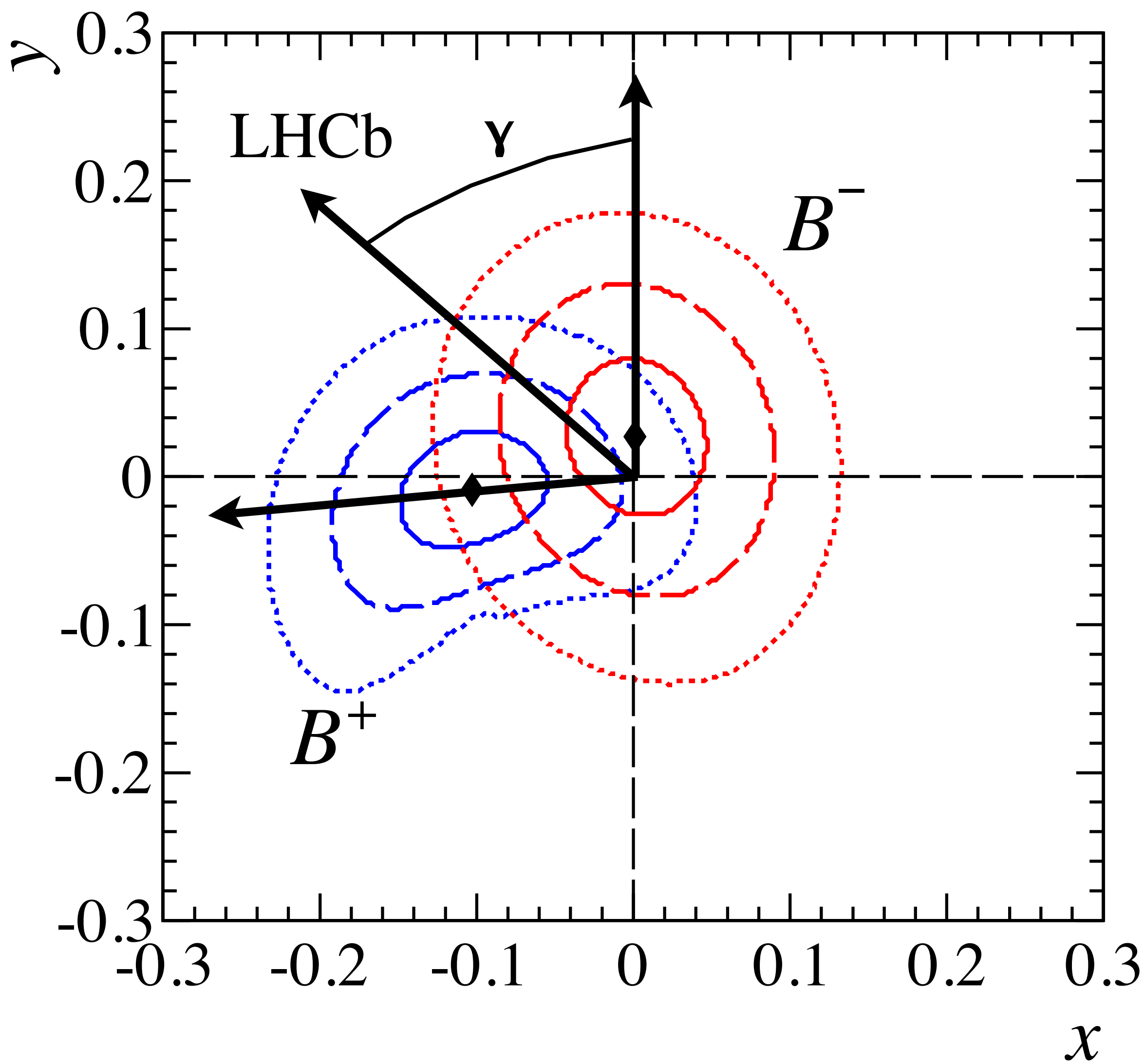
$x^{\pm}, y^{\pm}$



Largest systematic arises from the assumption of no CPV in the control mode $D\pi$

LHCb-PAPER-2012-027

$x^{\pm}, y^{\pm}$



Largest systematic arises from the assumption of no CPV in the control mode Dπ

LHCb-PAPER-2012-027

What has this enabled us to produce?

GLW/ADS in $B \to DK, D\pi$ with $D \to hh$

ADS in $B \to DK, D\pi$ with $D \to hhhh$

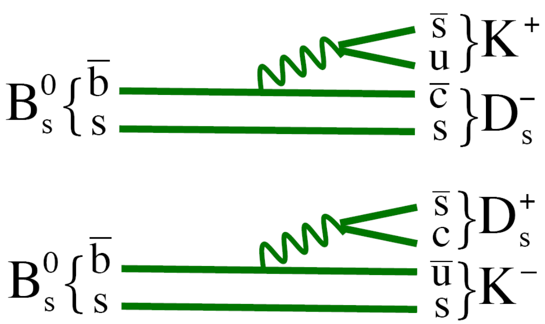
GGSZ in $B \to DK$ with $D \to K_S hh$

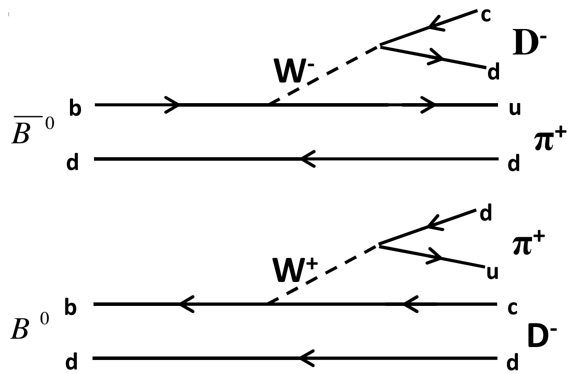
GLW in $B \to DK^{0*}$

GLW in $B \to Dhhh$

Time dependent CPV in $B_S \to D_S K$

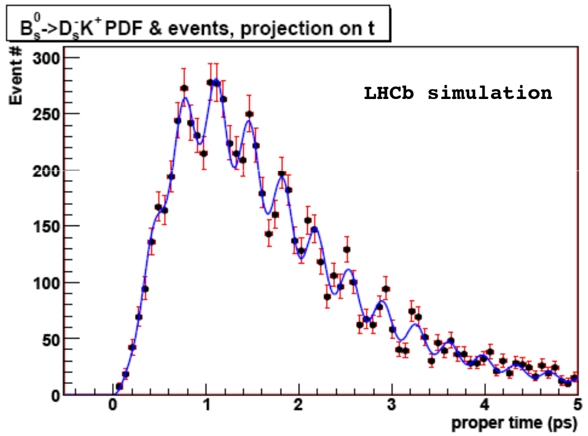
Observables ⇔ physics parameters

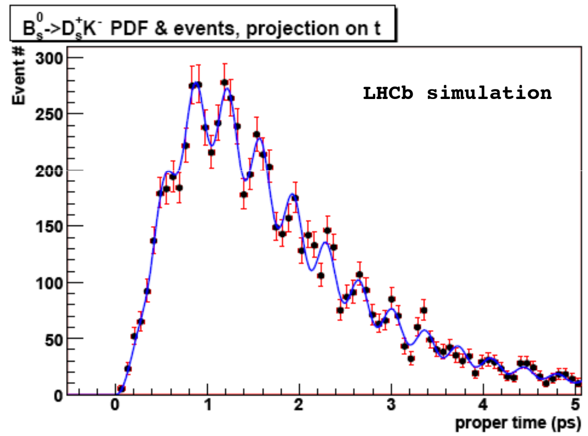


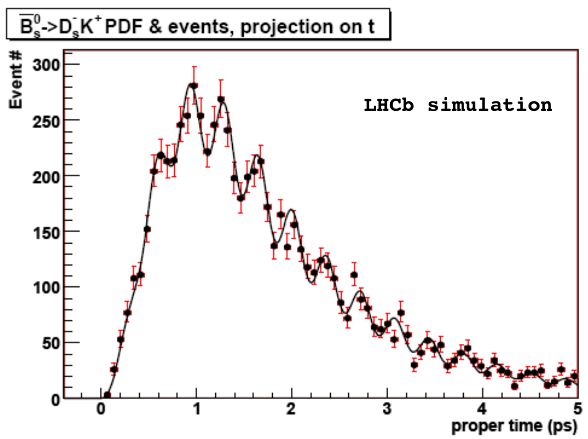


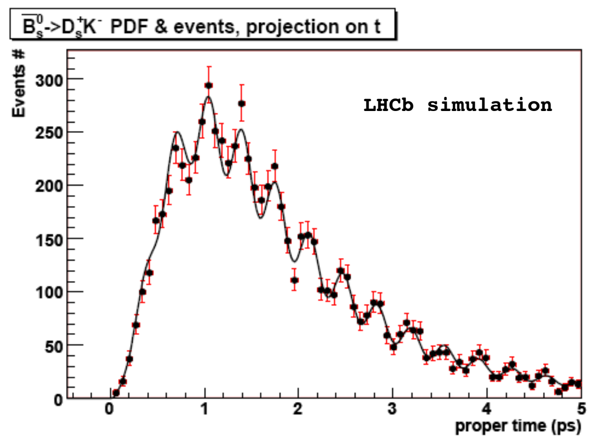
Sensitivity to γ comes from the time-dependent interference of the V_{ub} and V_{cb} decay rates.

Can perform both flavour tagged and flavour untagged measurements.









The sizes of the interfering diagrams are expected to be similar, leading to large interference and good per-event sensitivity to γ.

Observables ⇔ physics parameters

$$A\left(B_q^0 \to D_q \overline{u}_q\right) = \frac{C\cos(\Delta m\tau) + S\sin(\Delta m\tau)}{\cosh\left(\Delta\Gamma_q t/2\right) - A_{\Delta\Gamma}\sinh\left(\Delta\Gamma_q t/2\right)}$$

$$C = -\frac{1-\boxed{x_q^2}}{1+x_q^2}$$

Ratio of CKM-suppressed to CKM-favoured amplitudes, **~0.4 in $B_s \to D_s K$**

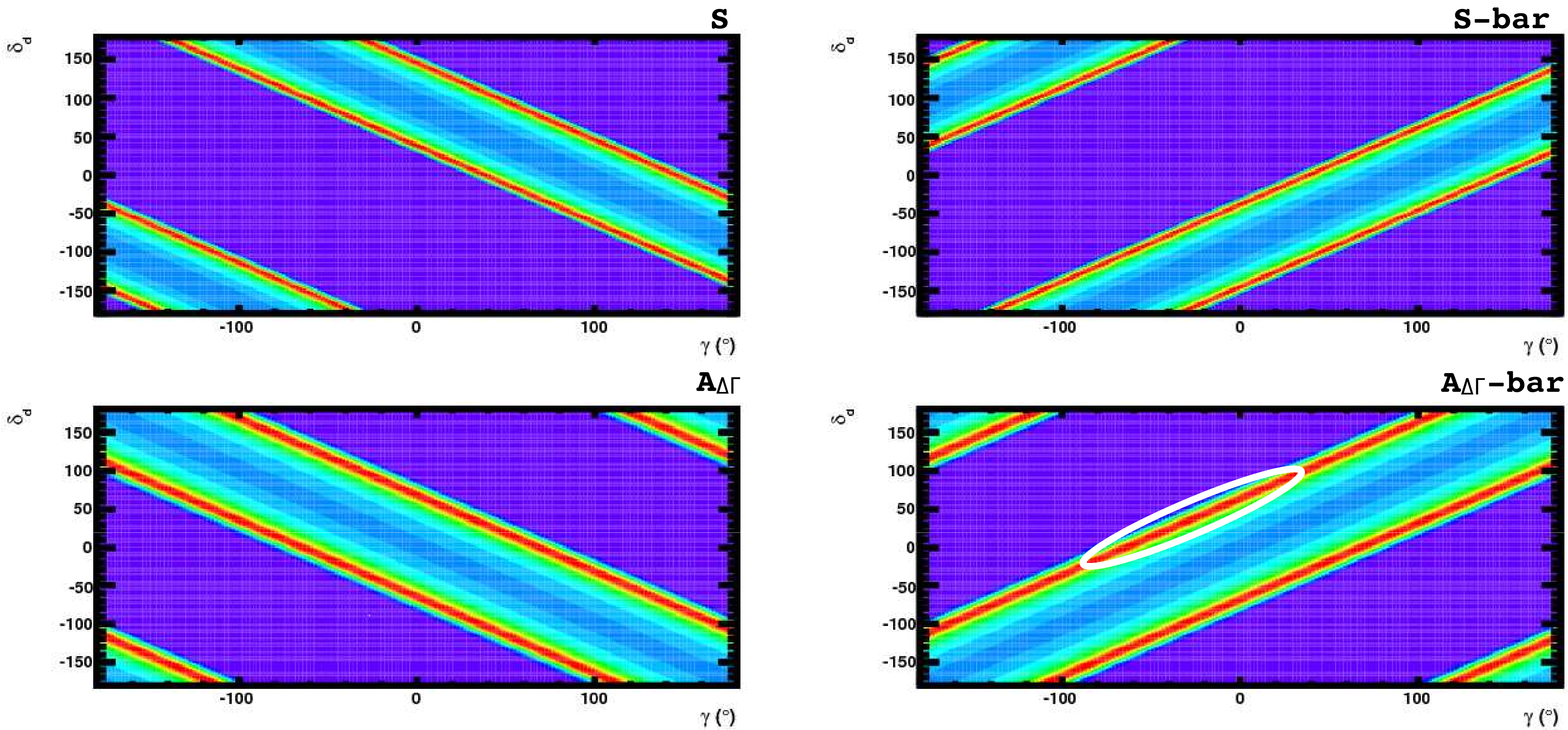
$$S = \frac{2x_q \sin\left(\gamma + \delta_q + \phi_q\right)}{\left(x_q^2 + 1\right)}$$

$$A_{\Delta\Gamma} = \frac{2x_q \cos\left(\gamma + \boxed{\delta_q} + \boxed{\varphi_q}\right)}{\left(x_q^2 + 1\right)}$$

Strong phase

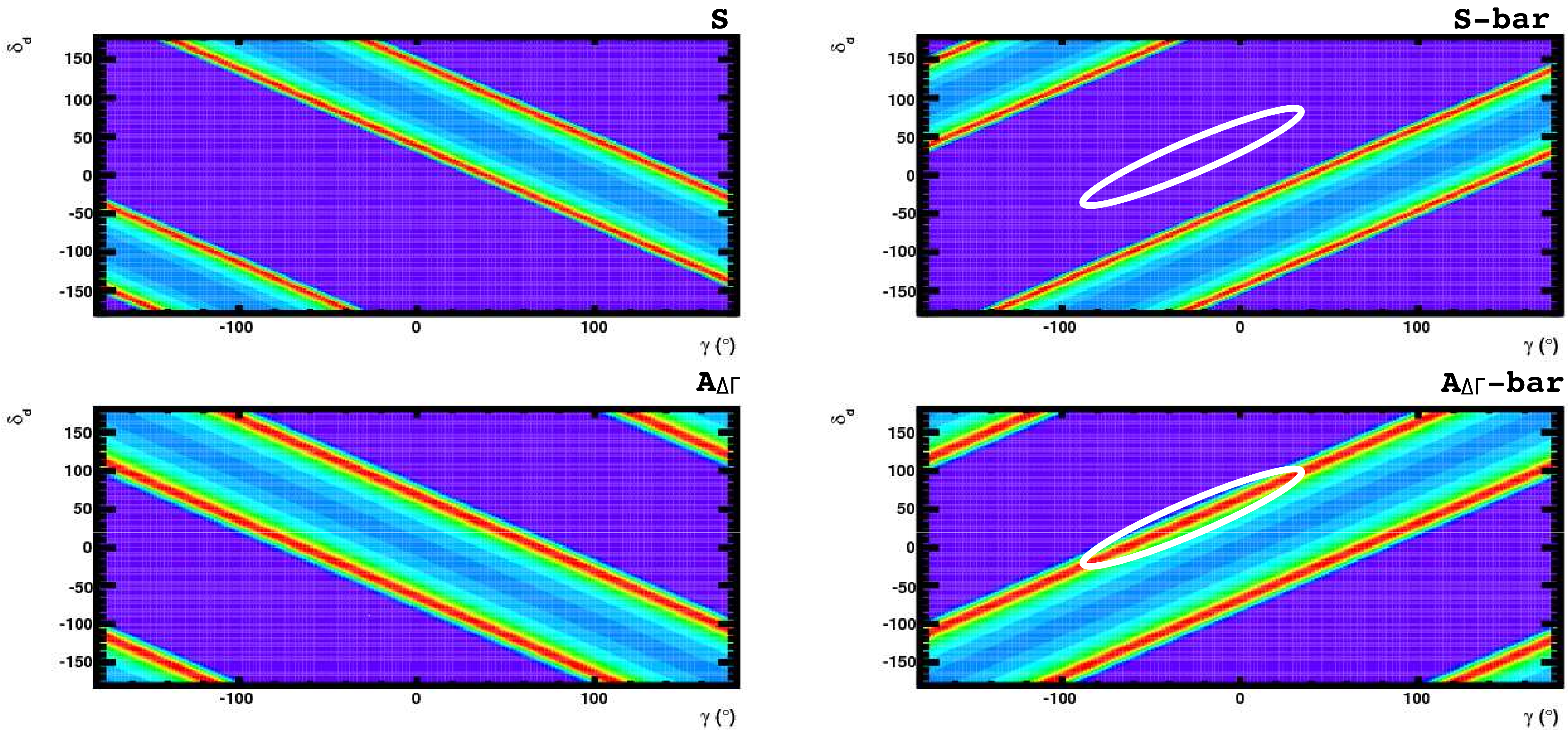
Weak mixing phase

Observables ⇔ physics parameters



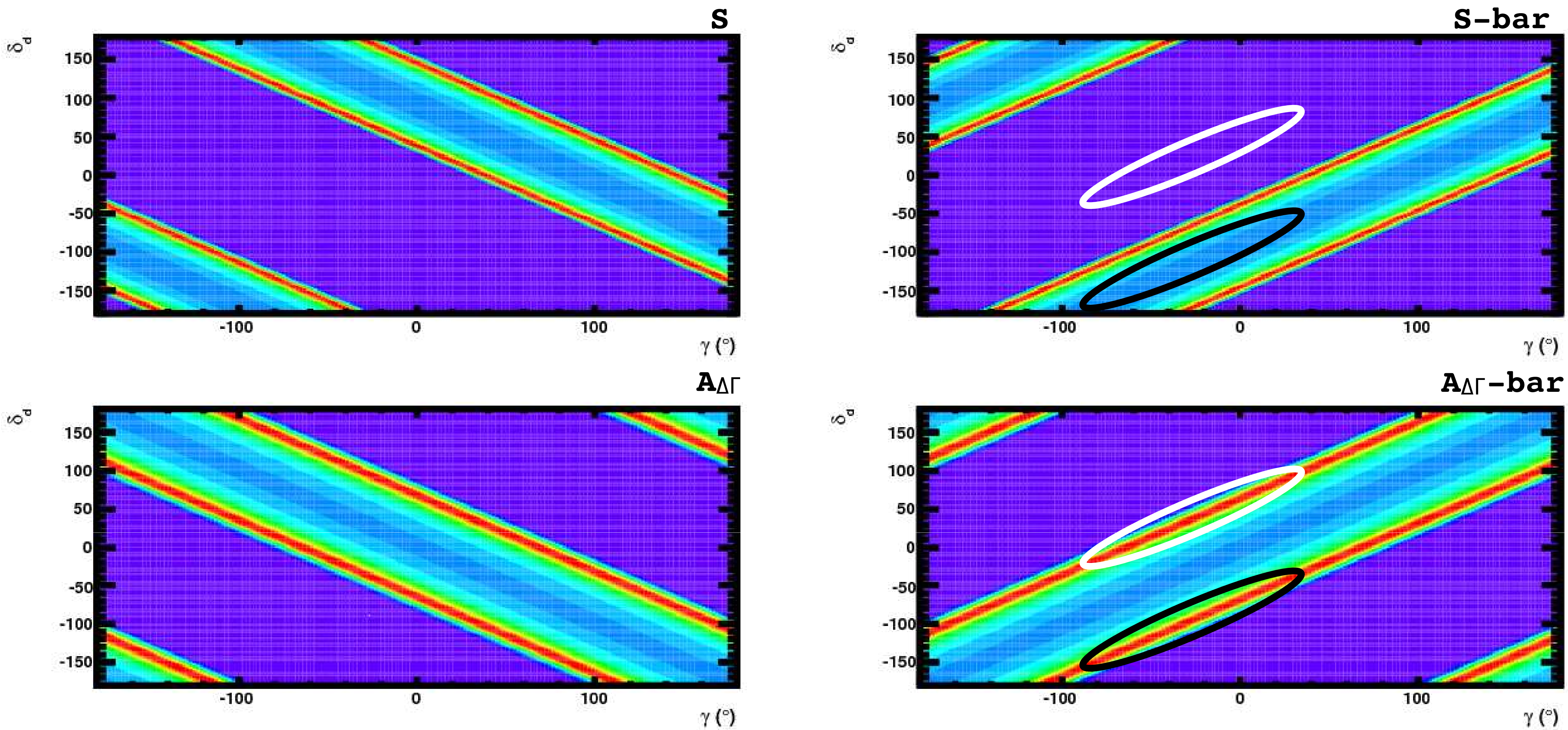
TOY SIMULATION

Observables ⇔ physics parameters



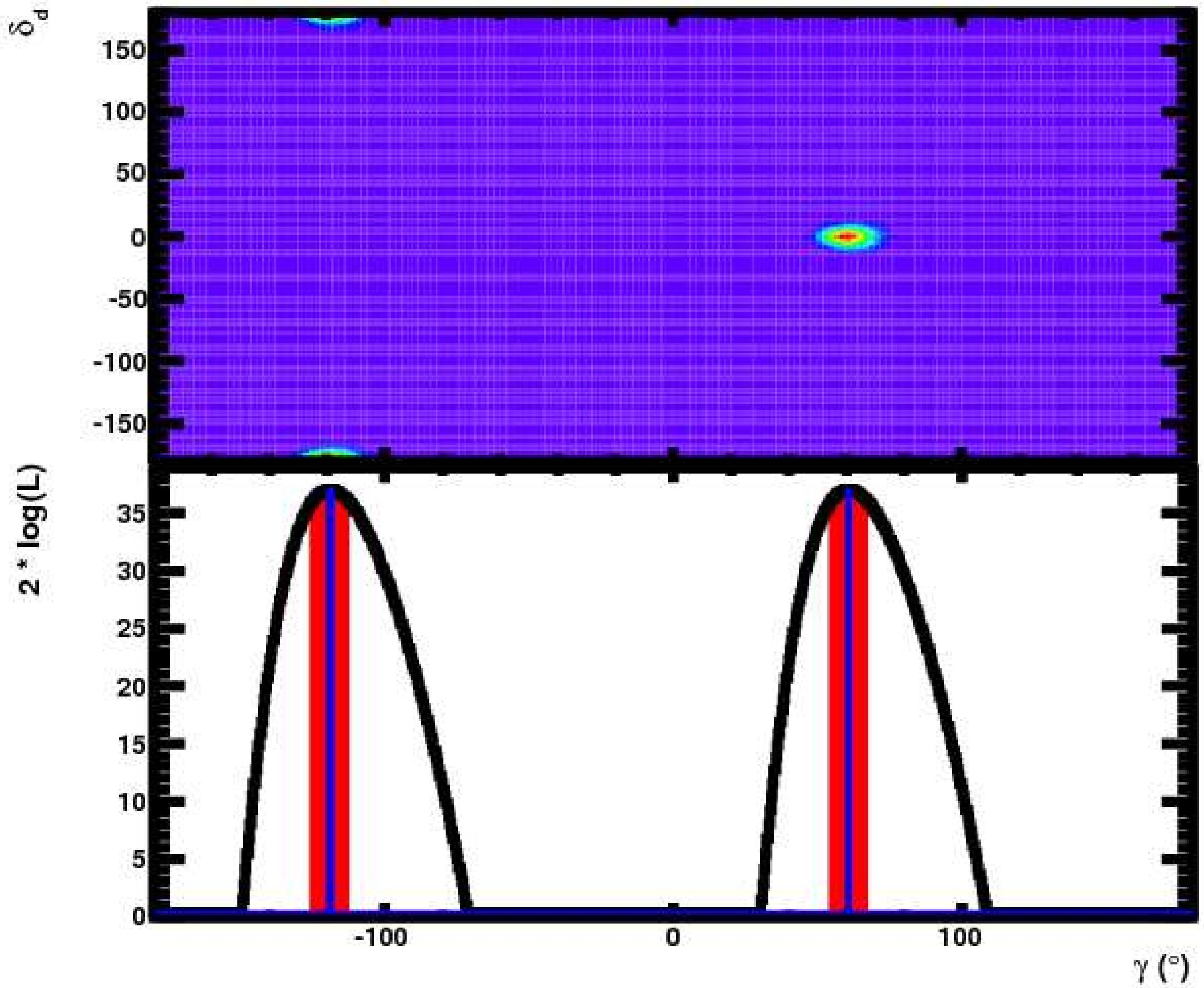
TOY SIMULATION

Observables ⇔ physics parameters



TOY SIMULATION

Observables ⇔ physics parameters



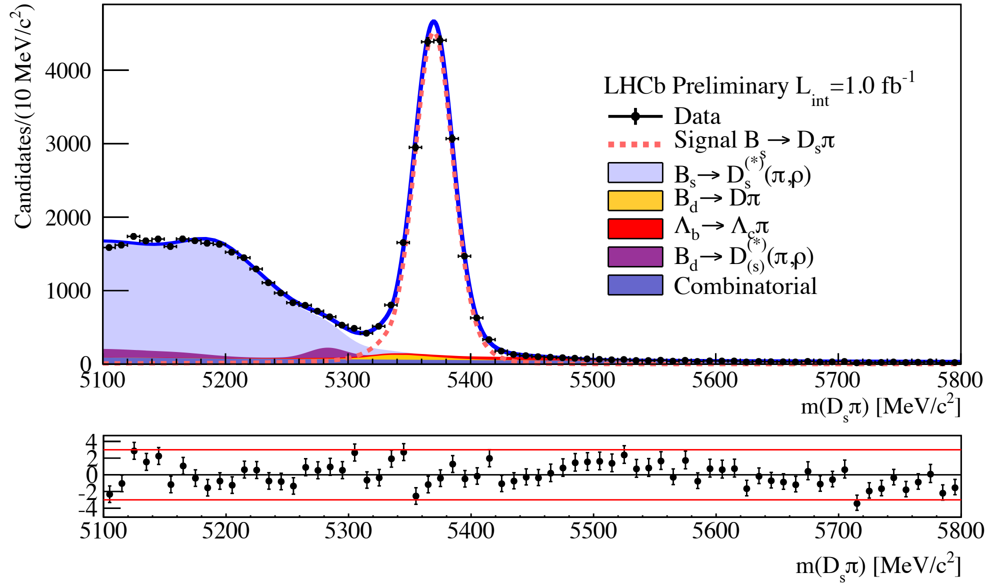
In the limit of large statistics, the different observables combine in such a way as to give only a twofold ambiguity on the angle γ

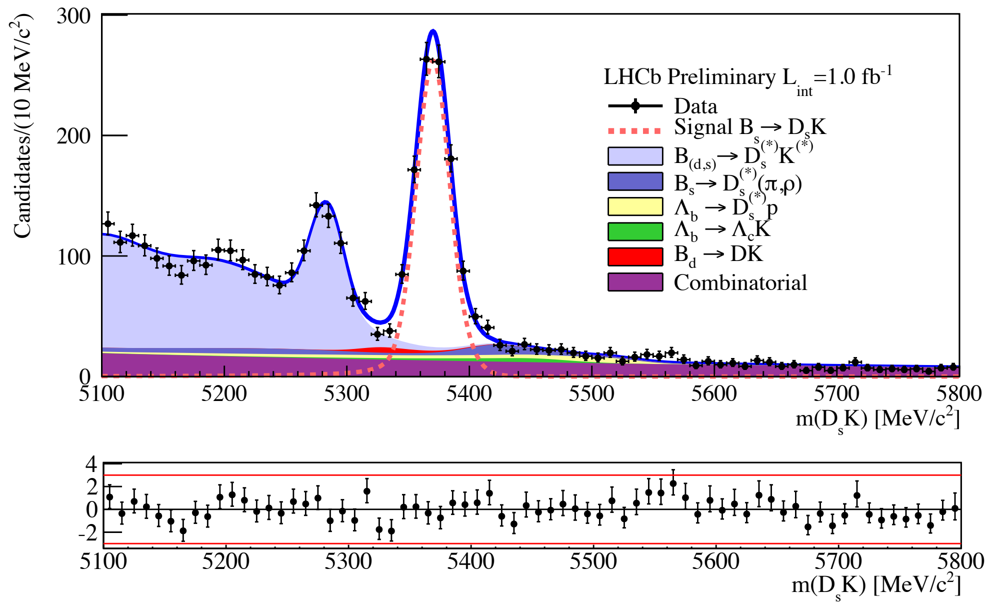
This relies on having both the "tagged" and "untagged" observables

Luckily nature has been kind with a large value of $\Delta\Gamma_S/\Gamma_S$ ~ 15.9%!

TOY SIMULATION

Signals in the data



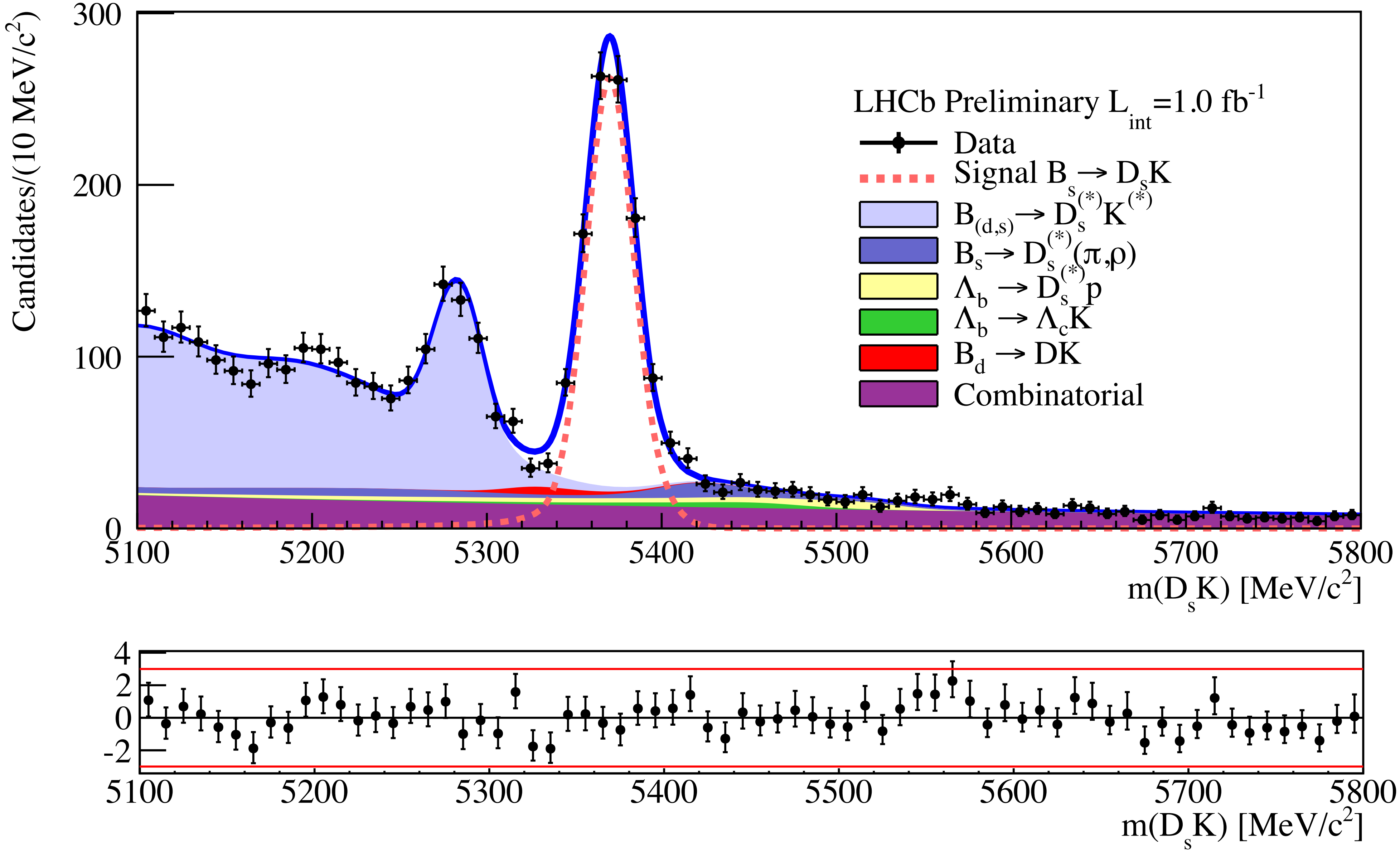


Clean high yield control mode $B_s \to D_s\pi$

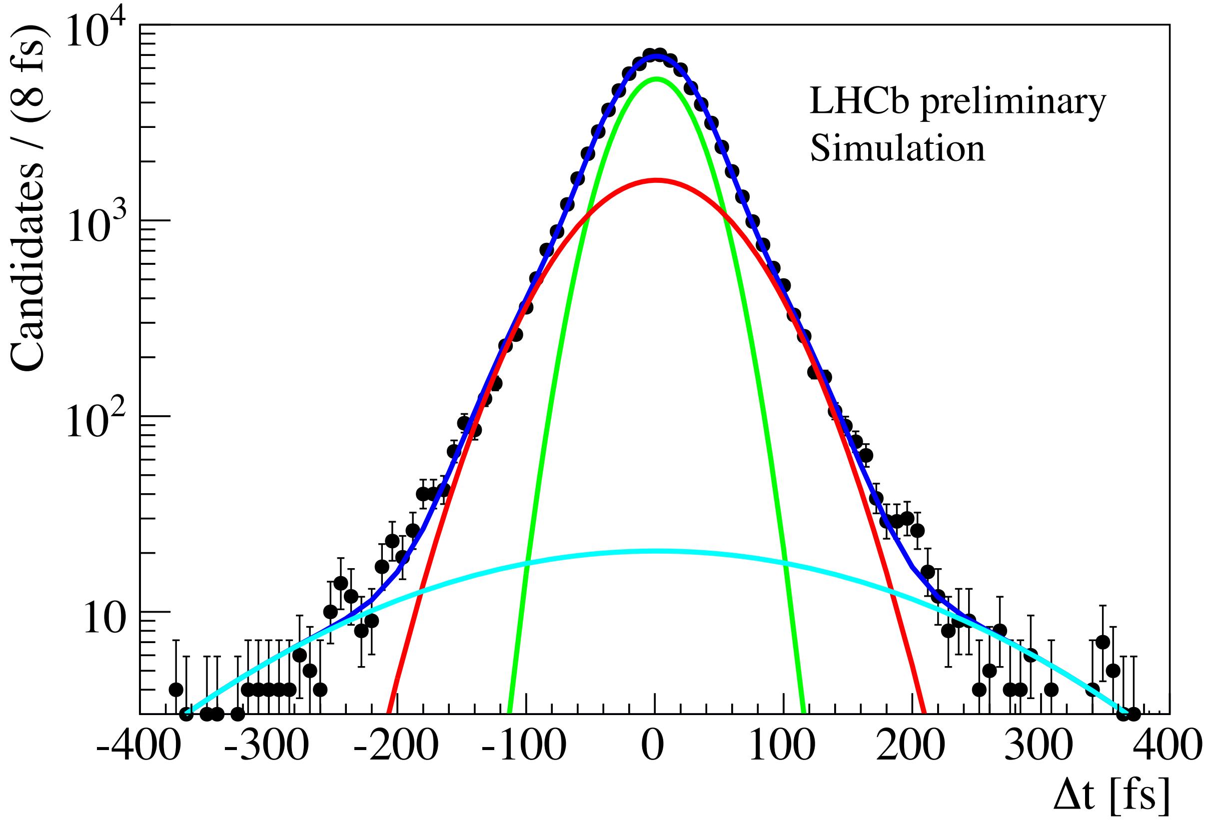
1) **Allows to constrain backgrounds in D_sK**

2) **Allows flavour tagging calibration**

Backgrounds in $D_S K$



Propertime resolution/acceptance



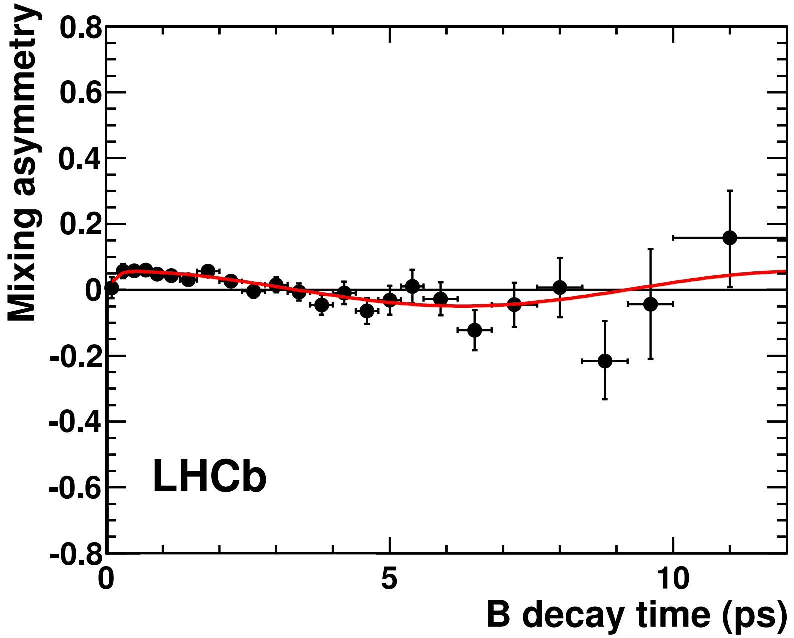
Propertime resolution taken from simulation scaled by the difference between simulation and data resolutions measured on a control channel (15%)

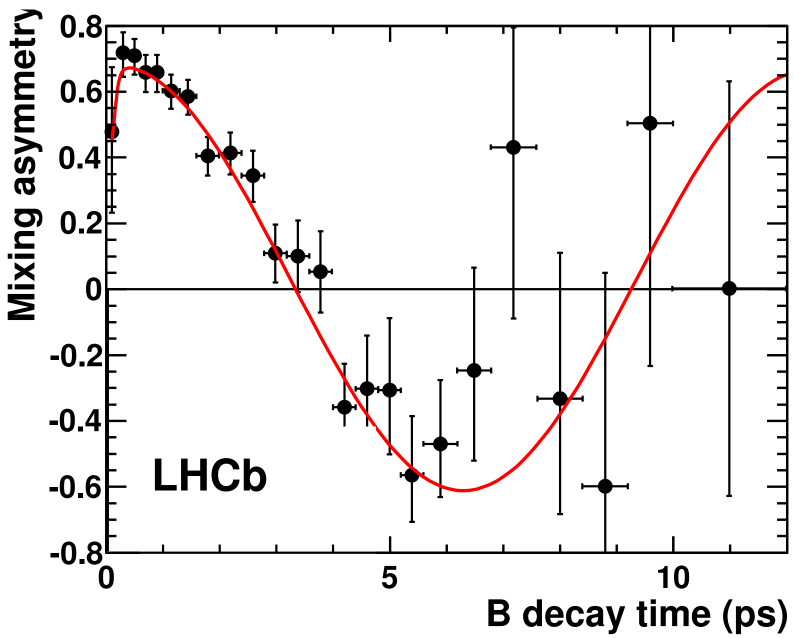
Effective propertime resolution is ~50 fs

Acceptance taken from a fit to the $B_S \to D_S \pi$ data fixing the lifetime and oscillation frequency to the WA values

- Corrected by the ratio of acceptances observed in the simulation

Tagging





Tagging based on the "opposite-side" B decay

Mixture of

- **Single particle tag : e,μ,K**
- **Vertex charge tag**

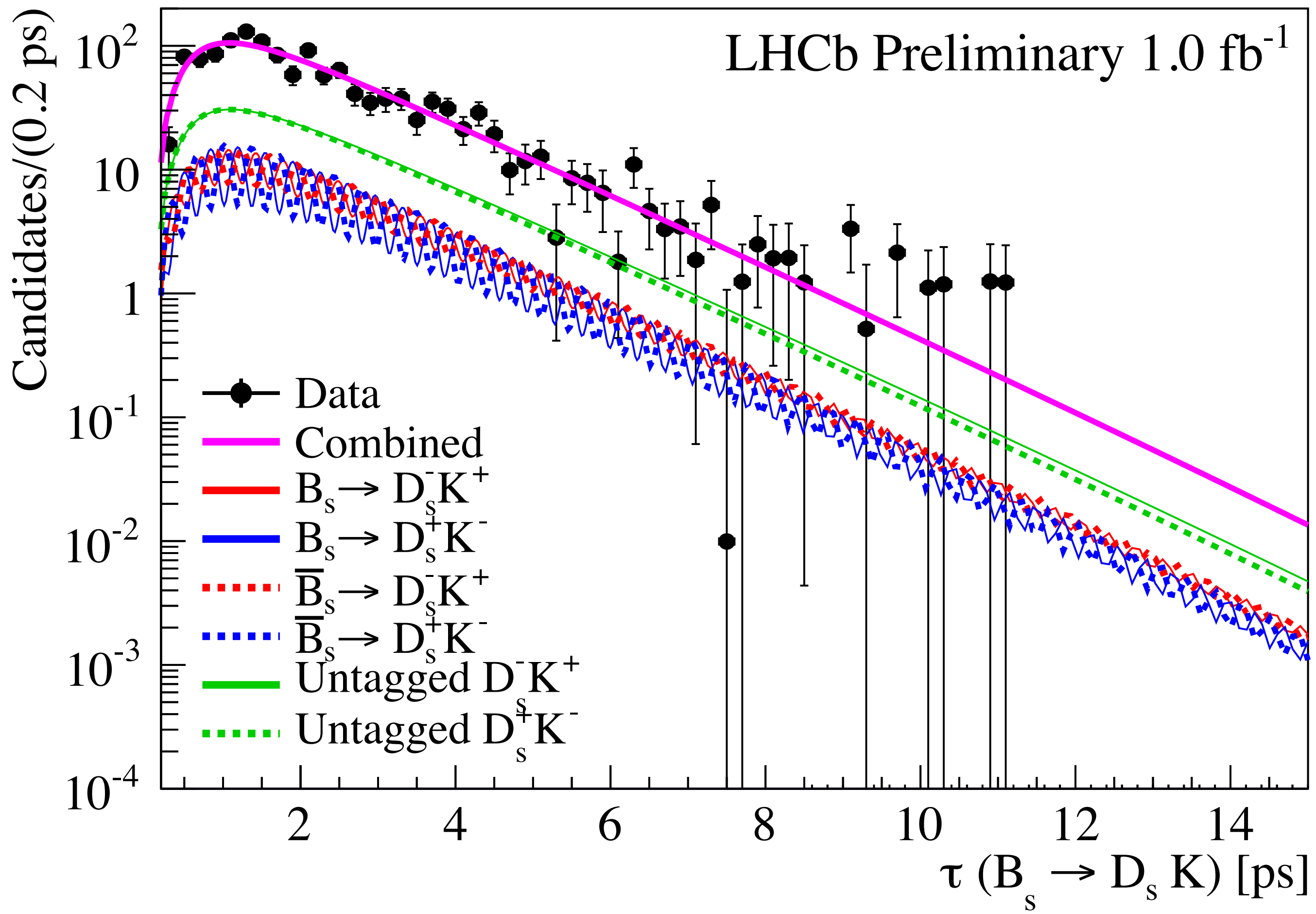
- **Combined using a Neural Network trained on simulated events**

Tagging performance is calibrated on self tagging control channels in the data

Analysis uses the predicted per-event mistag to maximize sensitivity

LHCb-PAPER-2011-027, LHCb-CONF-2012-026

Time fit



The time uses a statistical background subtraction technique (the "sPlot" method) in order to avoid modelling the time dependence of the backgrounds

Fit performance verified in through studies of 2000 pseudoexperiment ensembles

Systematic uncertainties calculated from similar pseudoexperiment ensembles, varying fixed parameters and computing toy-by-toy differences between the nominal and modified fit.

See Arxiv physics.data_an 0402083, 0905.0724

Results

Table 4: Fitted values of the $B_s^0 \to D_s^{\mp} K^{\pm}$ CP-asymmetry observables with statistical and systematic uncertainties. All systematics are given as fractions of the statistical uncertainty. Systematics are added in quadrature under the assumption that they are uncorrelated.

	C	S_f	$S_{\bar{f}}$	D_f	$D_{\bar{f}}$
Toy corrected central value	1.01	-1.25	0.08	-1.33	-0.81
Statistical uncertainty	0.50	0.56	0.68	0.60	0.56
Systematic uncertainties (σ_{stat})					
Decay-time bias	0.03	0.05	0.05	0.00	0.00
Decay-time resolution	0.11	0.08	0.09	0.00	0.00
Tagging calibration	0.23	0.17	0.16	0.00	0.00
Backgrounds	0.15	0.07	0.07	0.07	0.07
Fixed parameters	0.15	0.22	0.20	0.40	0.42
Asymmetries	0.12	0.01	0.04	0.00	0.02
Momentum/length scale	0.00	0.00	0.00	0.00	0.00
k-factors	0.27	0.27	0.27	0.08	0.08
Bias correction	0.03	0.03	0.03	0.03	0.03
Total systematic (σ_{stat})	0.46	0.50	0.35	0.43	0.46

No extraction of γ for now because we did not have the time to evaluate the correlations between systematic uncertainties and we saw a non-negligible effect of including these on γ.

Will be done for the eventual paper.

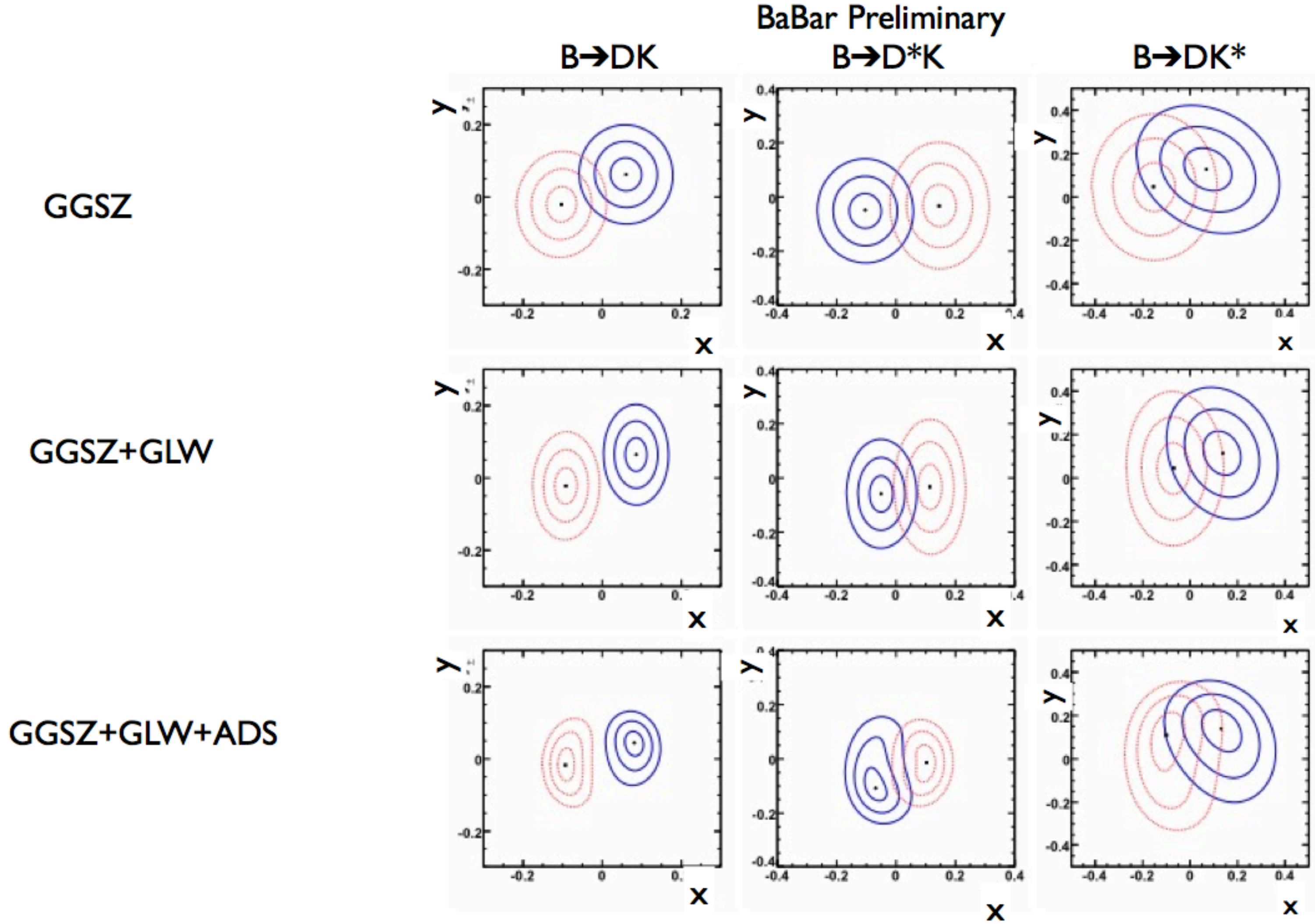
LHCb-CONF-2012-029

What do we know about γ/φ_3 today?

BaBar and BELLE and LHCb all came to CKM with their γ combinations!

What do we know about γ/φ_3 today?

BABAR : combination in Cartesian coordinates $\gamma = (69^{+17}_{-16})^\circ$

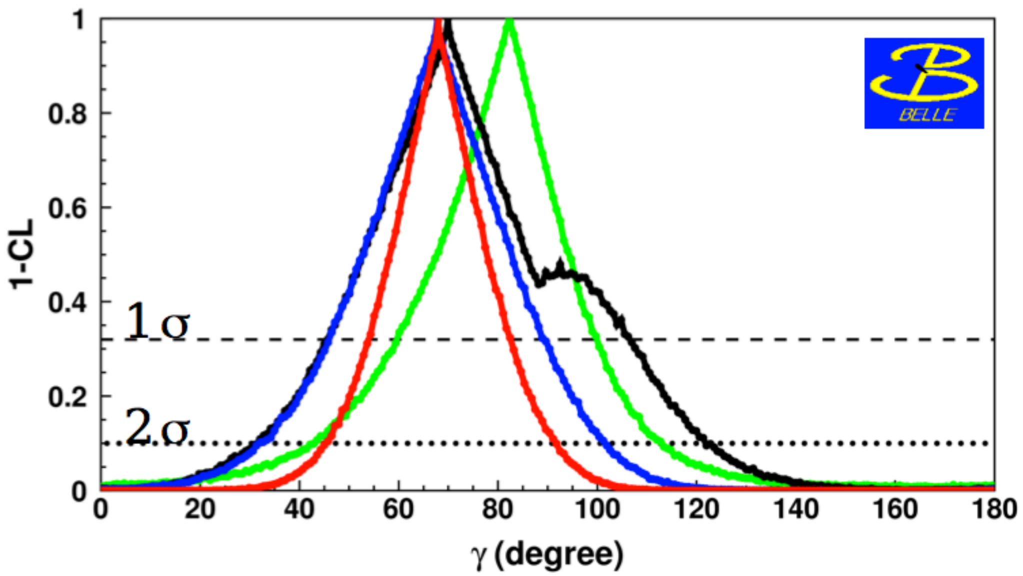


The improvement is clearly visible.

See D. Derkach, CKM 2012

What do we know about γ/φ_3 today?

BELLE : projections in γ, r_B



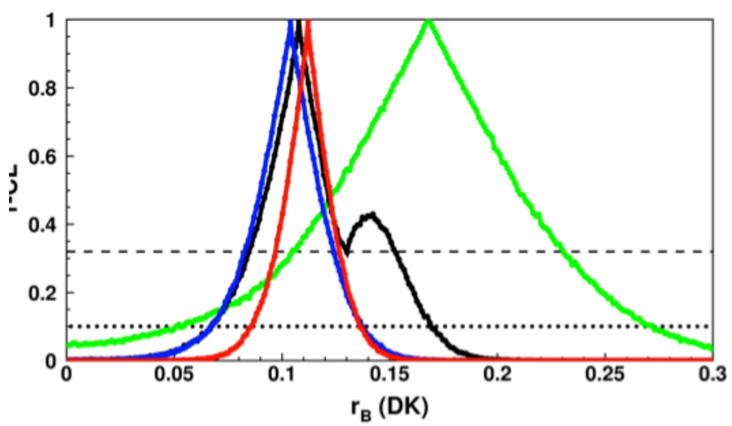
GGSZ
$\gamma = [82\,^{+18}_{-23}]^\circ$

GGSZ+ADS
$\gamma = [70\,^{+37}_{-24}]^\circ$

GGSZ+ADS+δ_D
$\gamma = [68 \pm 22]^\circ$

GGSZ+ADS+GLW+δ_D
$\gamma = [68\,^{+15}_{-14}]^\circ$

$(2\sigma = {}^{+28^\circ}_{-27})$



for B→DK:

$r_B = 0.168^{+0.063}_{-0.064}$

$r_B = 0.108^{+0.045}_{-0.023}$

$r_B = 0.104^{+0.020}_{-0.021}$

$\mathbf{r_B = 0.112^{+0.014}_{-0.015}}$

See K. Trabelsi, CKM 2012

What do we know about γ/φ_3 today?

LHCb : ok you'll forgive me a bias I do this in a bit more detail...

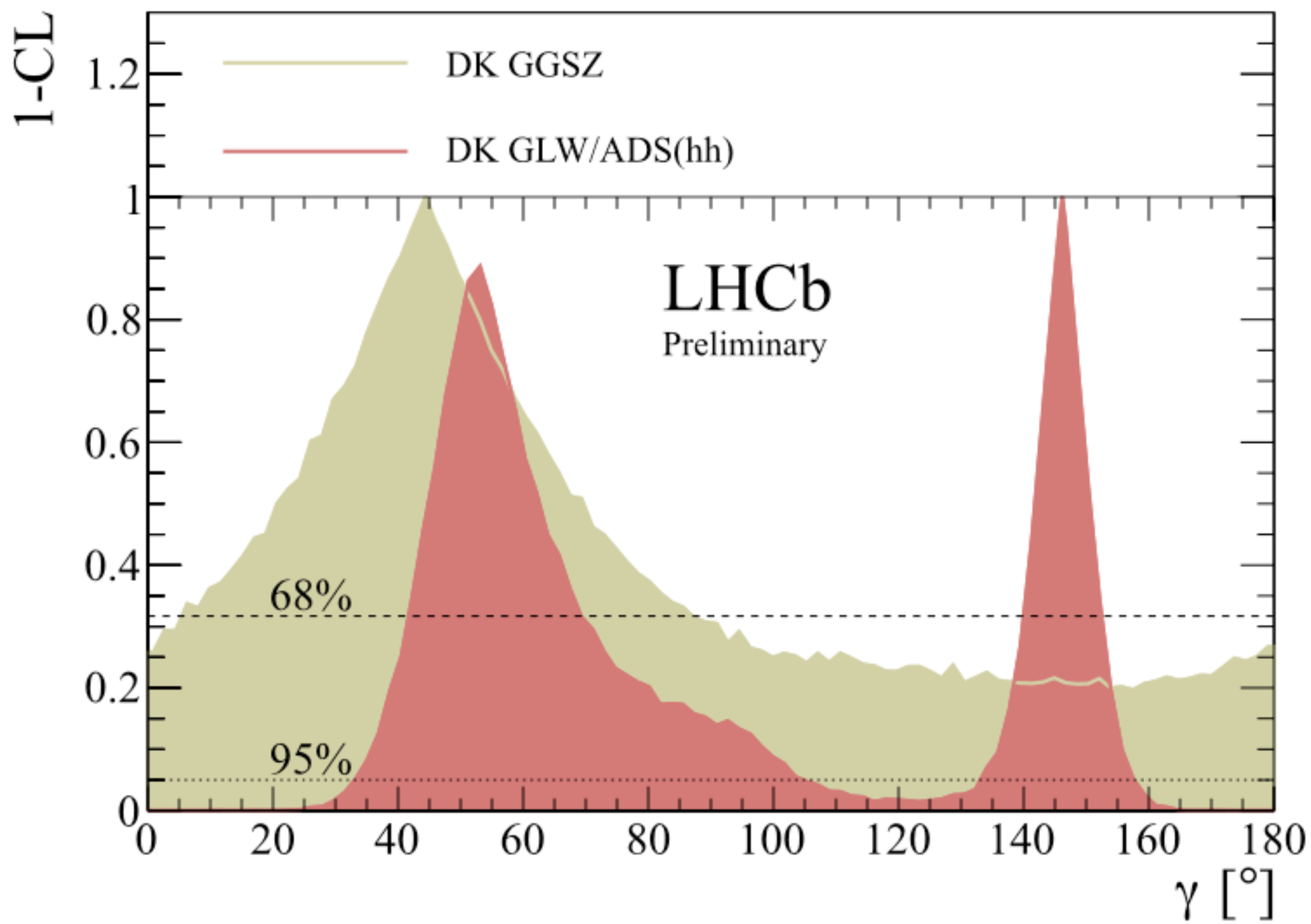
Everything was done with a frequentist approach, the so-called "plugin" method. Experimental likelihoods taken into account where non-Gaussian.

LHCb-CONF-2012-032

What do we know about γ/φ_3 today?

LHCb : look at ADS/GLW and GGSZ on their own

GGSZ has a poor standalone sensitivity because of an unlucky value of r_B.

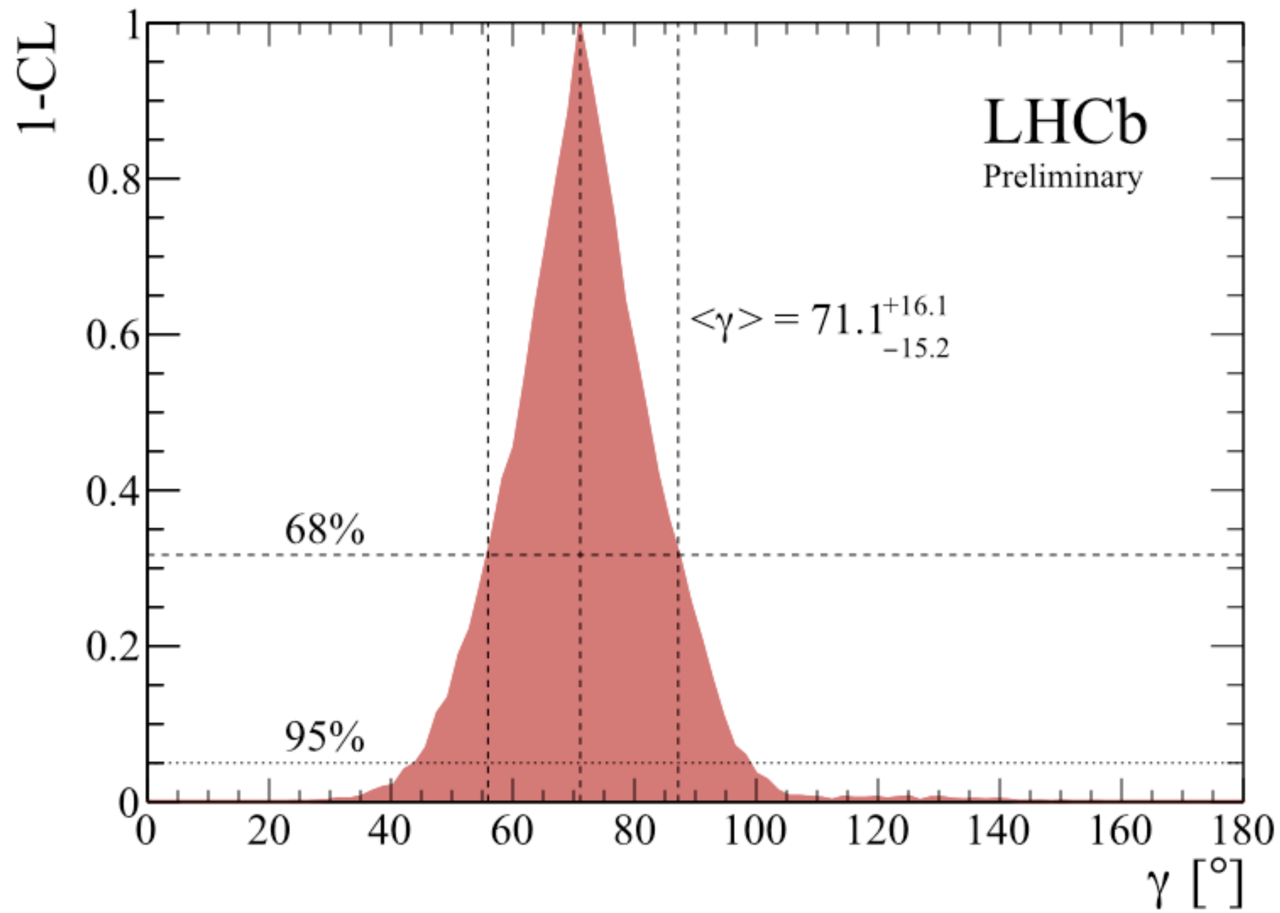


LHCb-CONF-2012-032

What do we know about γ/φ_3 today?

LHCb : now combine all DK measurements, including $D \to K3\pi$ ADS

Rather Gaussian behaviour!

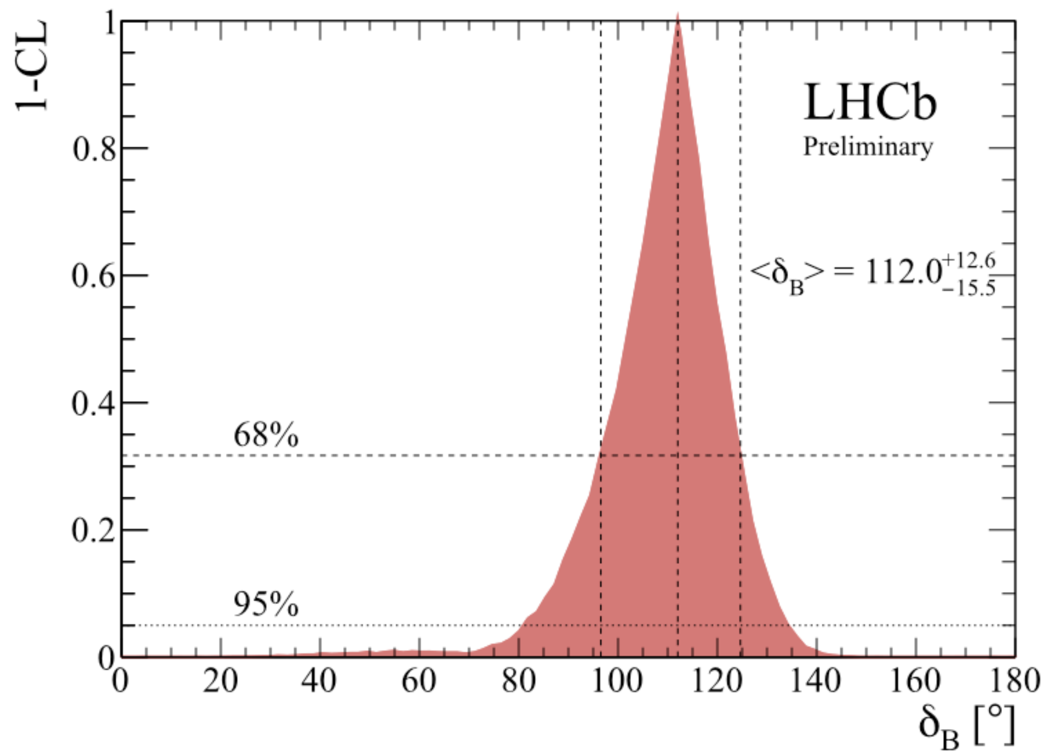


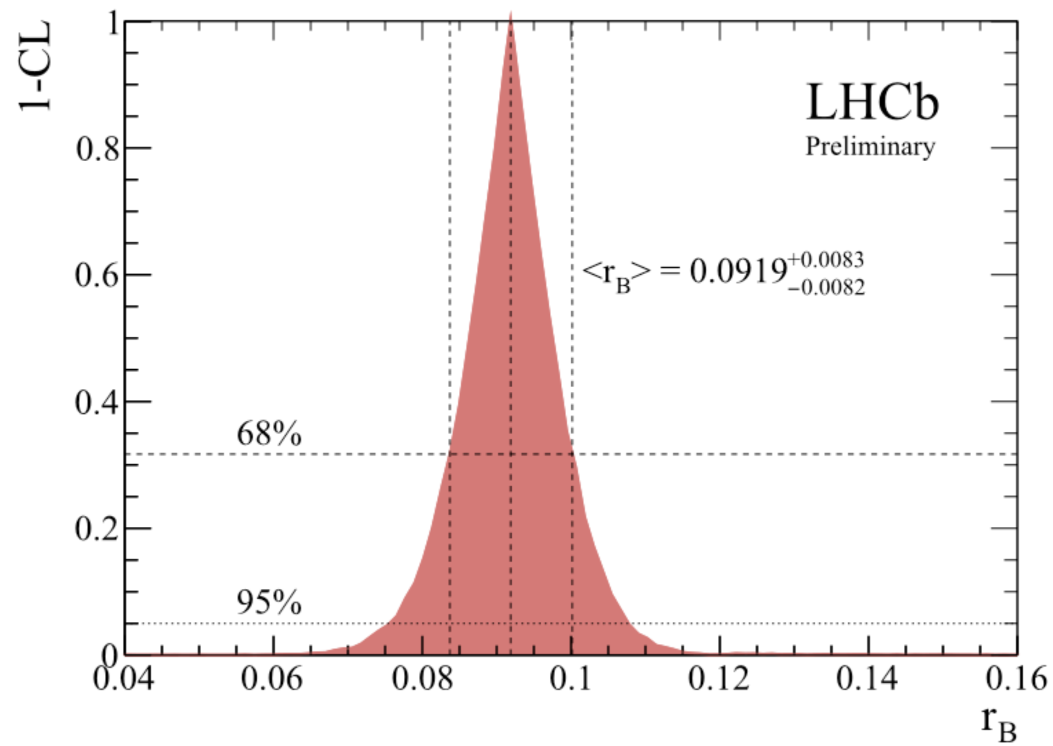
LHCb-CONF-2012-032

What do we know about γ/φ_3 today?

LHCb : now combine all DK measurements, including D→K3π ADS

Rather Gaussian behaviour!

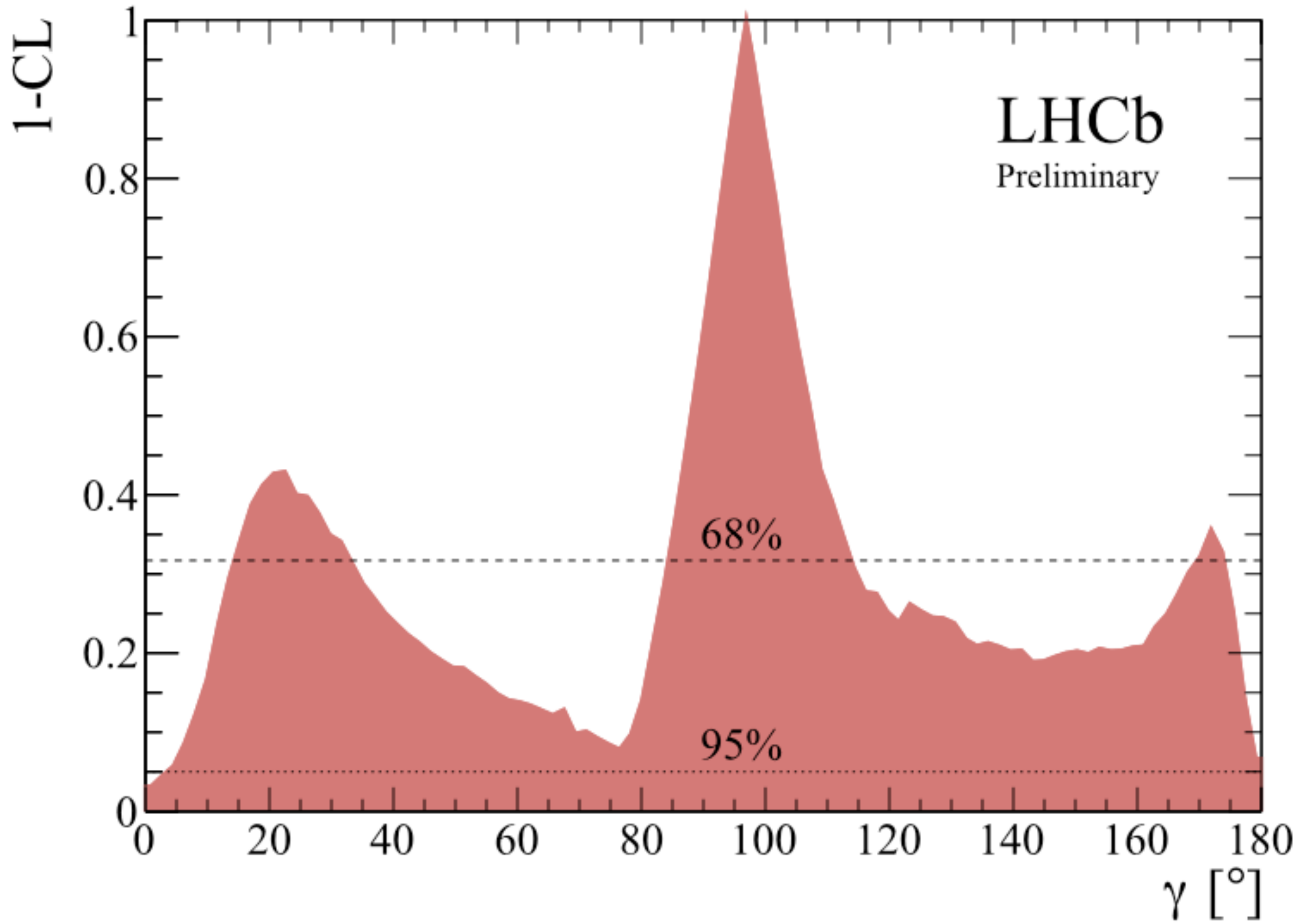




LHCb-CONF-2012-032

What do we know about γ/φ_3 today?

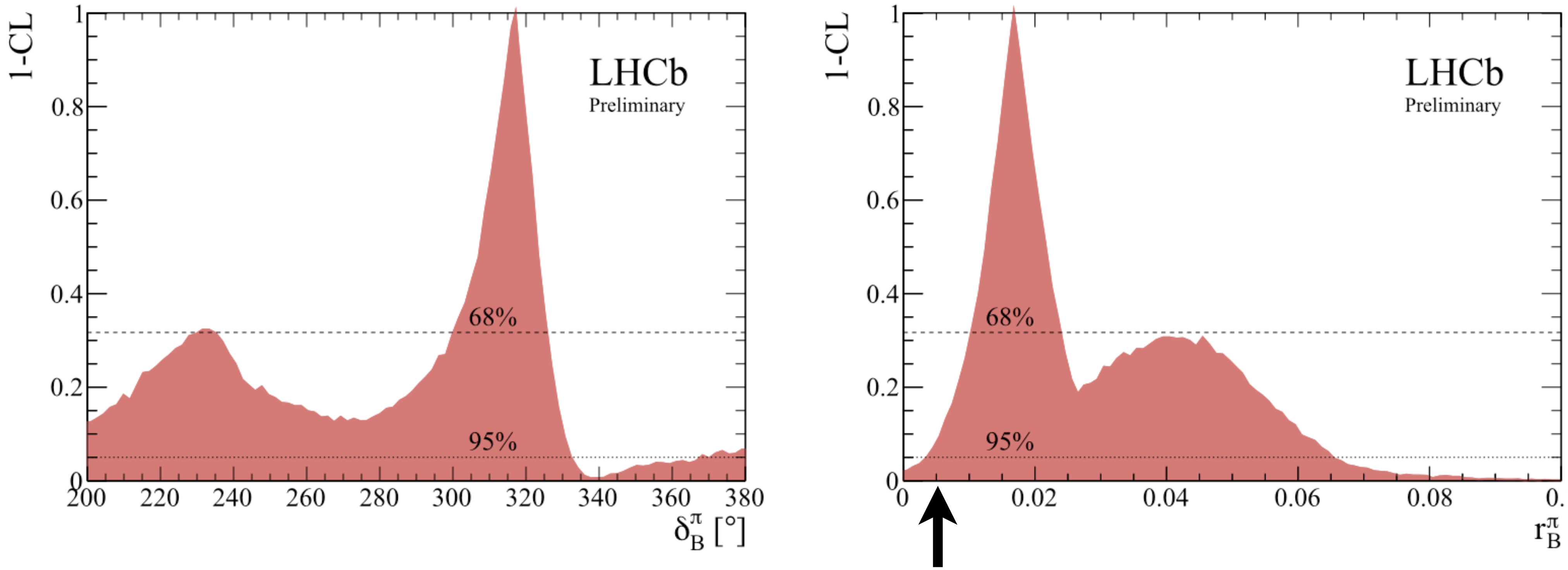
LHCb : the first combination of the ADS/GLW $D\pi$ measurements



What do we know about γ/φ_3 today?

LHCb : the first combination of the ADS/GLW $D\pi$ measurements

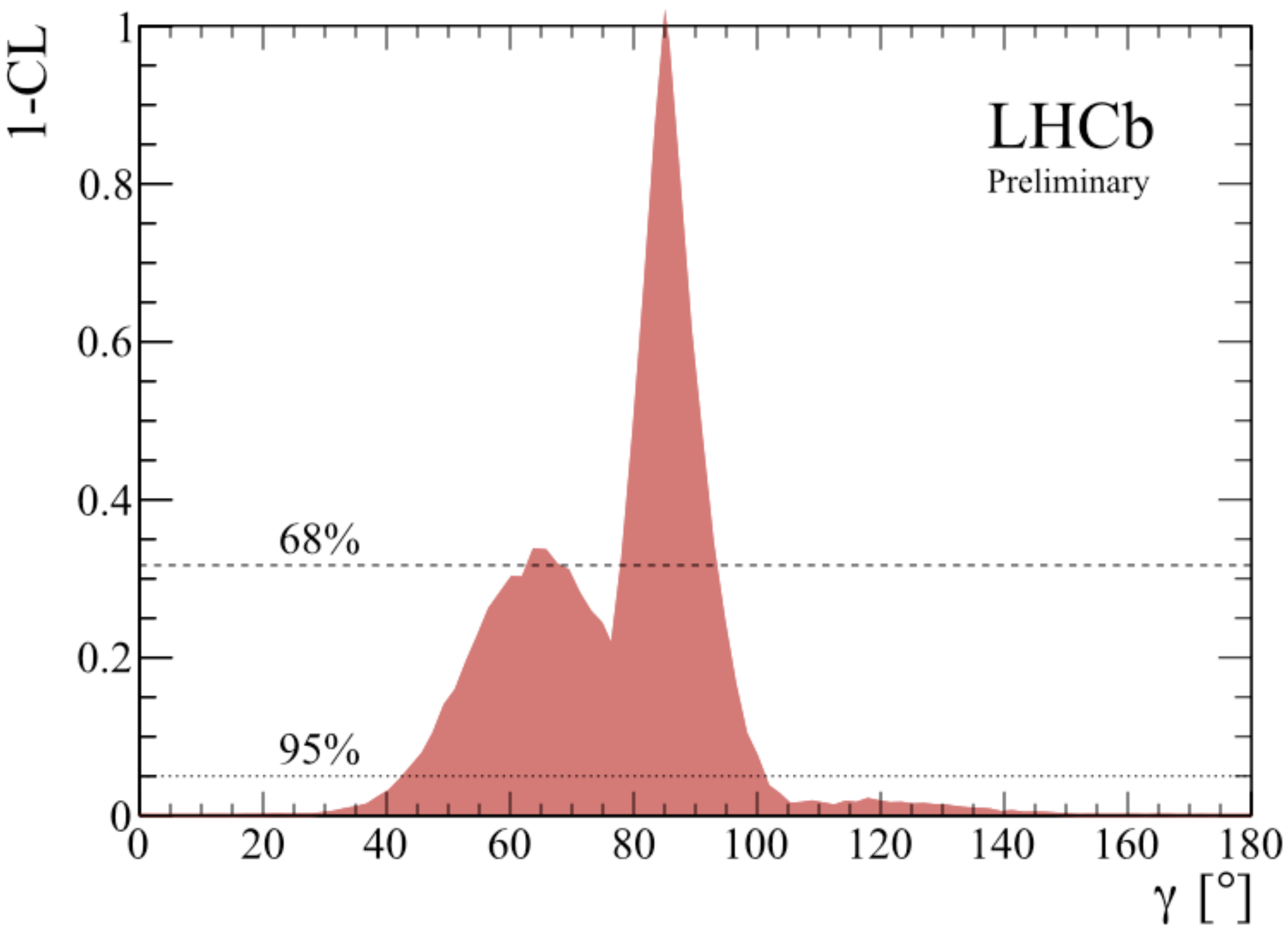
r^{π}_{B} larger than naively expected?



LHCb-CONF-2012-032

What do we know about γ/φ_3 today?

LHCb : putting it all together... very similar precision to BELLE/BABAR at 2σ. Our little child had a good 2011!



γ	63.7°	85.1°
68% CL	$[61.8, 67.8]^\circ$	$[77.9, 92.4]^\circ$
95% CL	$\leftarrow [43.8, 101.5]^\circ \rightarrow$	
$r_{B(K)}$	0.0948	
68% CL	$[0.0860, 0.1032]$	
95% CL	$[0.078, 0.111]$	
$\delta_{B(K)}$	119.0°	
68% CL	$[107.0, 129.1]^\circ$	
95% CL	$[79.7, 137.9]^\circ$	
$r_{B(\pi)}$	0.0239	
68% CL	$[0.0153, 0.0310]$	
95% CL	$[0.0, 0.037]$	
$\delta_{B(\pi)}$	373.7°	321.4°
68% CL	$[365.7, 387.0]^\circ$	$[311.2, 328.4]^\circ$
95% CL	$\leftarrow [160.5, 333.6]^\circ \rightarrow$	

LHCb-CONF-2012-032

And the future?

LHCb expects ~2 fb^{-1} on tape in 2012, combined with the slightly higher beam energy this will more than triple the available dataset

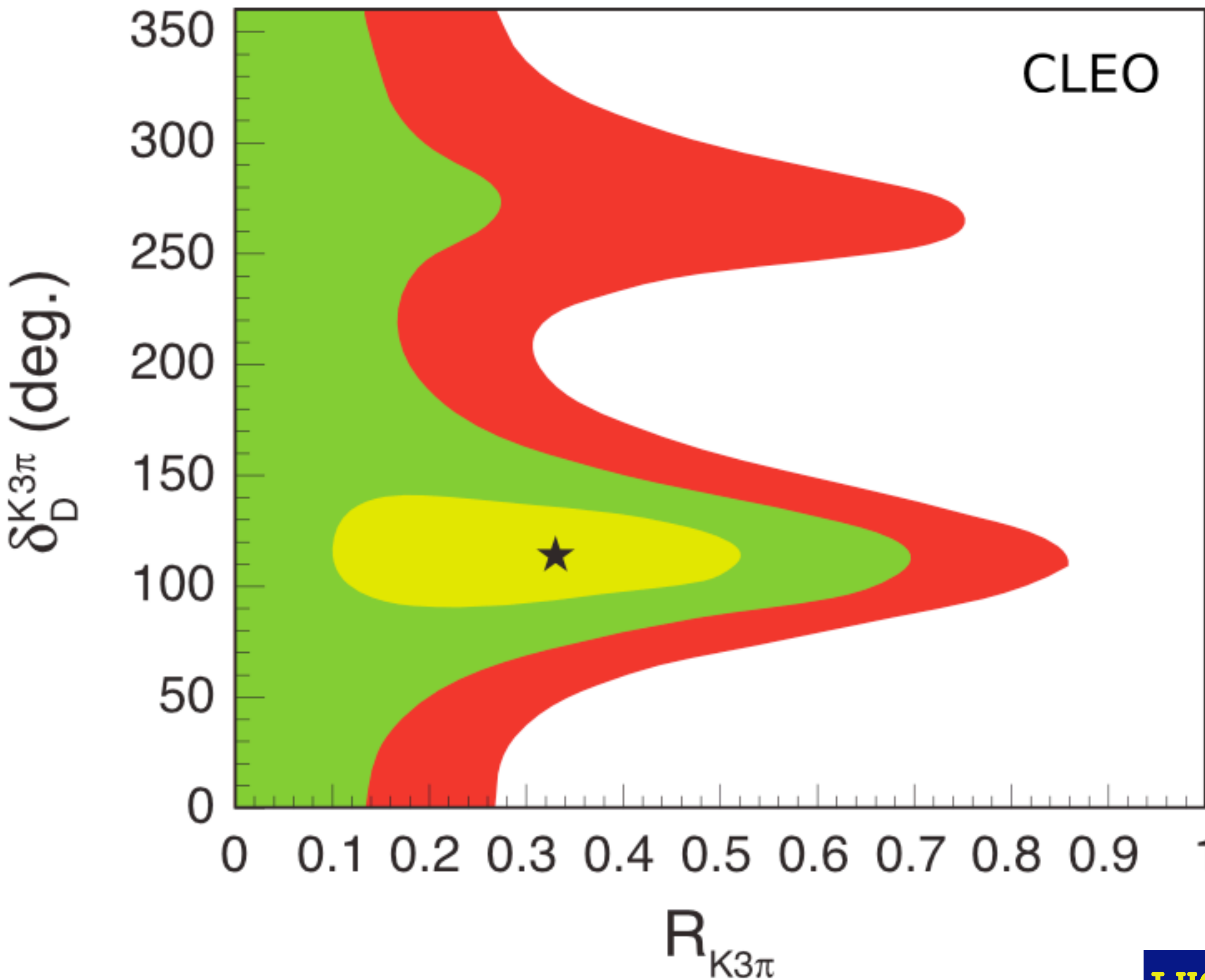
Many new modes will start to show sensitivity to γ, for example DK^* with ADS/GLW/GGSZ, D_SK, DHHH, DK with $D \to 4\pi$, etc.

The key will be systematic control and ensuring that the global fit to the physics parameters of interests shows an acceptable $\chi 2$ as new measurements are added in.

And for the upgrade, with 200x the dataset... qui vivra verra.

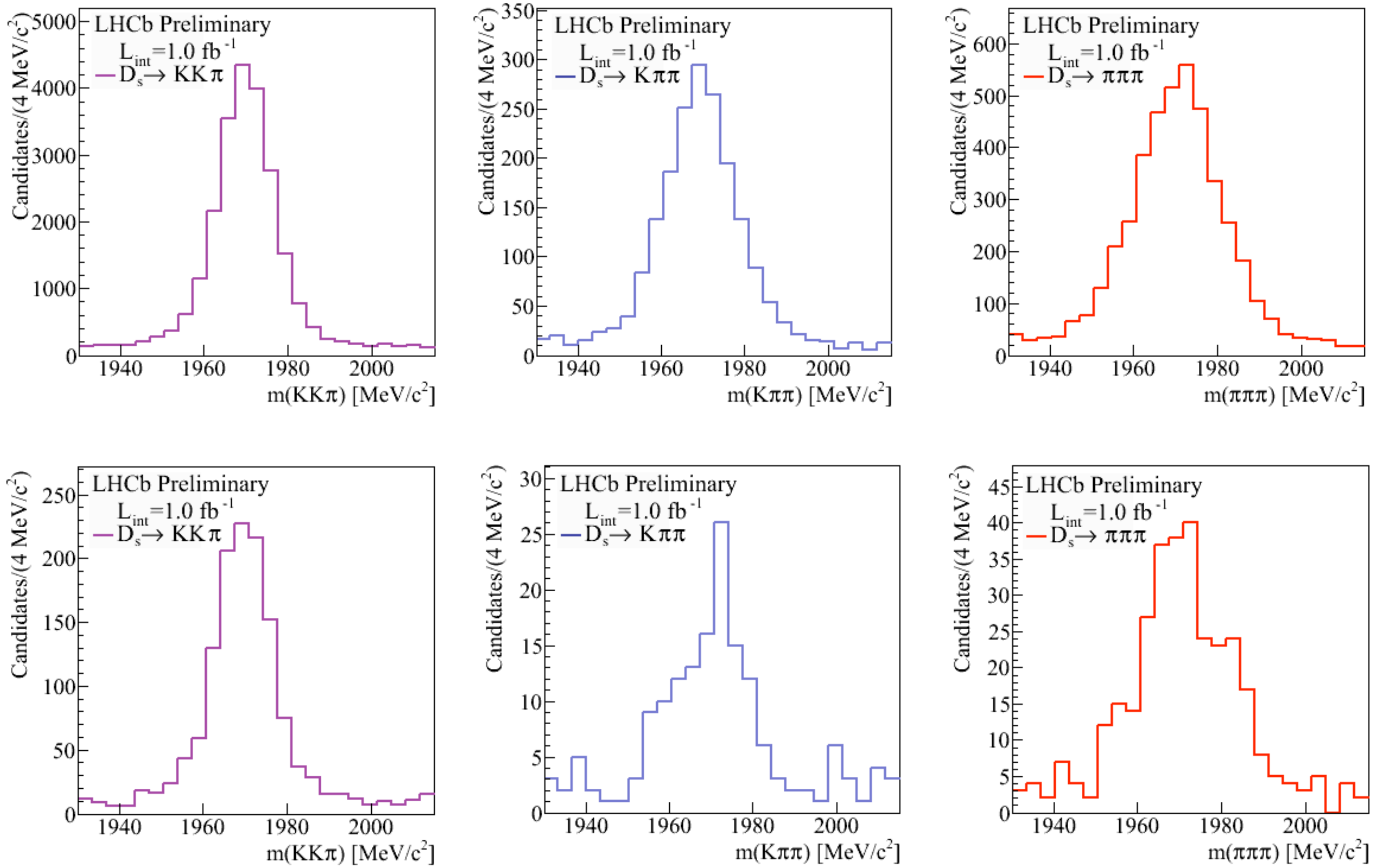
Backups

CLEO inputs



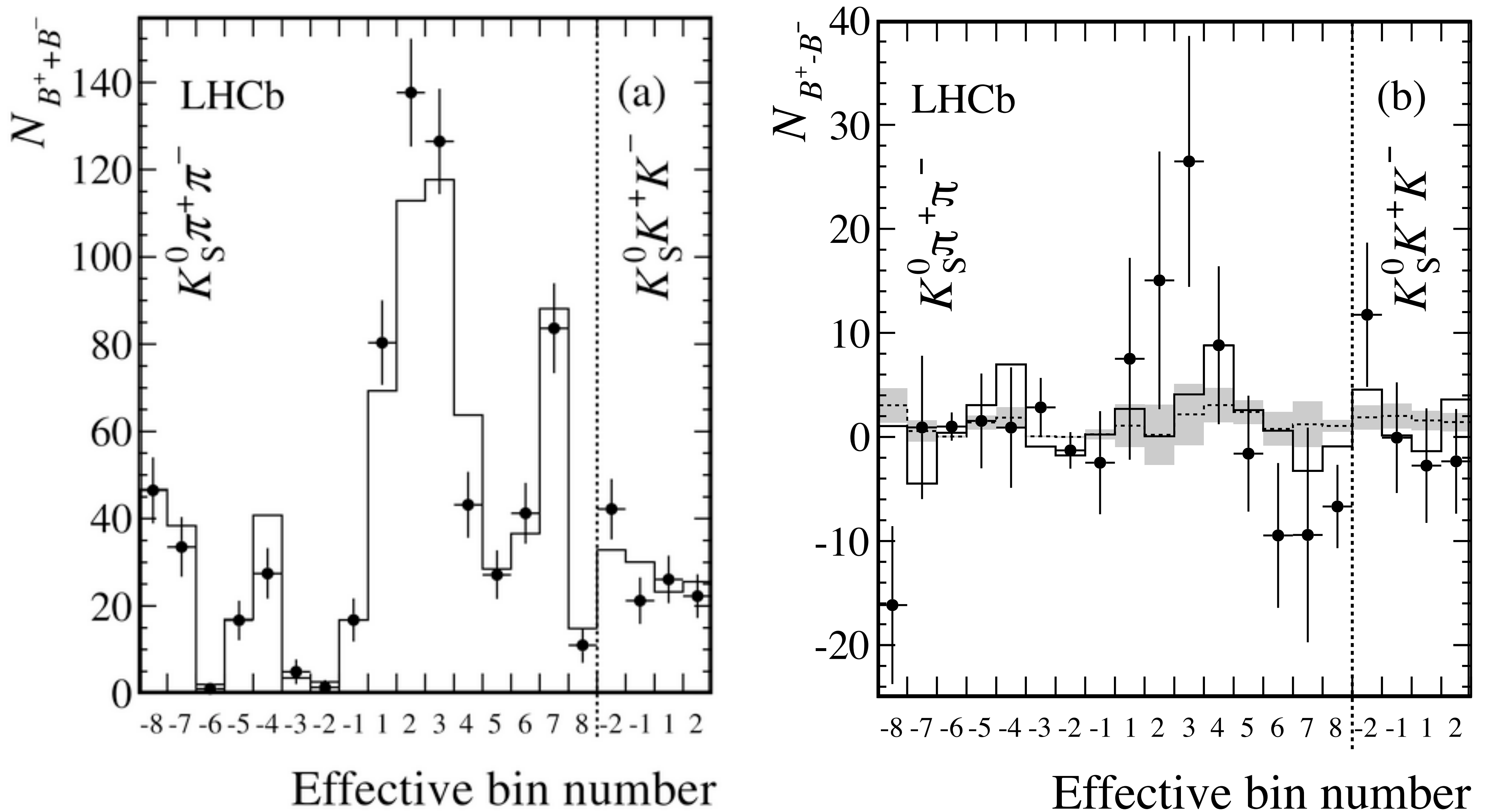
LHCb-CONF-2012-032

$D_S K$ charm signals



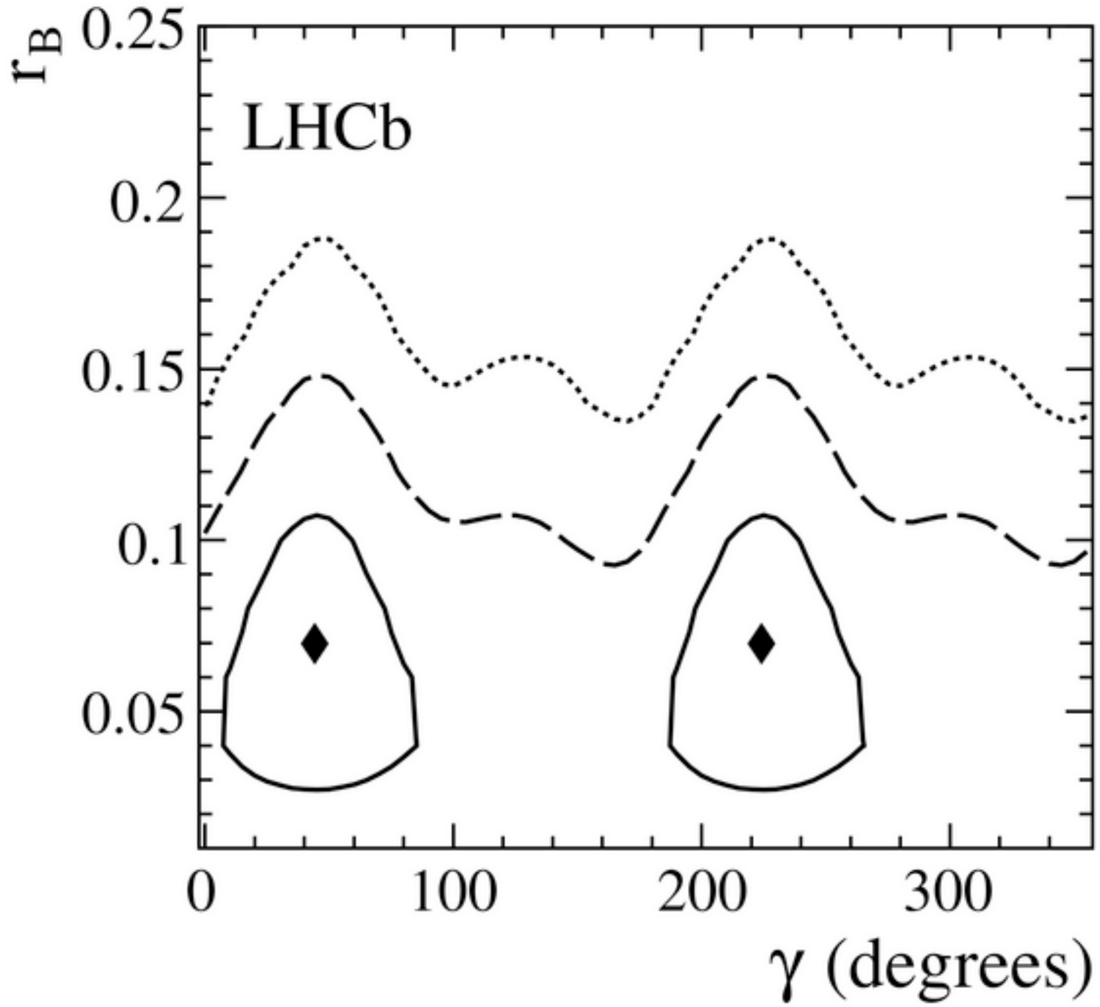
LHCb-CONF-2012-029

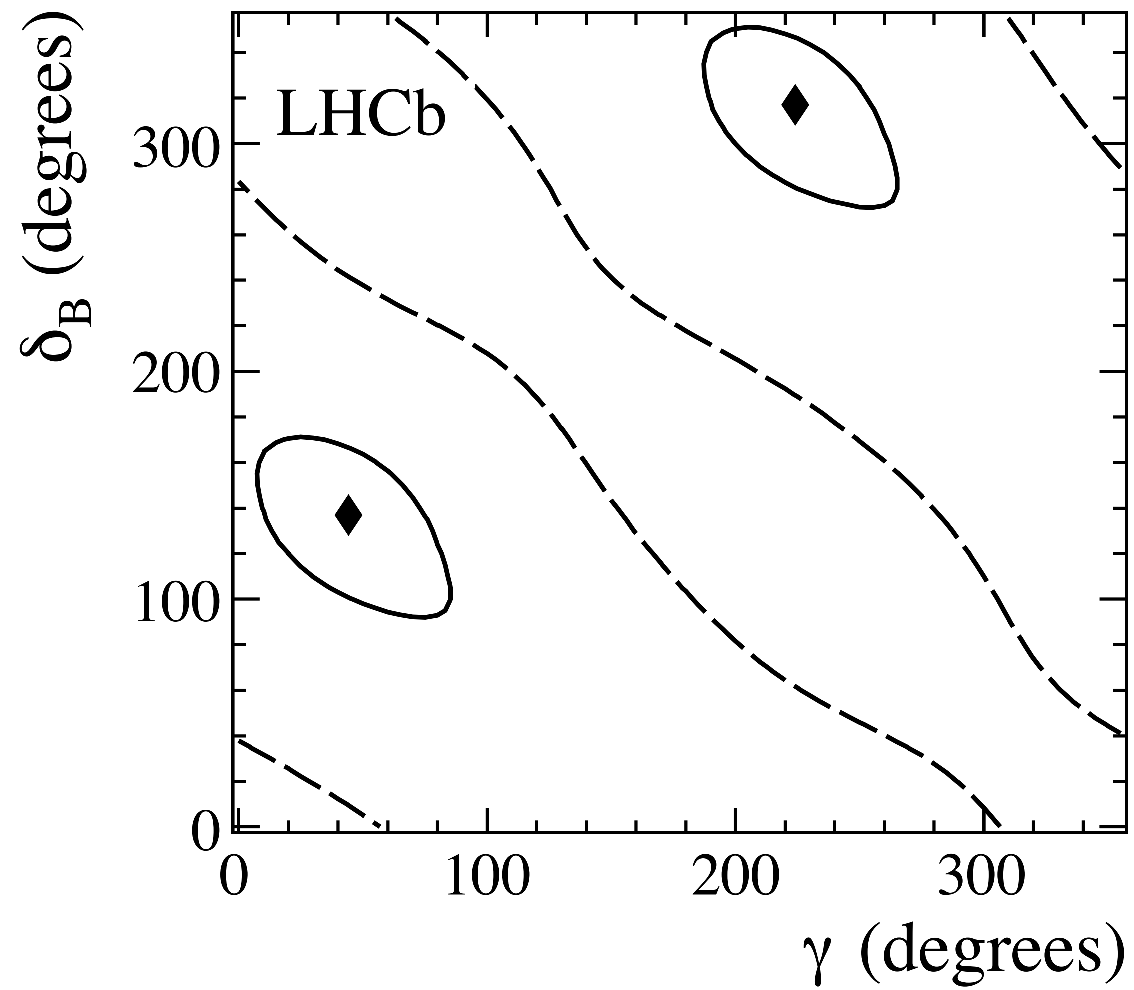
GGSZ asymmetries per bin



LHCb-PAPER-2012-027

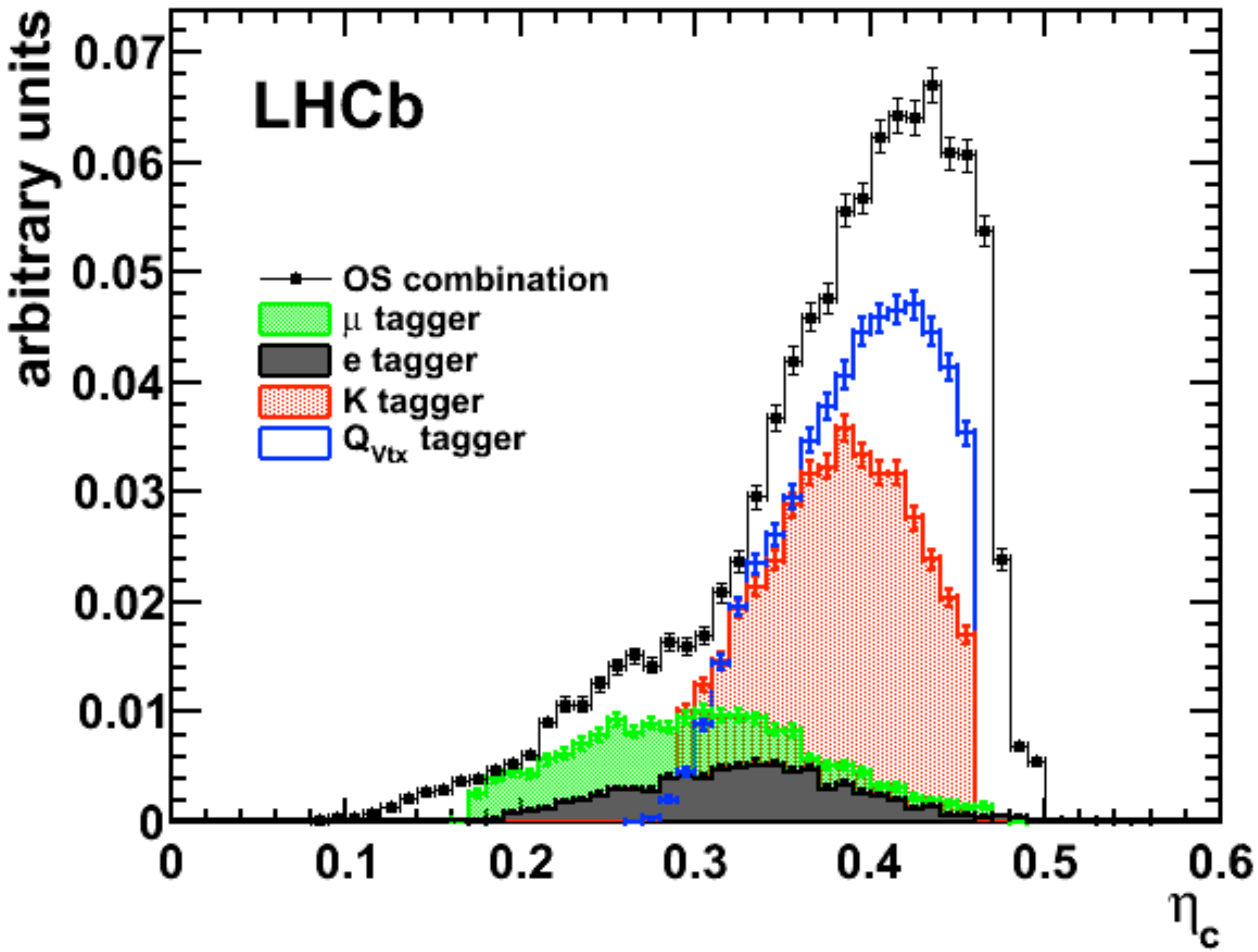
GGSZ only extractions





LHCb-PAPER-2012-027

Mistag distributions



GLW/ADS full results

$$R^{K\pi}_{K/\pi} = 0.0774 \pm 0.0012 \pm 0.0018$$
$$R^{KK}_{K/\pi} = 0.0773 \pm 0.0030 \pm 0.0018$$
$$R^{\pi\pi}_{K/\pi} = 0.0803 \pm 0.0056 \pm 0.0017$$
$$A^{K\pi}_{\pi} = -0.0001 \pm 0.0036 \pm 0.0095$$
$$A^{K\pi}_{K} = 0.0044 \pm 0.0144 \pm 0.0174$$
$$A^{KK}_{K} = 0.148 \pm 0.037 \pm 0.010$$
$$A^{\pi\pi}_{K} = 0.135 \pm 0.066 \pm 0.010$$
$$A^{KK}_{\pi} = -0.020 \pm 0.009 \pm 0.012$$
$$A^{\pi\pi}_{\pi} = -0.001 \pm 0.017 \pm 0.010$$
$$R^{-}_{K} = 0.0073 \pm 0.0023 \pm 0.0004$$
$$R^{+}_{K} = 0.0232 \pm 0.0034 \pm 0.0007$$
$$R^{-}_{\pi} = 0.00469 \pm 0.00038 \pm 0.00008$$
$$R^{+}_{\pi} = 0.00352 \pm 0.00033 \pm 0.00007.$$

Table 2: Systematic uncertainties on the observables. PID refers to the fixed efficiency of the $\mathrm{DLL}_{K\pi}$ cut on the bachelor track. PDFs refers to the variations of the fixed shapes in the fit. "Sim" refers to the use of simulation to estimate relative efficiencies of the signal modes which includes the branching fraction estimates of the Λ^0_b background. $A_{\text{instr.}}$ quantifies the uncertainty on the production, interaction and detection asymmetries.

$\times 10^{-3}$	PID	PDFs	Sim	$A_{\text{instr.}}$	Total
$R^{K\pi}_{K/\pi}$	1.4	0.9	0.8	0	1.8
$R^{KK}_{K/\pi}$	1.3	0.8	0.9	0	1.8
$R^{\pi\pi}_{K/\pi}$	1.3	0.6	0.8	0	1.7
$A^{K\pi}_{\pi}$	0	1.0	0	9.4	9.5
$A^{K\pi}_{K}$	0.2	4.1	0	16.9	17.4
A^{KK}_{K}	1.6	1.3	0.5	9.5	9.7
$A^{\pi\pi}_{K}$	1.9	2.3	0	9.0	9.5
A^{KK}_{π}	0.1	6.6	0	9.5	11.6
$A^{\pi\pi}_{\pi}$	0.1	0.4	0	9.9	9.9
R^{-}_{K}	0.2	0.4	0	0.1	0.4
R^{+}_{K}	0.4	0.5	0	0.1	0.7
R^{-}_{π}	0.01	0.03	0	0.07	0.08
R^{+}_{π}	0.01	0.03	0	0.07	0.07

LHCb-PAPER-2012-001

GLW/ADS 4h full results

Table 2: Systematic uncertainties on the observables. PID refers to the fixed efficiency for the bachelor $\mathrm{DLL}_{K\pi}$ requirement which is determined using the $D^{*\pm}$ calibration sample. PDFs refers to the variations of the fixed shapes in the fit. Sim refers to the use of simulation to estimate relative efficiencies of the signal modes. $A_{\mathrm{instr.}}$ quantifies the uncertainty on the production, interaction and detection asymmetries.

$\times 10^{-3}$	PID	PDFs	Sim	$A_{\mathrm{instr.}}$	Total
$R^{K3\pi}_{K/\pi}$	1.7	1.2	1.5	0.0	2.6
$A^{K3\pi}_{\pi}$	0.2	1.3	0.1	9.9	10.0
$A^{K3\pi}_{K}$	0.6	4.4	0.3	17.1	17.7
$R^{K3\pi,-}_{K}$	0.4	0.7	0.1	0.1	0.8
$R^{K3\pi,+}_{K}$	0.4	0.9	0.2	0.1	1.0
$R^{K3\pi,-}_{\pi}$	0.02	0.09	0.01	0.06	0.11
$R^{K3\pi,+}_{\pi}$	0.04	0.08	0.02	0.06	0.11

$$
\begin{aligned}
R^{K3\pi}_{K/\pi} &= 0.0771 \pm 0.0017 \pm 0.0026 \\
A^{K3\pi}_{K} &= -0.029 \pm 0.020 \pm 0.018 \\
A^{K3\pi}_{\pi} &= -0.006 \pm 0.005 \pm 0.010 \\
R^{K3\pi,-}_{K} &= 0.0072 \,{}^{+0.0036}_{-0.0032} \pm 0.0008 \\
R^{K3\pi,+}_{K} &= 0.0175 \,{}^{+0.0043}_{-0.0039} \pm 0.0010 \\
R^{K3\pi,-}_{\pi} &= 0.00417 \,{}^{+0.00054}_{-0.00050} \pm 0.00011 \\
R^{K3\pi,+}_{\pi} &= 0.00321 \,{}^{+0.00048}_{-0.00045} \pm 0.00011
\end{aligned}
$$

LHCb-CONF-2012-030

GGSZ full results

Table 3: Results for $x_\pm$ and $y_\pm$ from the fits to the data in the case when both $D \to K_S^0\pi^+\pi^-$ and $D \to K_S^0K^+K^-$ are considered and when only the $D \to K_S^0\pi^+\pi^-$ final state is included. The first, second, and third uncertainties are the statistical, the experimental systematic, and the error associated with the precision of the strong-phase parameters, respectively. The correlation coefficients are calculated including all sources of uncertainty (the values in parentheses correspond to the case where only the statistical uncertainties are considered).

Parameter	All data	$D \to K_S^0\pi^+\pi^-$ alone
x_- $[\times 10^{-2}]$	$0.0 \pm 4.3 \pm 1.5 \pm 0.6$	$1.6 \pm 4.8 \pm 1.4 \pm 0.8$
y_- $[\times 10^{-2}]$	$2.7 \pm 5.2 \pm 0.8 \pm 2.3$	$1.4 \pm 5.4 \pm 0.8 \pm 2.4$
corr(x_-,y_-)	-0.10 (-0.11)	-0.12 (-0.12)
x_+ $[\times 10^{-2}]$	$-10.3 \pm 4.5 \pm 1.8 \pm 1.4$	$-8.6 \pm 5.4 \pm 1.7 \pm 1.6$
y_+ $[\times 10^{-2}]$	$-0.9 \pm 3.7 \pm 0.8 \pm 3.0$	$-0.3 \pm 3.7 \pm 0.9 \pm 2.7$
corr(x_+,y_+)	0.22 (0.17)	0.20 (0.17)

LHCb-PAPER-2012-027