Physics with B to Open Charm Decays

Charlotte Wallace
on behalf of the LHCb collaboration

Phenomenology 2014 Symposium
5-7 May 2014, University of Pittsburgh

European Research Council
Established by the European Commission

THE UNIVERSITY OF WARWICK

Introduction

- B to open charm decays can be used for a variety of measurements, some recent ones are presented here...
  - $\Lambda_b \to Dph$, $\Lambda_b \to \Lambda_c D_{(s)}$ etc in J. McCarthy's talk
  - $B_s \to D_s D_{(s)}$ effective lifetime in A. Pritchard's talk
- The main area is measurements of the CKM angle γ
- I will discuss a selection of methods, focusing on more recent results
  - $B^{\pm} \to DK^{\pm}$ decay with GLW / ADS and GGSZ methods
  - Combination of $1fb^{-1}$ results from these analyses
  - Updated combination to include GGSZ results with an extra $2fb^{-1}$
  - Recent results using $D \to K_S K^{\pm}\pi^{\mp}$
  - Potential of $B_s \to \overline{D}^0\varphi$ for determining γ

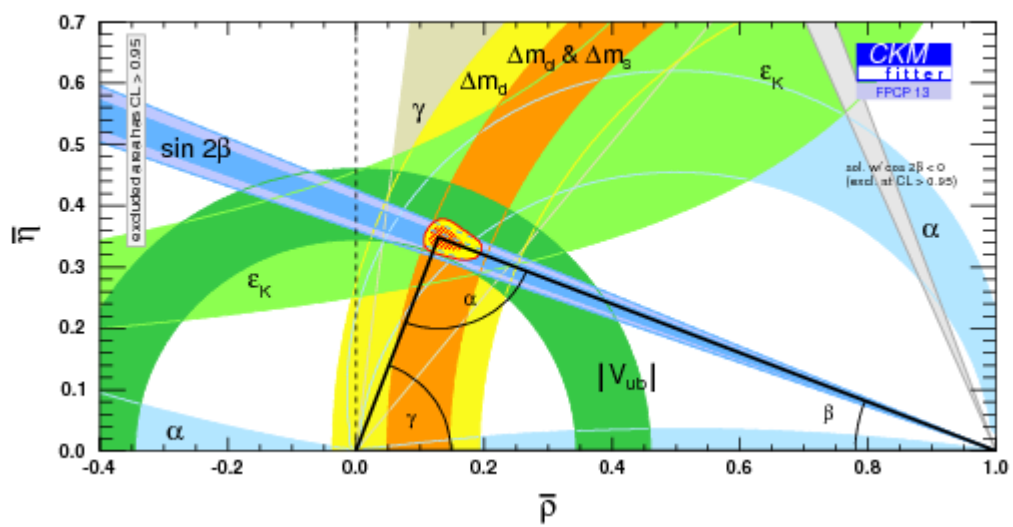
CKM angle γ

- γ is the least well-known angle of the unitarity triangle

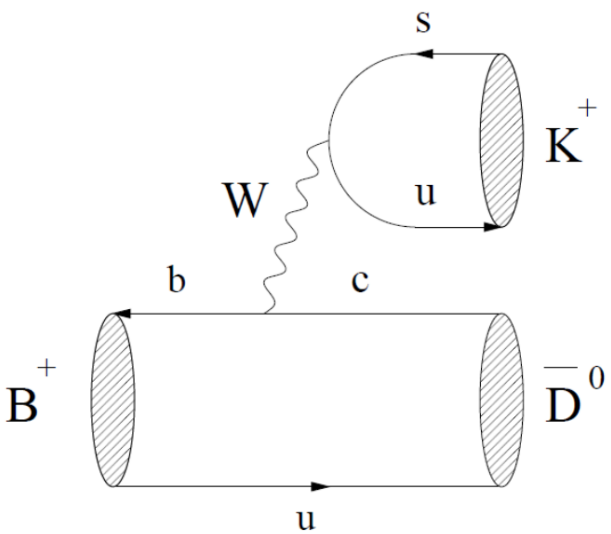
$$\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

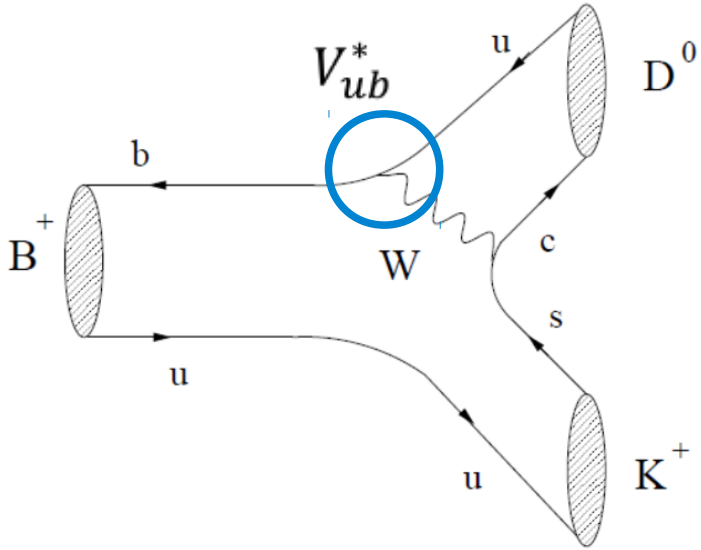
  - Precision measurement of γ is one of the main goals of LHCb
  - CKMFitter, FPCP 2013 **$(68.0^{+8.0}_{-8.5})°$** UTfit, Post-EPS 2013 **(70.1 ± 7.1)°**

- Measurable with tree and loop processes
  - Tree diagrams are theoretically very clean ($\delta\gamma/\gamma \sim O(10^{-7})$)
  - New Physics may enter in loops



$B^{\pm} \to DK^{\pm}$





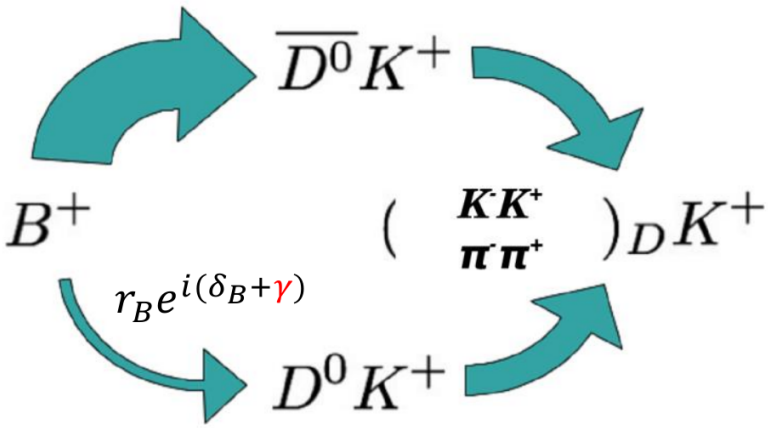
$$\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

- The most sensitive channel to measure γ at LHCb
- Measure the same final state for D^0 and $\overline{D}^0$ to exploit interference
  - Different methods use different D final states
- Can also use B → Dπ but sensitivity is reduced as interference is smaller

B → DK ... 3 methods

GLW

Gronau, London, Wyler
Phys. Lett. **B 253** (1991) 483
Phys. Lett. **B 265** (1991) 172

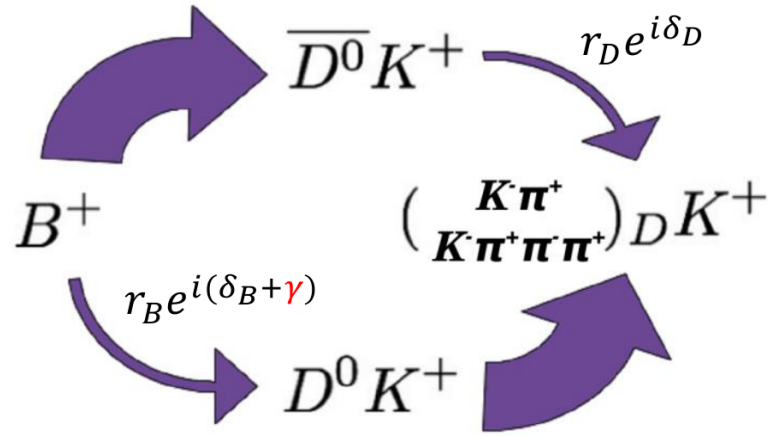


Final states are CP eigenstates, e.g. D→KK, D→ππ
(δ_D = 0 and r_D = 1)

Interference = O(10%)

ADS

Atwood, Dunietz, Soni
Phys. Rev. Lett. **78** (1997) 3257
Phys. Rev. **D 63** (2001) 036005



Final states are quasi-flavour-specific, e.g. D→Kπ, D→Kπππ
($\delta_D \neq 0$ and $r_D \neq 1$)

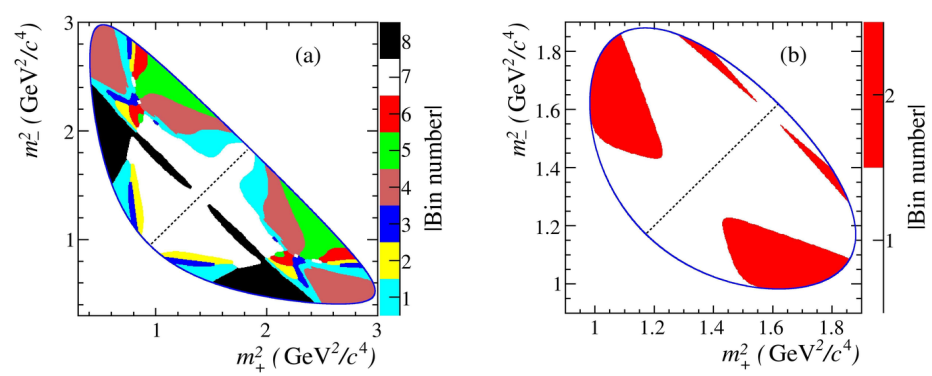
2 routes have comparable amplitudes, so interference is large

GGSZ

Giri, Grossman, Soffer, Zupan
Phys. Rev. **D 68** (2003) 054018

Use 3-body self-conjugate modes, e.g. $D \to K_S KK$, $D \to K_S \pi\pi$

Fit to event distributions in the $D \to K_S hh$ Dalitz plot
Bin Dalitz plot in regions of similar δ_D



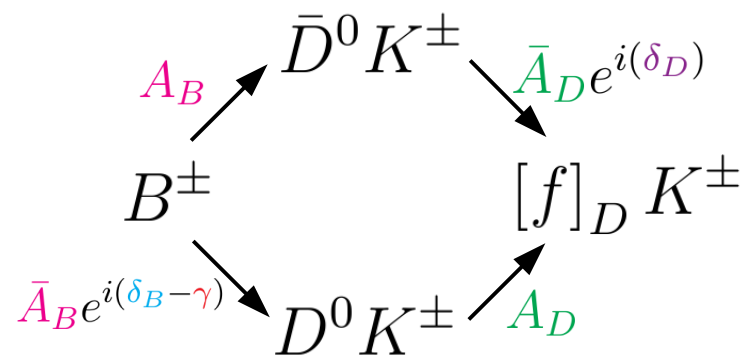
γ observables

- Measure many γ-related observables that give different but complementary information about γ
  - Observables are yield ratios (R) and charge asymmetries (A), so many systematics cancel
  - 24 different observables included in combination

- GLW:

$$R_{CP+} = 1 + r_B^2 + 2r_B \cos\delta_B \cos\gamma$$

$$A_{CP+} = \frac{2r_B \sin\delta_B \sin\gamma}{R_{CP+}}$$



- ADS:

$$R_{ADS}^{K\pi} = r_D^2 + r_B^2 + 2r_B r_D \cos(\delta_B + \delta_D)\cos\gamma$$

$$A_{ADS}^{K\pi} = \frac{2r_B r_D \sin(\delta_B + \delta_D)\sin\gamma}{R_{ADS}^{K\pi}}$$

- For the 4-body case, use $\delta_D^{K3\pi}$ and coherence factor $\kappa_D^{K3\pi}$

- GGSZ:

$$x_\pm = r_B \cos(\delta_B \pm \gamma)$$

$$y_\pm = r_B \sin(\delta_B \pm \gamma)$$

$r_B = A_B/\bar{A}_B$

$r_D = A_D/\bar{A}_D$

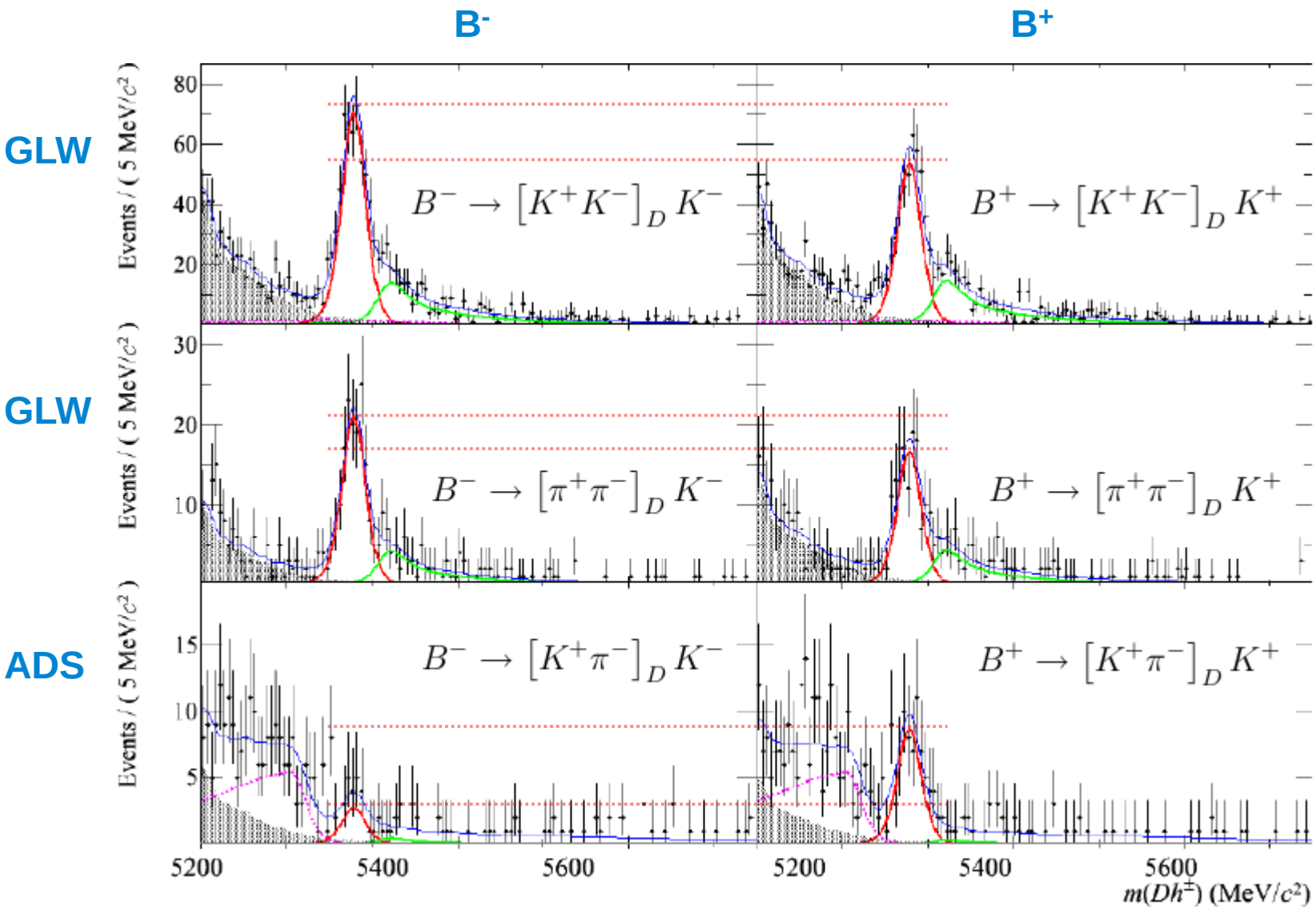
$\delta_{D(B)}$ = Strong phase difference between B(D) decays

γ = Weak phase difference

2-body GLW/ADS analysis (1 fb^{-1})

(Phys. Lett. **B 712** (2012) 203)

- Visible CP violation in B → DK, so γ ≠ 0



1 fb^{-1} γ combination

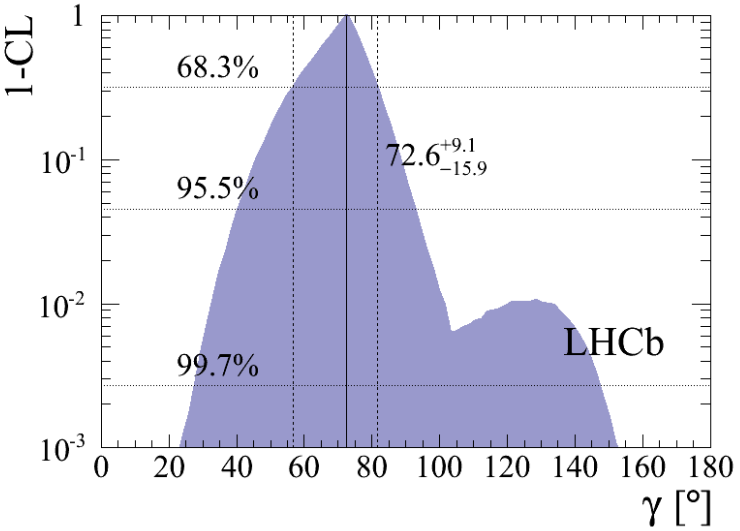
(Phys. Lett. **B 726** (2013) 151)

- LHCb's published γ combination includes:
  - 2-body GLW/ADS ($D \to KK$, $\pi\pi$ or $K\pi$) (Phys. Lett. **B 712** (2012) 203)
  - 4-body ADS ($D \to K\pi\pi\pi$) (Phys. Lett. **B 723** (2013) 44)
  - GGSZ ($D \to K_S KK$, $K_S\pi\pi$) (Phys. Lett. **B 718** (2012) 43)
  - Strong phase information from CLEO data (Phys. Rev. **D 80** (2009) 031105, Phys. Rev. **D 80** (2009) 032002)

- Observables combined using a Frequentist procedure
  - First combination to include $B \to D\pi$
  - Assume mostly Gaussian observables and Gaussian systematic uncertainties
  - D^0 mixing and CP violation in charm decays are taken into account

$(72.6^{+9.1}_{-15.9})°$

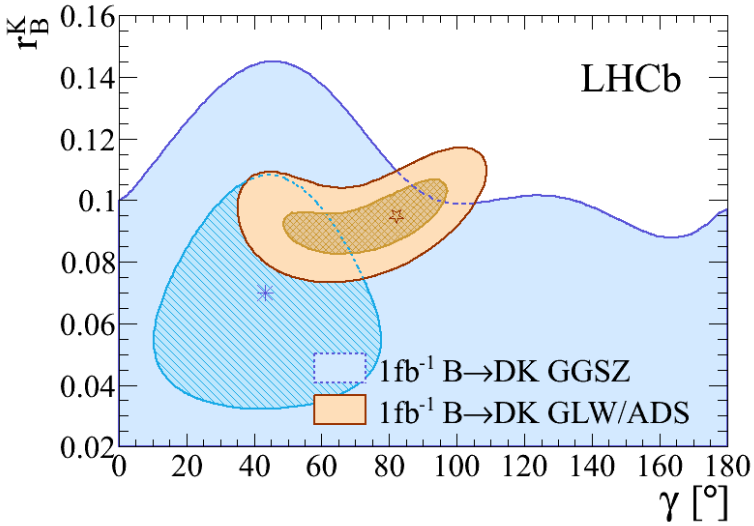
at 68% CL

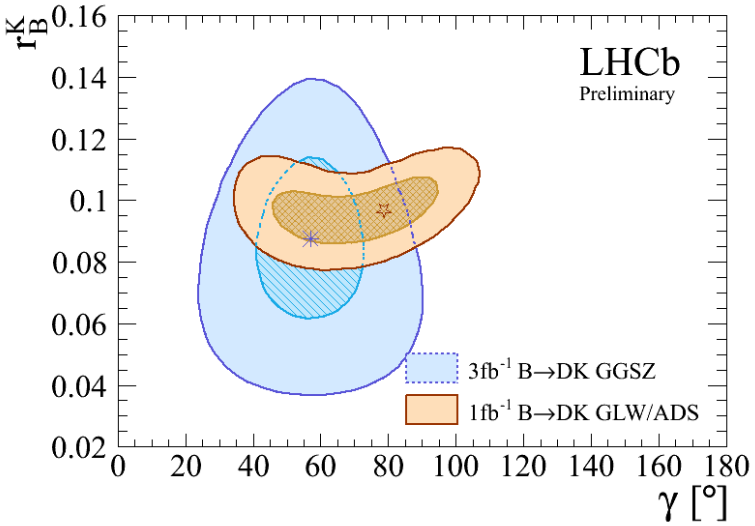


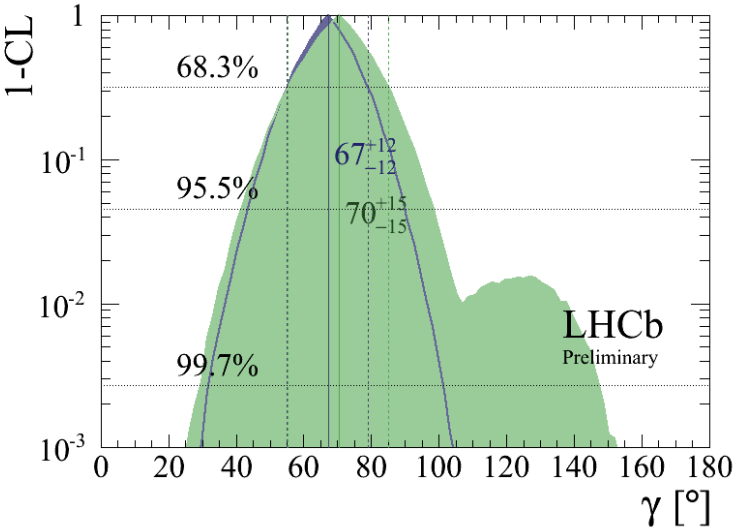
Preliminary 3 fb^{-1} γ combination

(LHCb-CONF-2013-006)

- Updated to include 2012 GGSZ result (LHCb-CONF-2013-004)

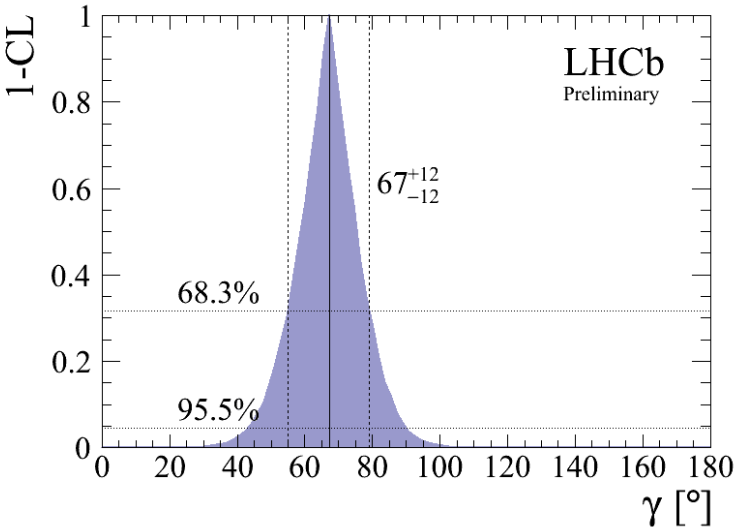






1 fb^{-1} only and updated confidence intervals (B → DK only)

(67 ± 12)° at 68% CL

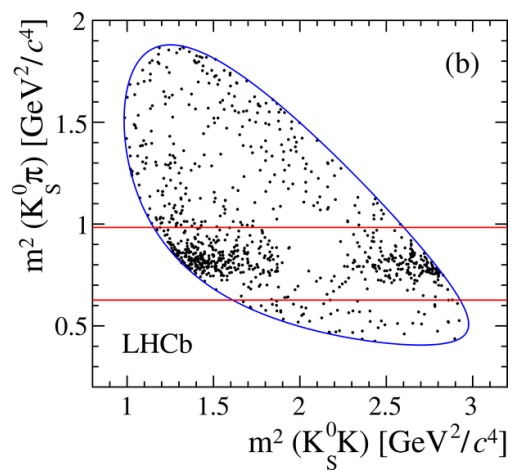


$D \to K_S K\pi$

(Phys. Lett. **B 733C** (2014) 36)

- Study of additional final states can further constrain γ
  - ADS-like analysis, studying different Dalitz plot regions separately
  - Uses 3 fb^{-1} data sample and a BDT constructed for GGSZ analysis

- Analysis of the 3-body final state requires knowledge of strong phase variation across Dalitz plot
  - $\delta_{K_S K\pi}$ (average strong phase difference) and $\kappa_{K_S K\pi}$ (coherence factor) information taken from CLEO data (Phys. Rev. **D 85** (2012) 092016)
  - $\delta_{K_S K\pi}$ and $\kappa_{K_S K\pi}$ measured over whole Dalitz plot and in region around K*(892) resonance
  - $\kappa_{K_S K\pi}$ larger around K*(892) so higher sensitivity in this region



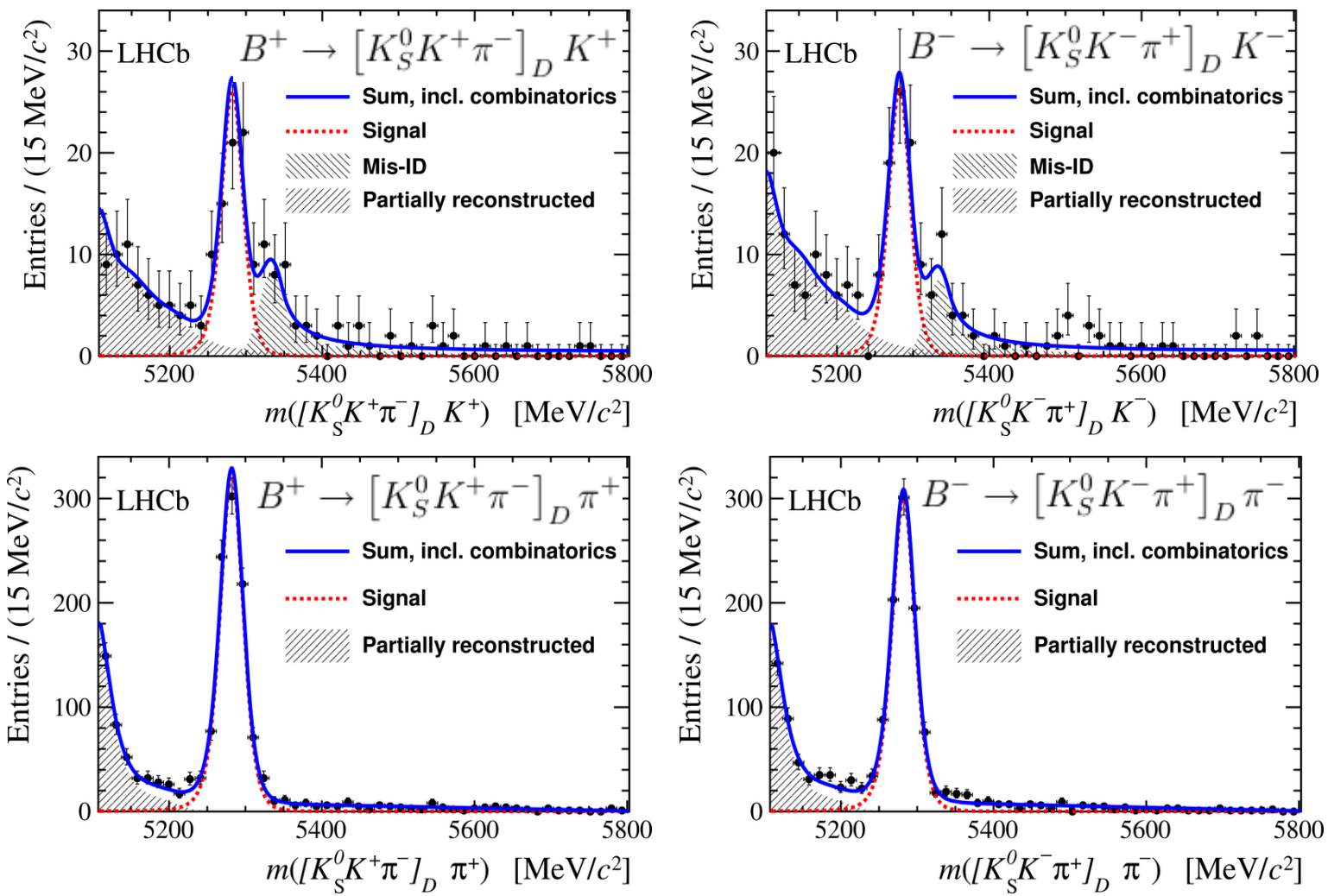
- 8 mass fits, data separated by $K^{+/-}$ and $B^{+/-}$
  - $K_S K^{\pm}\pi^{\mp}$ is same sign (SS) and $K_S K^{\mp}\pi^{\pm}$ is opposite sign (OS)

$D \to K_S K\pi$

(Phys. Lett. **B 733C** (2014) 36)

- Mass fits for SS modes (candidates from whole Dalitz plot)
  - No significant direct CP violation observed

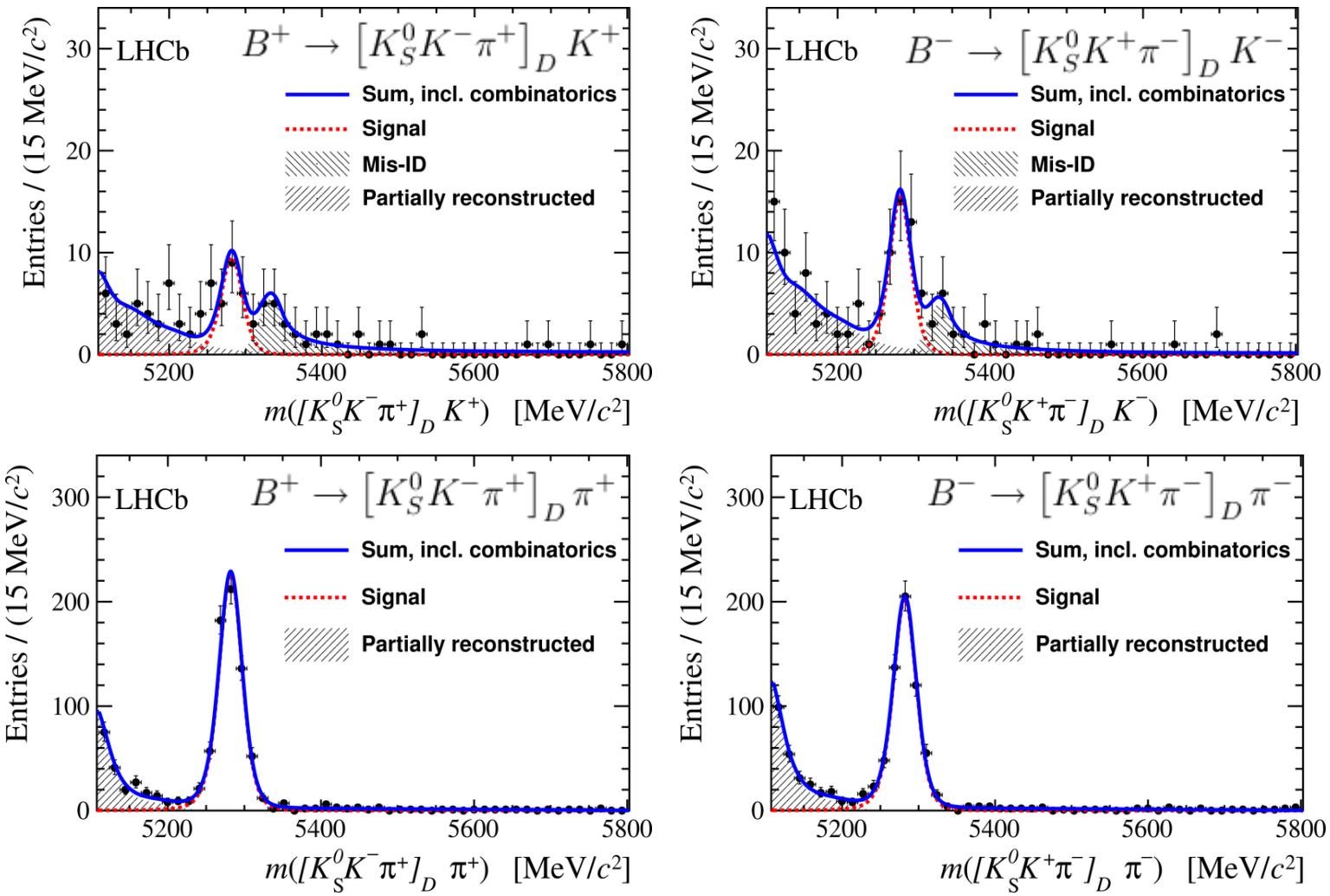
B+ **B-**



$D \to K_S K\pi$

(Phys. Lett. **B 733C** (2014) 36)

- Mass fits for OS modes (candidates from whole Dalitz plot)
  - No significant direct CP violation observed



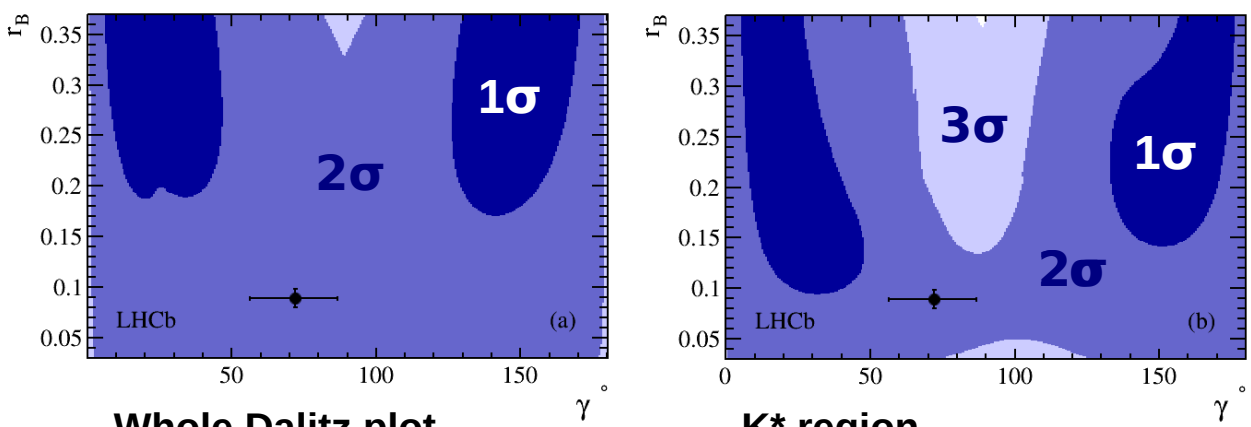
$D \to K_S K\pi$

(Phys. Lett. **B 733C** (2014) 36)

- 8 yields measured for $B^\pm \to Dh^\pm$ form 7 observables:
  - Ratio of SS/OS yields for $B \to D\pi$
  - Ratios of DK/Dπ yields for SS and OS
  - 4 charge asymmetries

Observable	Whole Dalitz plot	$K^*(892)^\pm$ region
$\mathcal{R}_{SS/OS}$	$1.528 \pm 0.058 \pm 0.025$	$2.57 \pm 0.13 \pm 0.06$
$\mathcal{R}_{DK/D\pi,\,SS}$	$0.092 \pm 0.009 \pm 0.004$	$0.084 \pm 0.011 \pm 0.003$
$\mathcal{R}_{DK/D\pi,\,OS}$	$0.066 \pm 0.009 \pm 0.002$	$0.056 \pm 0.013 \pm 0.002$
$\mathcal{A}_{SS,\,DK}$	$0.040 \pm 0.091 \pm 0.018$	$0.026 \pm 0.109 \pm 0.029$
$\mathcal{A}_{OS,\,DK}$	$0.233 \pm 0.129 \pm 0.024$	$0.336 \pm 0.208 \pm 0.026$
$\mathcal{A}_{SS,\,D\pi}$	$-0.025 \pm 0.024 \pm 0.010$	$-0.012 \pm 0.028 \pm 0.010$
$\mathcal{A}_{OS,\,D\pi}$	$-0.052 \pm 0.029 \pm 0.017$	$-0.054 \pm 0.043 \pm 0.017$

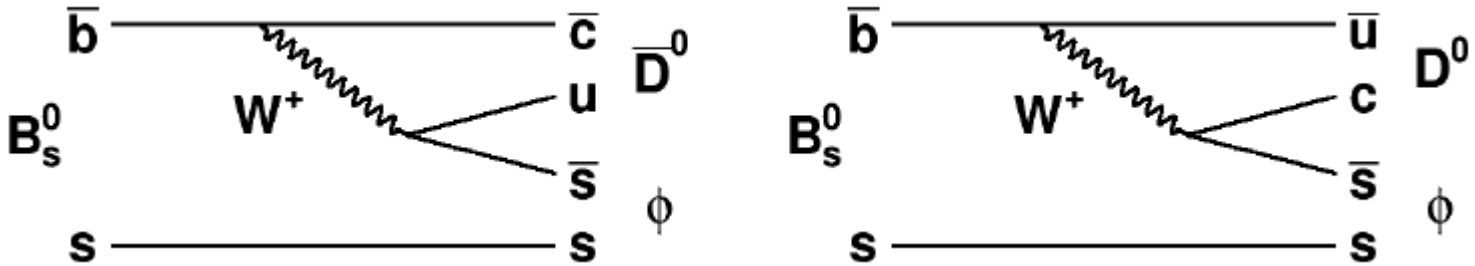
- Higher $\kappa_{K_S K\pi}$ around K*(892) improves γ sensitivity
- Good future prospects with more data



Whole Dalitz plot **K* region**

γ from neutral B modes

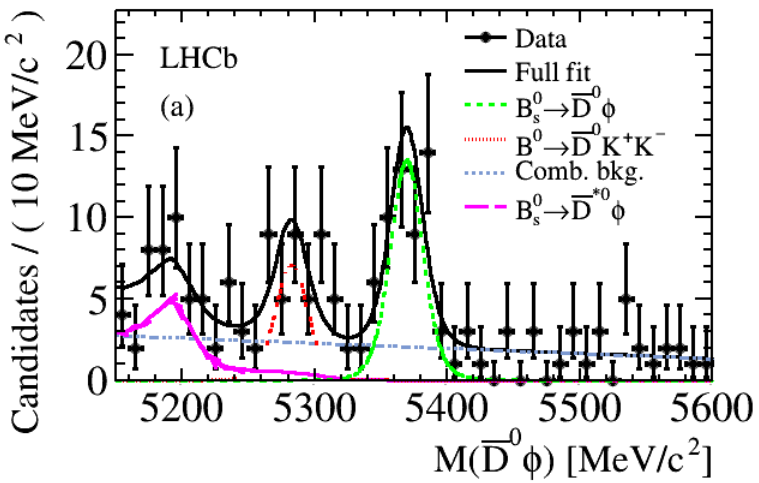
- Aim to use as many channels as possible to measure γ
- Neutral B mesons usually need time-dependent analyses
  - Except for self-tagging modes e.g. $B^0 \to DK^{*0}$ (JHEP 03 (2013) 067)
  - Flavour tagging is not required for $B_s \to \overline{D}^0\varphi$ (LHCb-PUB-2010-005)
- Measurements of $B_s \to \overline{D}^0\varphi$ can give information about CKM angles γ and β_s
  - Time-integrated decay rates used in the same way as for $B \to DK$
  - No loop corrections, so no theoretical uncertainties
  - Just need to measure enough D final states



$B_s \to \overline{D}^0\varphi$

(Phys. Lett. **B 727** (2013) 403)

- Blind analysis to search for $B_s \to \overline{D}^0\varphi$ with 1 fb^{-1} data
  - Search relative to $B_s \to \overline{D}^0\overline{K}^{*0}$
  - $\overline{D}^0 \to K^+\pi^-$ and $\varphi \to K^+K^-$ studied
  - First observation, with 6.5σ significance
  - 43 ± 8 $B_s \to \overline{D}^0\varphi$ events observed



- Branching fraction measured:

$$\mathcal{B}(B_s^0 \to \overline{D}^0\phi) = [2.3 \pm 0.4\ (\text{stat}) \pm 0.2\ (\text{syst}) \pm 0.2\ (f_s/f_d) \pm 0.3\ (\mathcal{B}(B^0 \to \overline{D}^0 K^{*0}))] \times 10^{-5}$$

- Also improved measurement of $\mathcal{B}(B_s \to \overline{D}^0\overline{K}^{*0})$

$$\mathcal{B}(B_s^0 \to \overline{D}^0 \overline{K}^{*0}) = [3.3 \pm 0.3\ (\text{stat}) \pm 0.1\ (\text{syst}) \pm 0.3\ (f_s/f_d) \pm 0.5\ (\mathcal{B}(B^0 \to \overline{D}^0 K^{*0}))] \times 10^{-4}$$

- More data will allow the study of more D final states
  - Future results from this mode can contribute to γ and β_s measurements

Summary

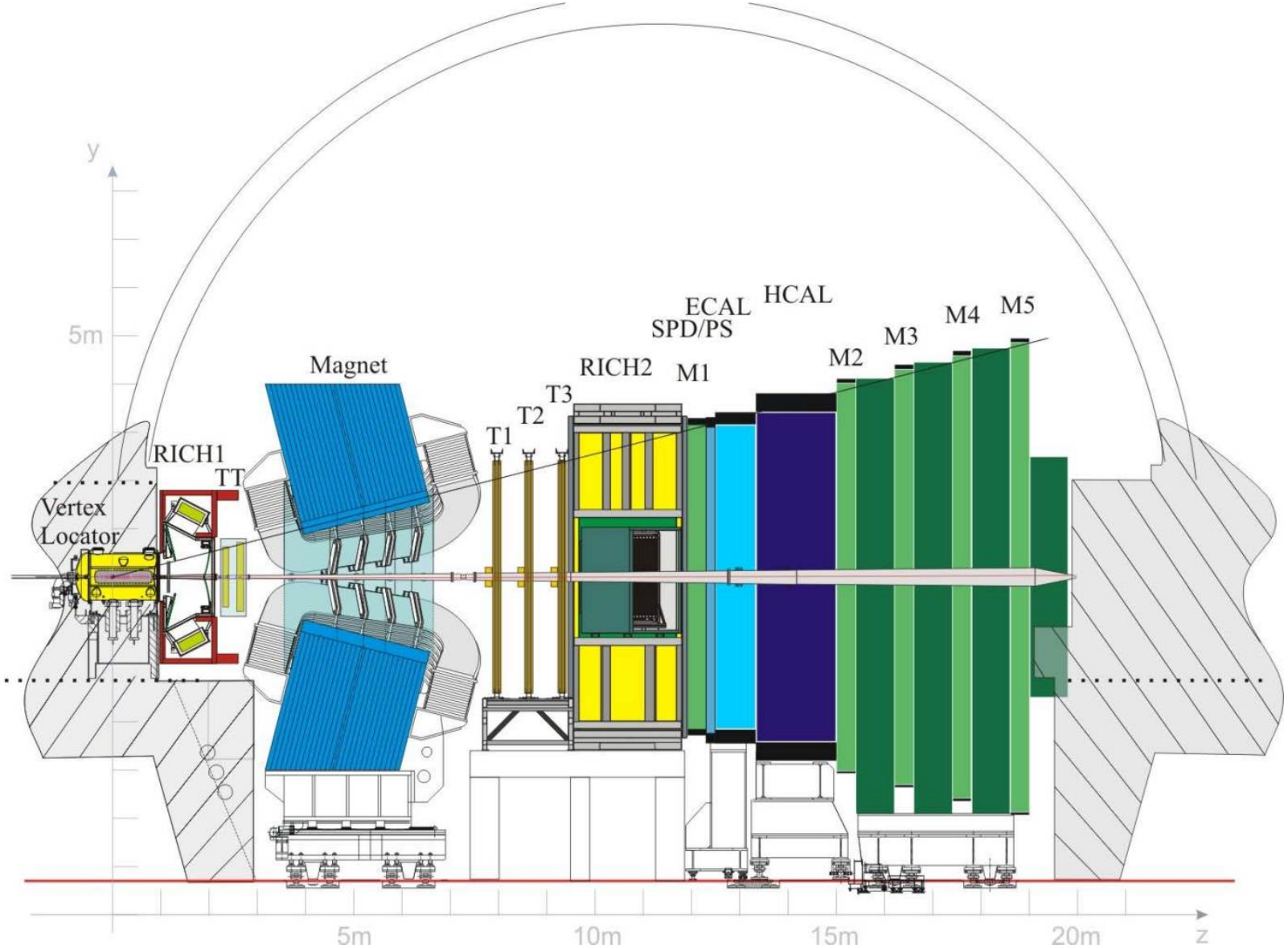
- Preliminary γ combination uses results from LHCb analyses to find **$\gamma = (67 \pm 12)°$** at 68% CL
  - Excellent agreement with B factories
  - Most precise measurement of γ from a single experiment

- This will get more precise
  - Update the GLW/ADS $B \to DK$ analyses with 2012 data
  - Include results with different final states, e.g. $B \to D(K_S K\pi)h$
  - Make measurements with new decay modes e.g. $B_s \to D^0\varphi$, as well as $B^0 \to DK^{*0}$, $B^- \to D^0K^-\pi^+\pi^-$
  - Results expected from $B_s \to D_sK$ very soon (LHCb-CONF-2012-029)

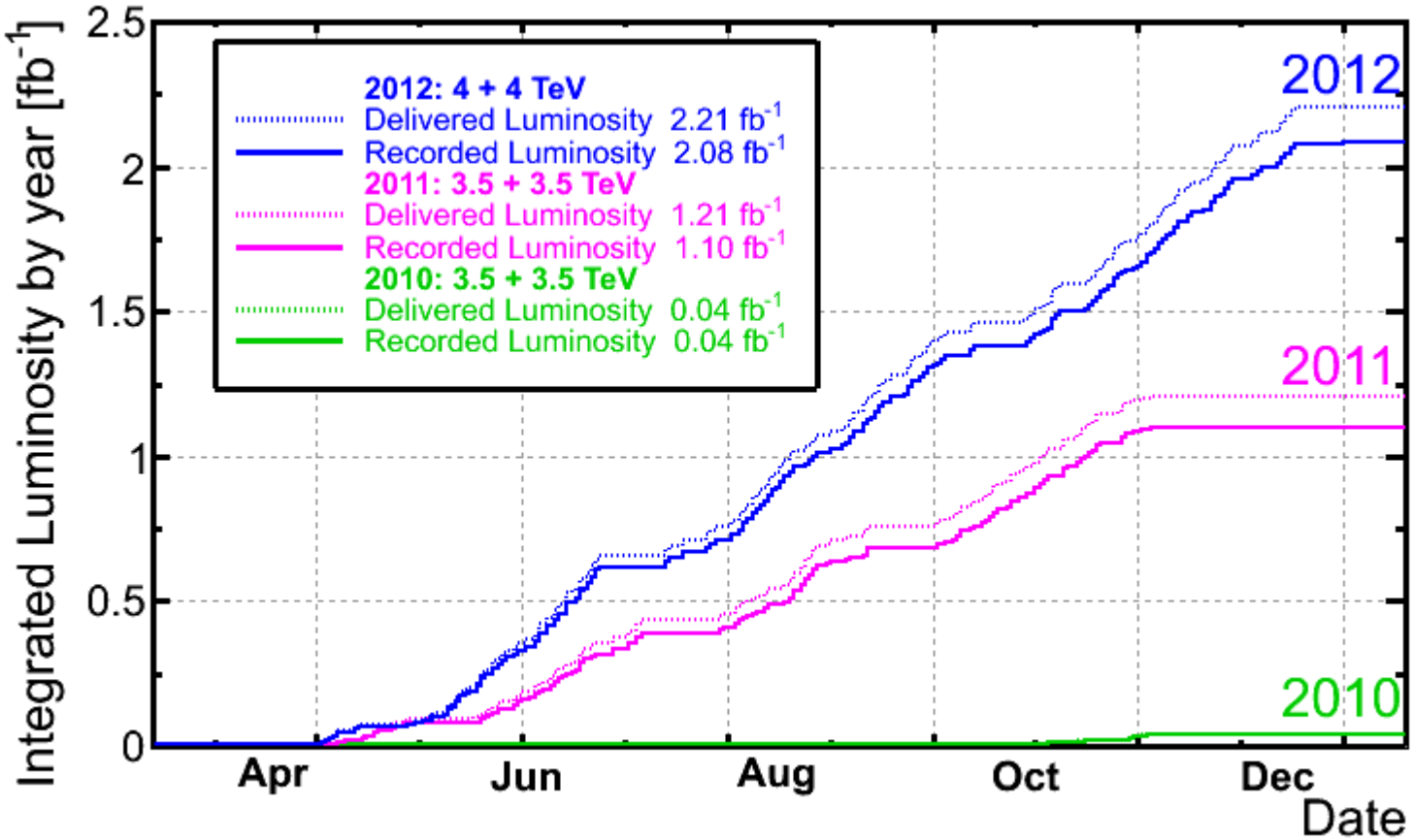
- Look out for more exciting results in this area!

Backup slides

LHCb detector

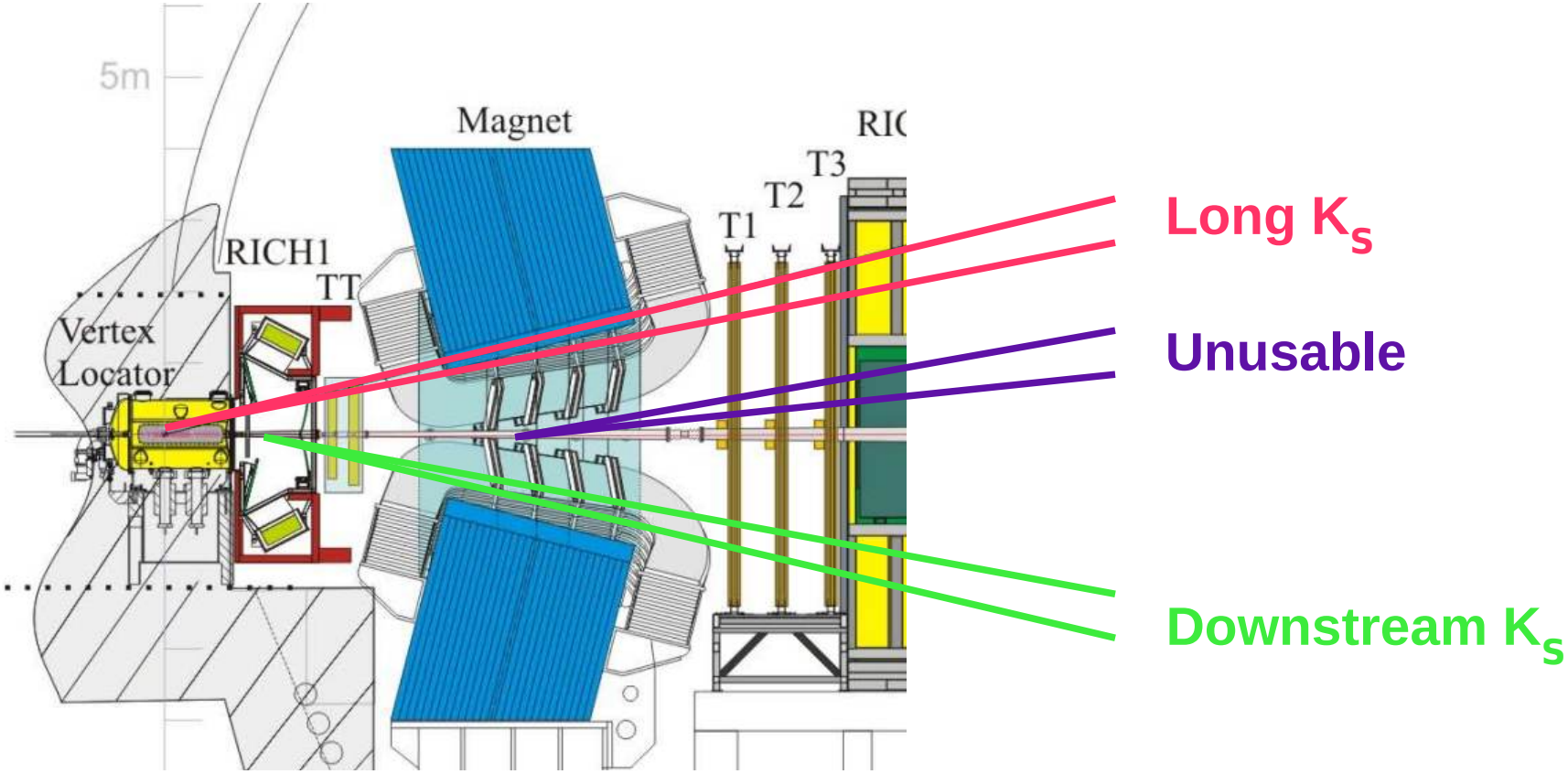


Luminosity


Integrated Luminosity by year [fb^{-1}]
2.5
2
1.5
1
0.5
0
2012: 4 + 4 TeV
Delivered Luminosity 2.21 fb^{-1}
Recorded Luminosity 2.08 fb^{-1}
2011: 3.5 + 3.5 TeV
Delivered Luminosity 1.21 fb^{-1}
Recorded Luminosity 1.10 fb^{-1}
2010: 3.5 + 3.5 TeV
Delivered Luminosity 0.04 fb^{-1}
Recorded Luminosity 0.04 fb^{-1}
2012
2011
2010
Apr
Jun
Aug
Oct
Dec
Date

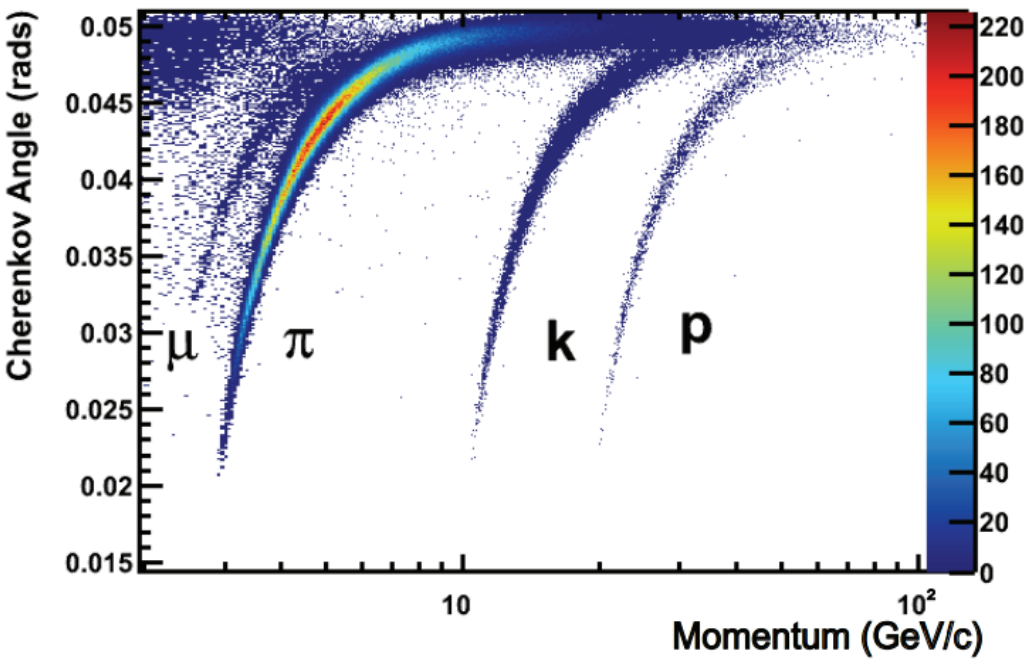
K_S reconstruction

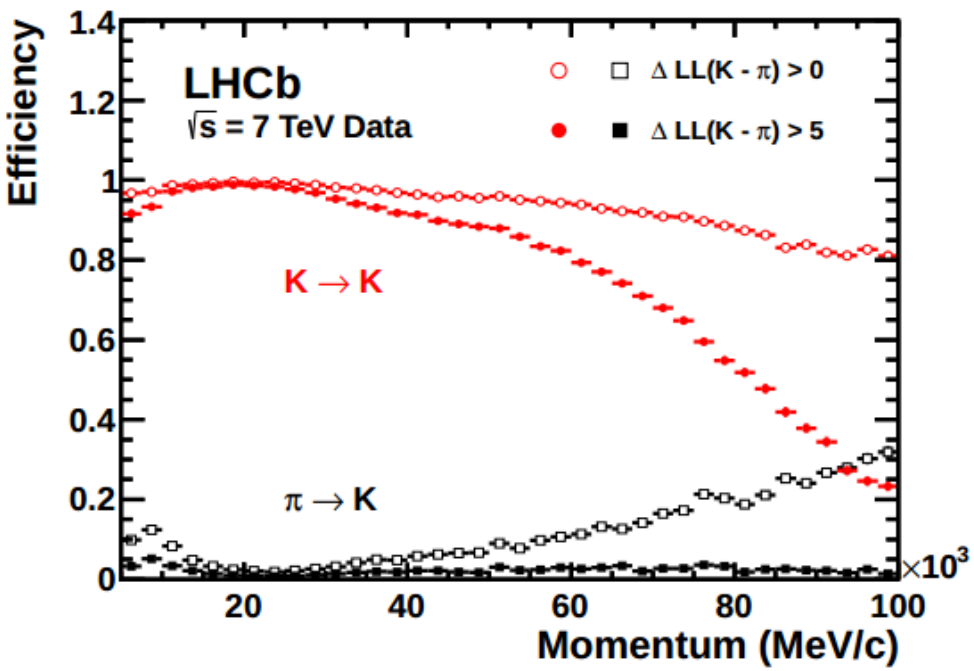
- K_S candidates separated by where they decay in detector
- ~70% of reconstructable K_S candidates decay downstream of the VELO



K/π separation

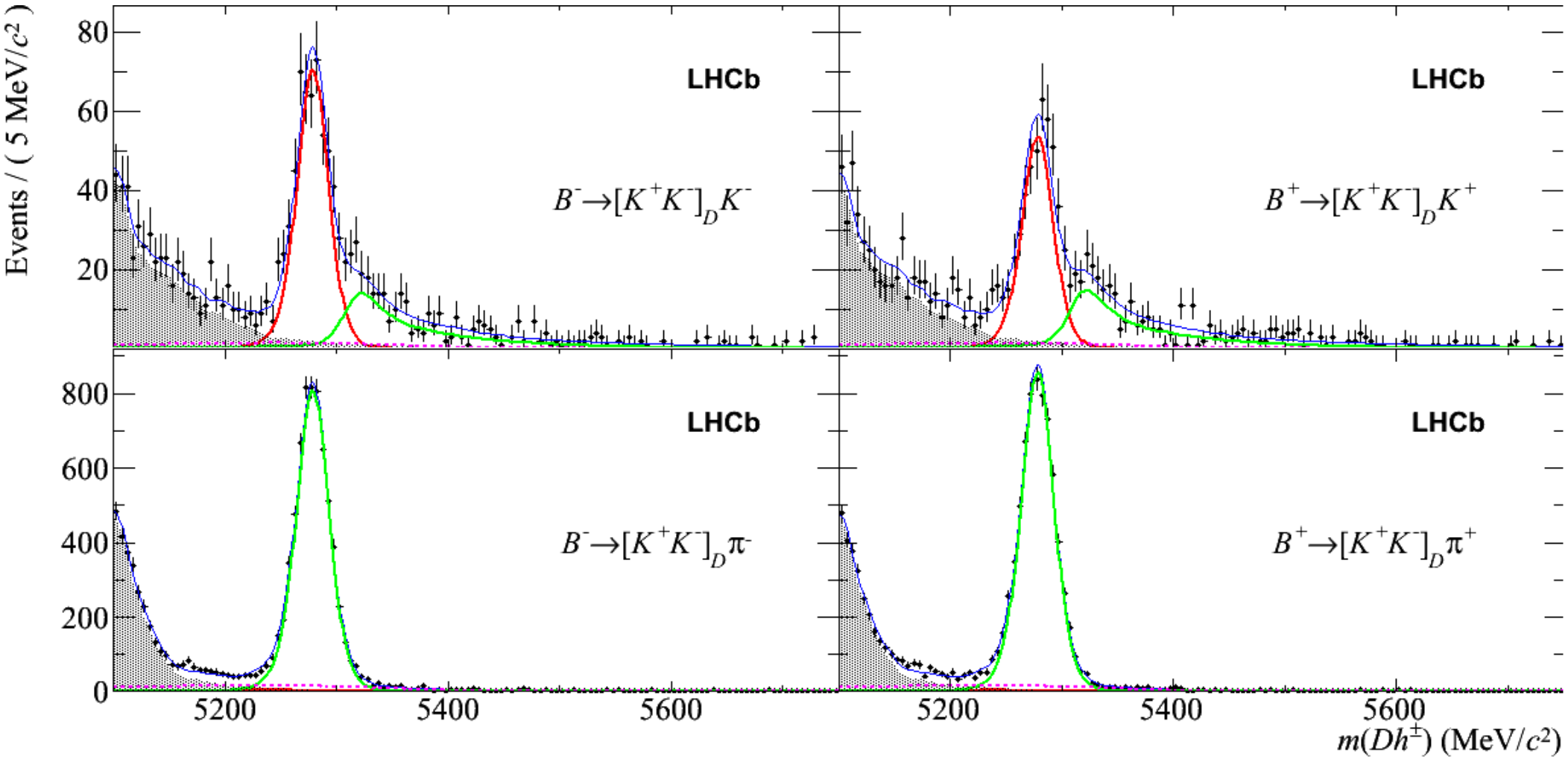
- Ring Imaging Cherenkov detectors give most information for particle identification
- Good separation over a large momentum range





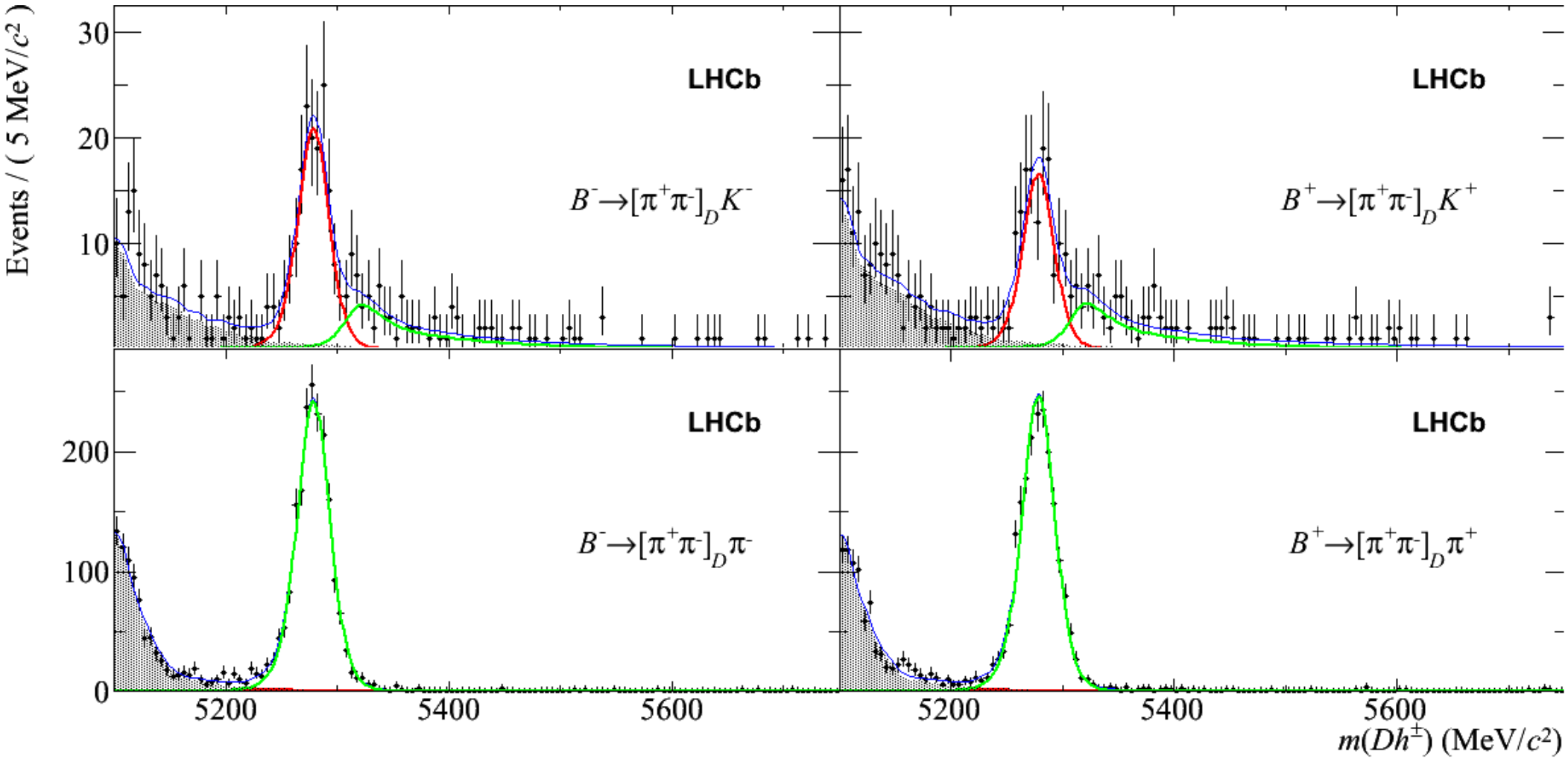
2-body GLW analysis (1 fb^{-1})

(Phys. Lett. **B 712** (2012) 203)



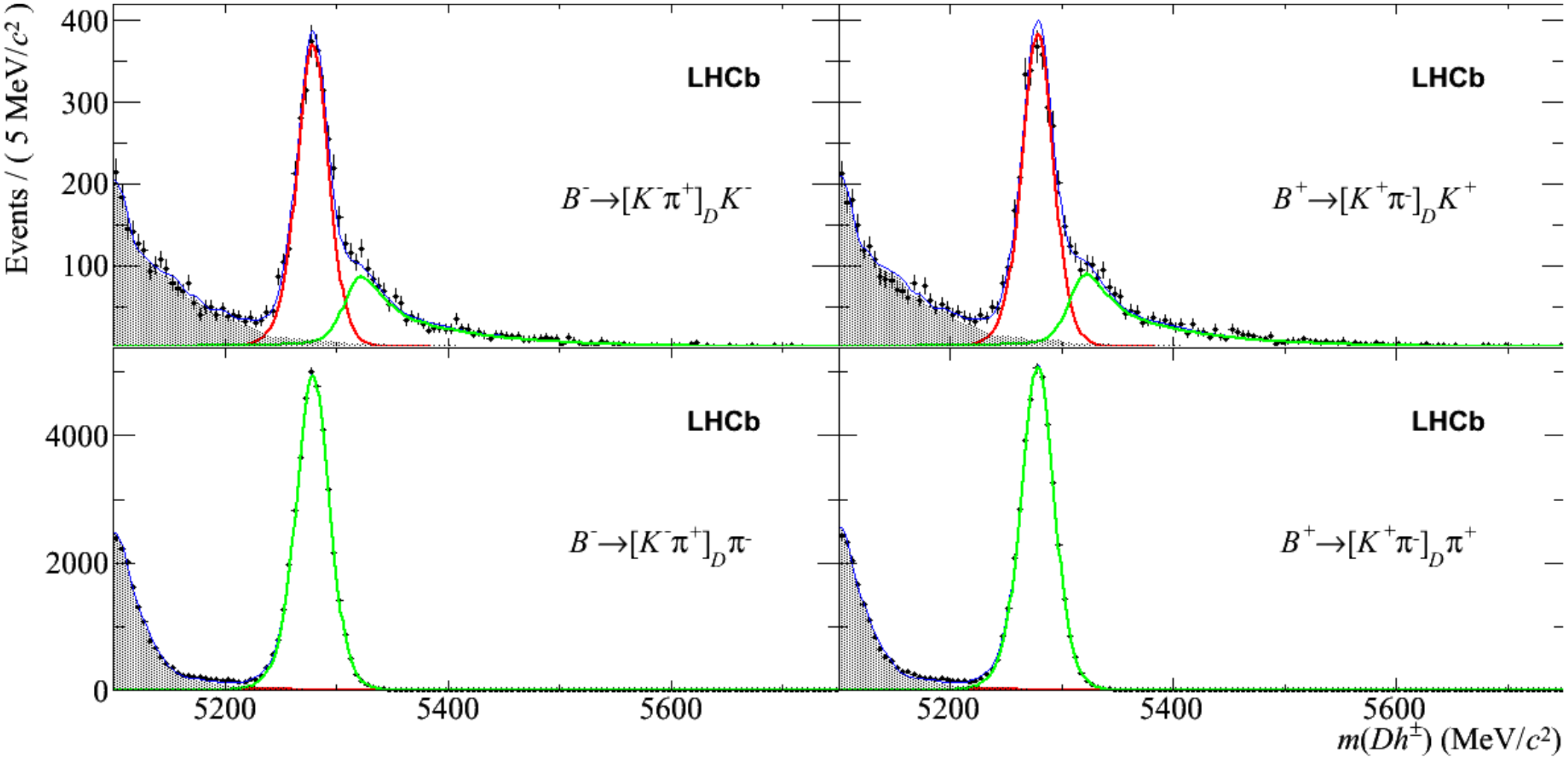
2-body GLW analysis (1 fb^{-1})

(Phys. Lett. **B 712** (2012) 203)



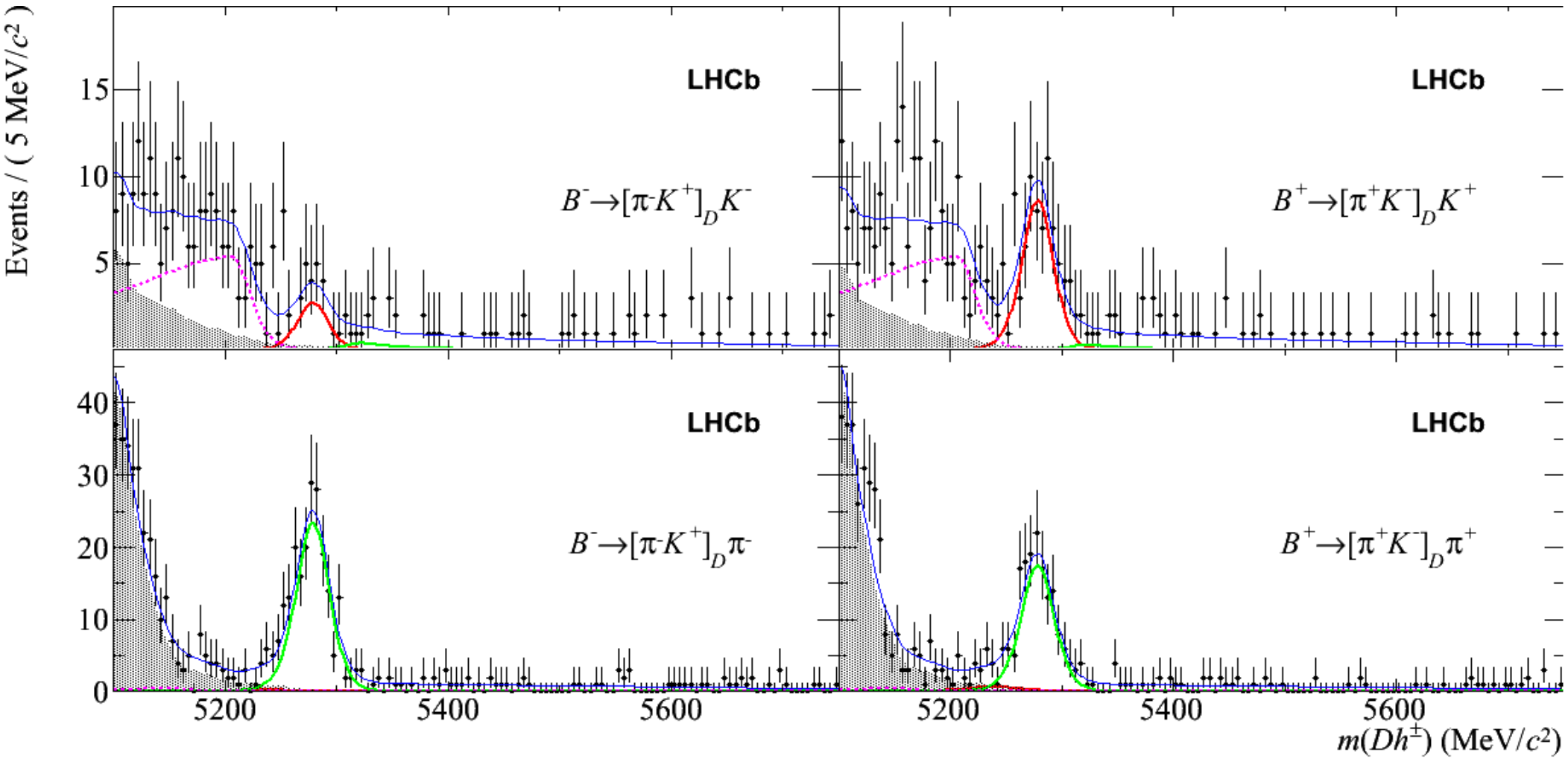
2-body ADS analysis (1 fb^{-1})

(Phys. Lett. **B 712** (2012) 203)



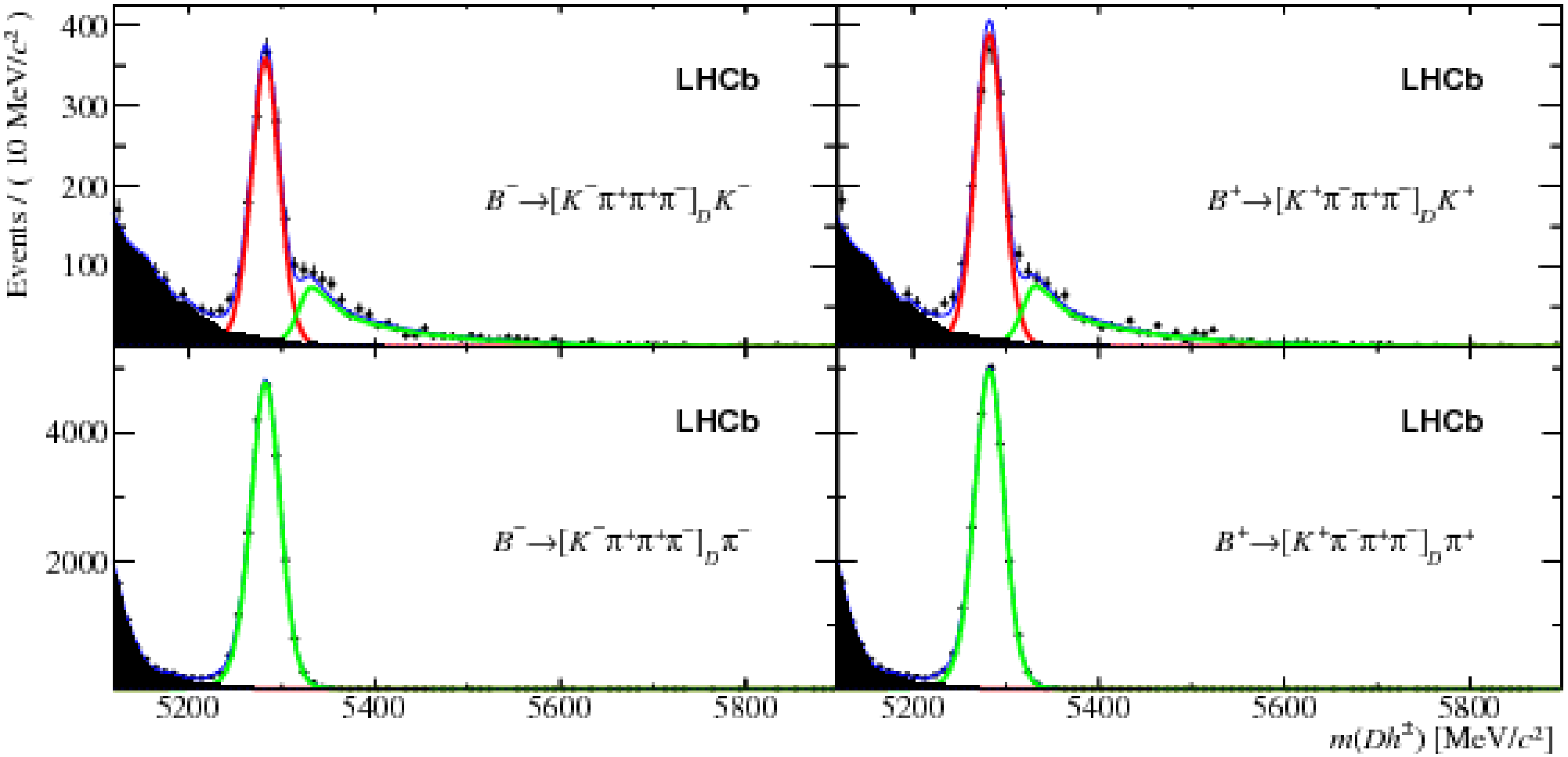
2-body ADS analysis (1 fb^{-1})

(Phys. Lett. **B 712** (2012) 203)



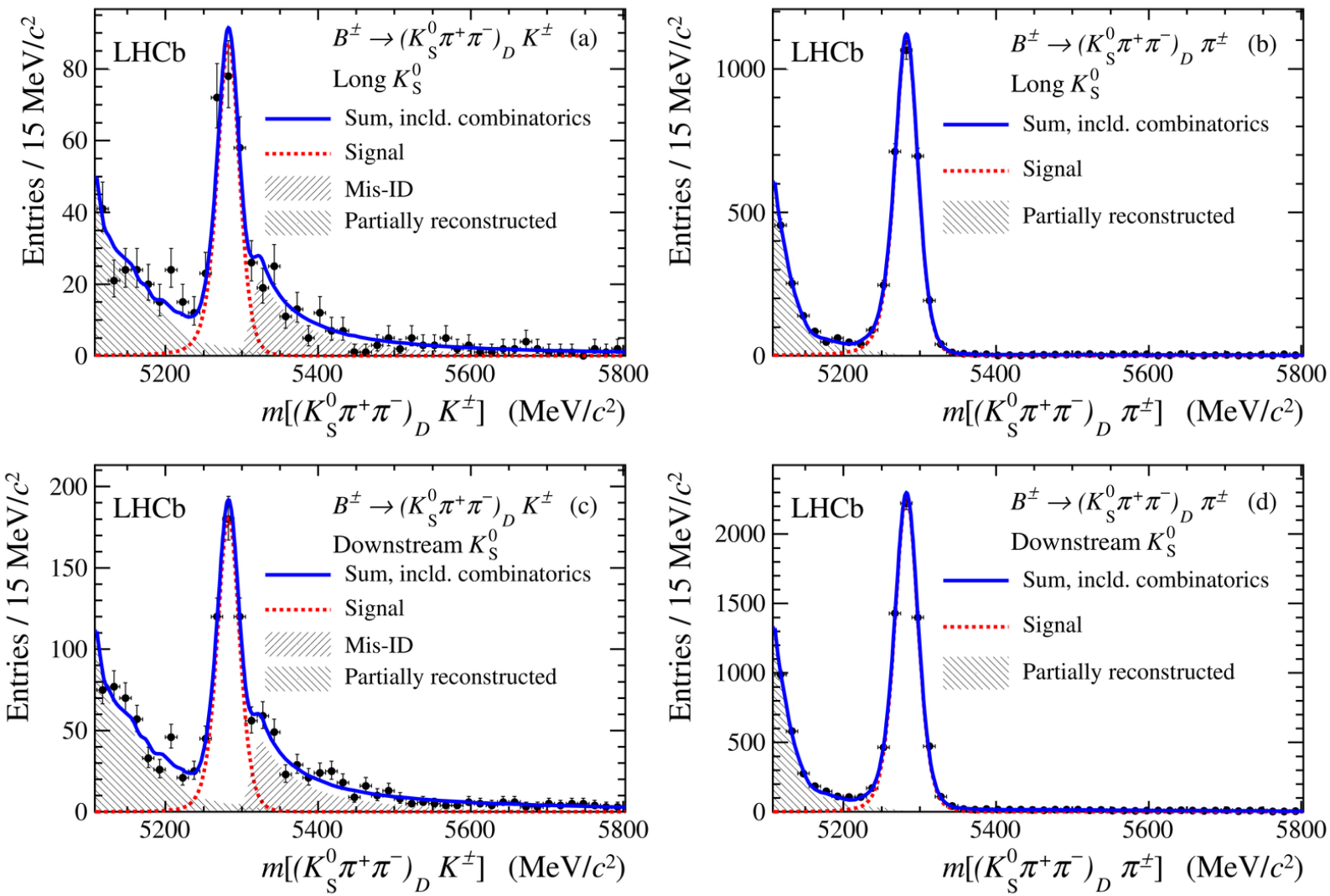
4-body ADS analysis (1 fb^{-1})

(Phys. Lett. **B 723** (2013) 44)



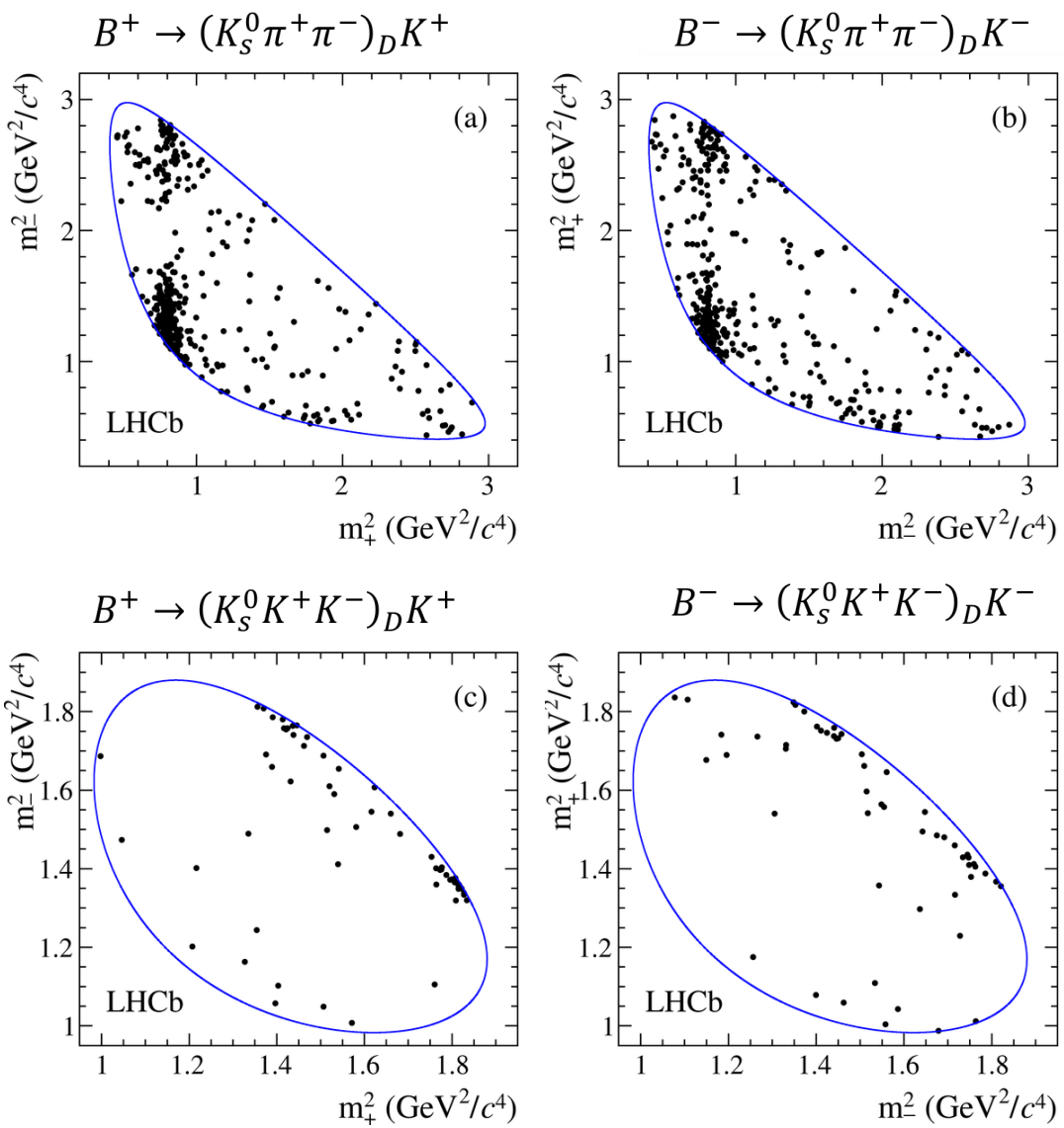
GGSZ analysis (1 fb^{-1})

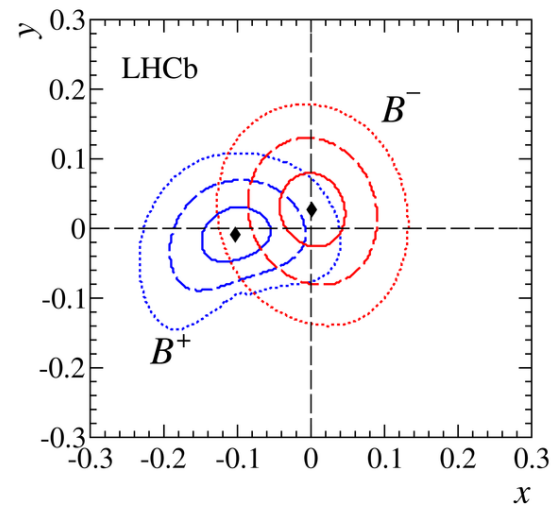
(Phys. Lett. **B 718** (2012) 43)

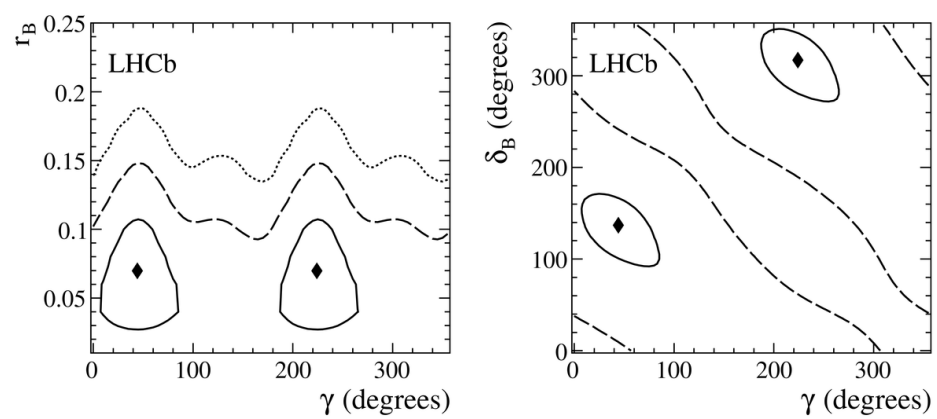


GGSZ analysis (1 fb^{-1})

(Phys. Lett. **B 718** (2012) 43)



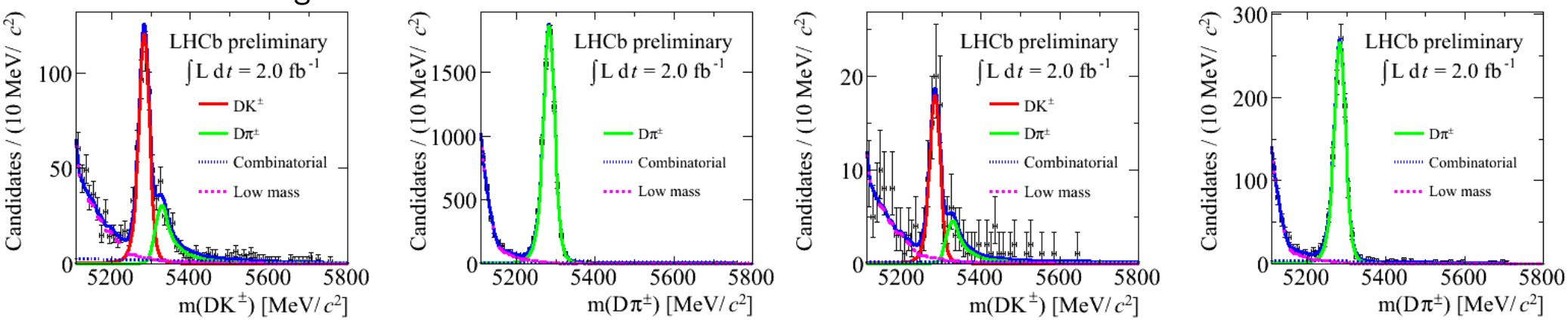




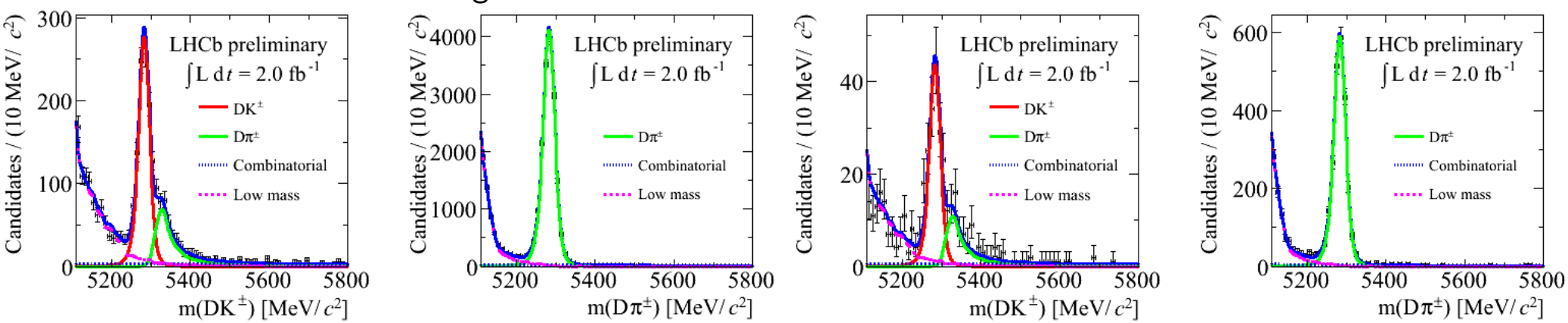
GGSZ analysis (2 fb^{-1})

(LHCb-CONF-2013-004)

- Long K_S



- Downstream K_S



$B^{\pm} \to (K_S^0\pi^+\pi^-)_D K^{\pm}$ $B^{\pm} \to (K_S^0\pi^+\pi^-)_D \pi^{\pm}$ $B^{\pm} \to (K_S^0 K^+K^-)_D K^{\pm}$ $B^{\pm} \to (K_S^0 K^+K^-)_D \pi^{\pm}$

GGSZ analysis (2 fb^{-1})

(LHCb-CONF-2013-004)