New results in B decays

THE UNIVERSITY OF WARWICK

erc European Research Council

LHCb

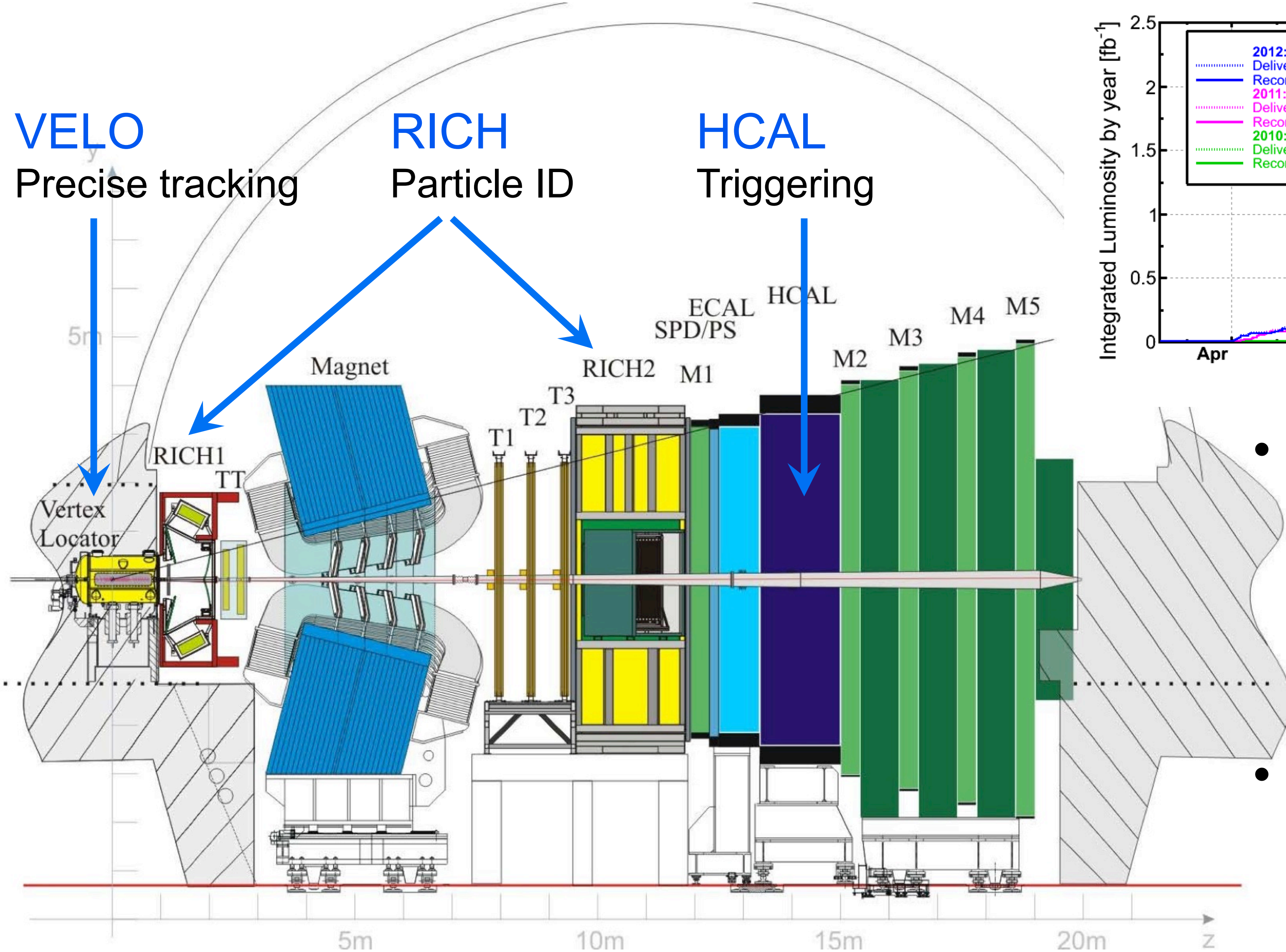
Mark Whitehead – for the LHCb collaboration

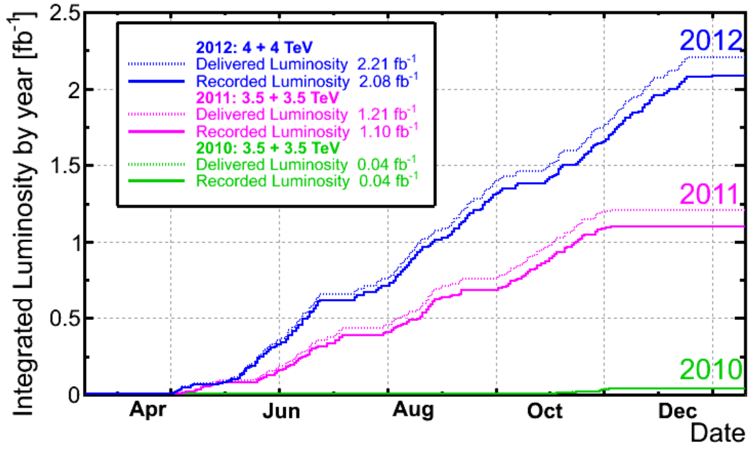
LHCb experiment

VELO
Precise tracking

RICH
Particle ID

HCAL
Triggering





- Data samples
  - 2011 - 1fb^{-1}
  - 2012 - 2fb^{-1}
  - 3fb^{-1} combined
- Overview
  - γ studies
  - Baryons

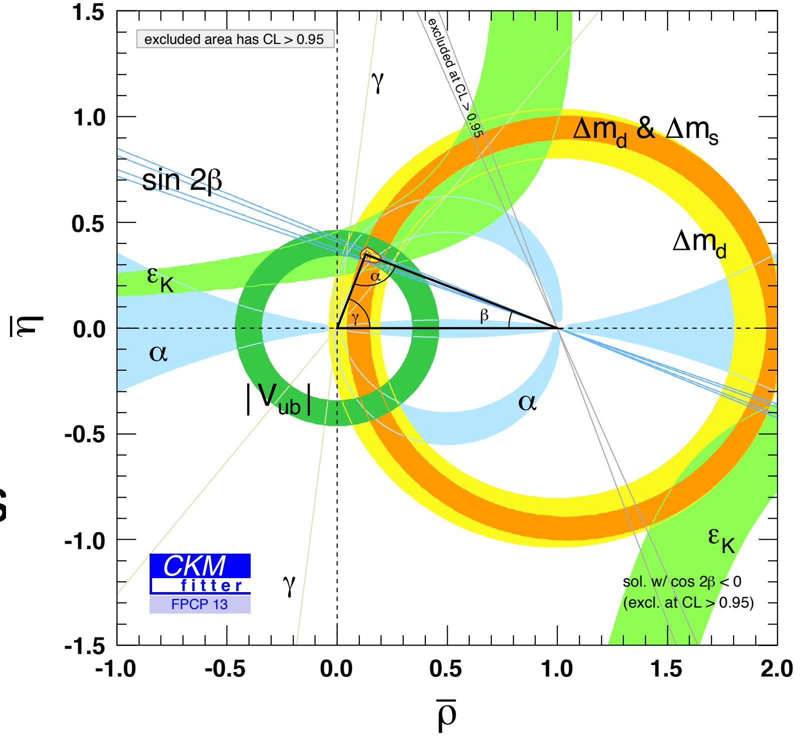
Why always γ?

- The least well measured angle of the unitarity triangle
  - CKM fitter FPCP 2013: $(68.0\ ^{+8.0}_{-8.5})^{o}$
  - UT fit Post EPS 2013: $(70.1 \pm 7.1)^{o}$
  - Key goal of LHCb is to improve this situation

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

- A probe for new physics?
  - Tree processes theoretically very clean
  - Loop processes may see deviations

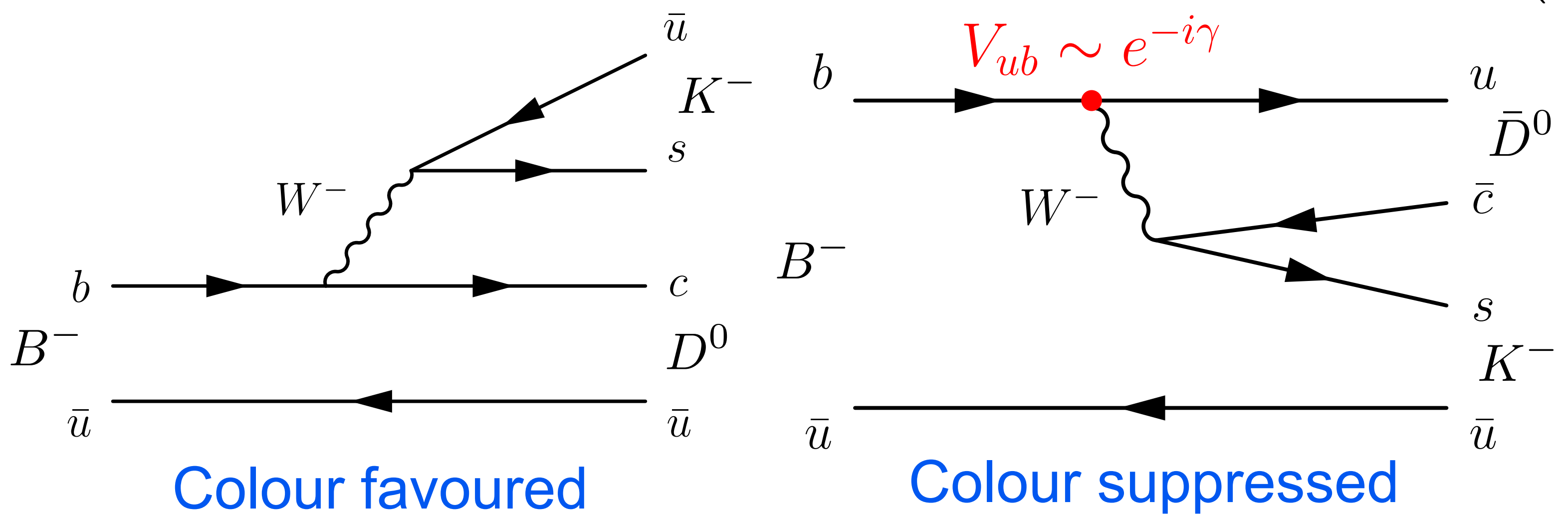
- Focus so far has been on $B^{\pm}\to DK^{\pm}$ decays
  - Interference of $b\to c$ and $b\to u$ transitions



$B^{\pm}\rightarrow DK^{\pm}$ decays

- The flagship γ channel at LHCb

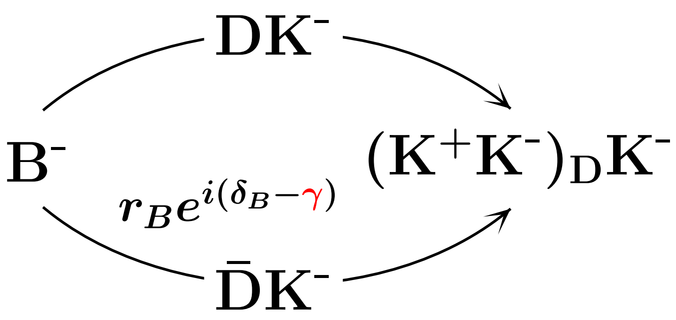
$$\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$



- The angle γ is the weak phase between b→c and b→u transitions
  - Interference occurs when D^0 and $\bar{D}^0$ decay to the same final state

Methods to measure γ

- GLW

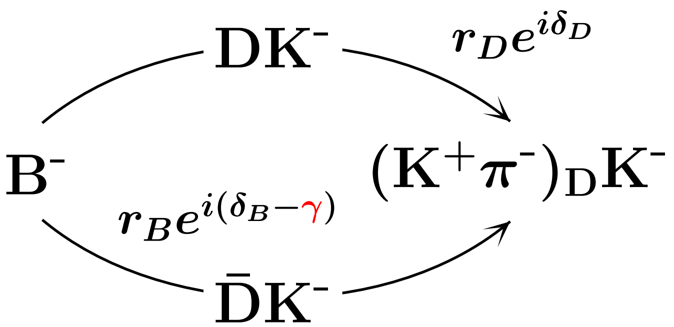


$$A_{\mathcal{CP}+} = \frac{2 r_B \sin\delta_B \sin\gamma}{R_{\mathcal{CP}+}}$$

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

Phys. Lett. B 253 (1991) 483, Phys. Lett. B 265 (1991) 172

- ADS



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

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

Phys. Rev. Lett. 78 (1997) 3257, Phys. Rev. D 63 (2001) 036005

- GGSZ
  - 3 body self conjugate decays
  - Eg: $D \rightarrow K_S \pi\pi$

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

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

Phys. Rev. D 68 (2003) 054018

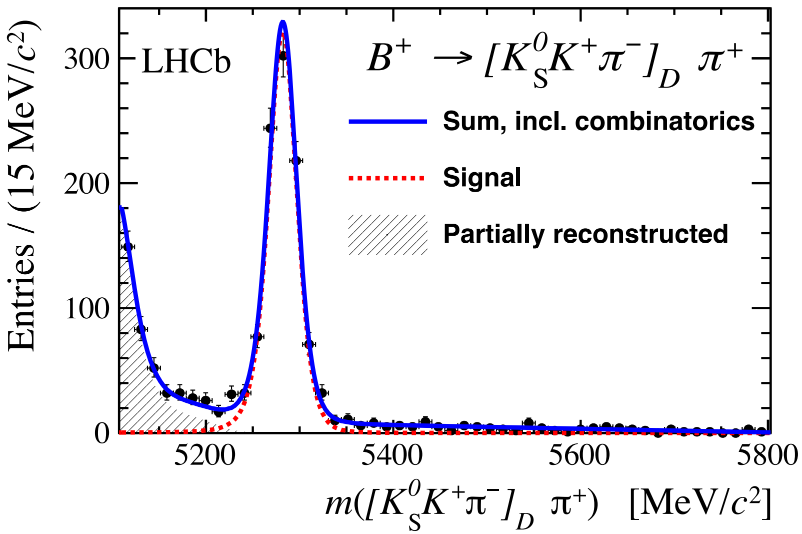
$B^{\pm} \to D(K_S K\pi)h^{\pm}$

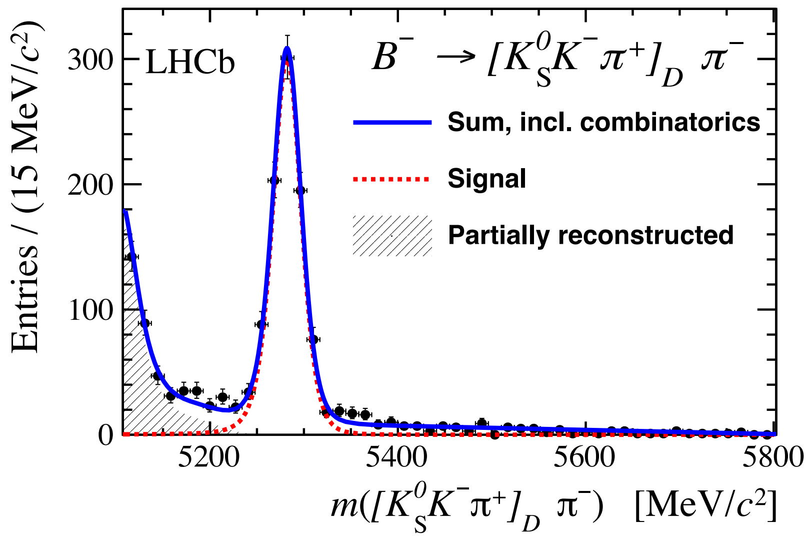
Phys. Lett. B 733C (2014) 36

- Recent result from $B \to DK$ studies
  - ADS-like analysis using a singly Cabibbo-supressed decay
  - Split the decay modes by the charge of the charged K_D and B mesons
  - Same sign (SS) and opposite sign (OS)
- Take input from CLEO measurements
  - Coherence factor (κ) and the average strong phase difference (δ)
  - Both measured over the full Dalitz plot and a $K^*(892)^{\pm}$ region.
- Full $3fb^{-1}$ 2011+2012 data sample used

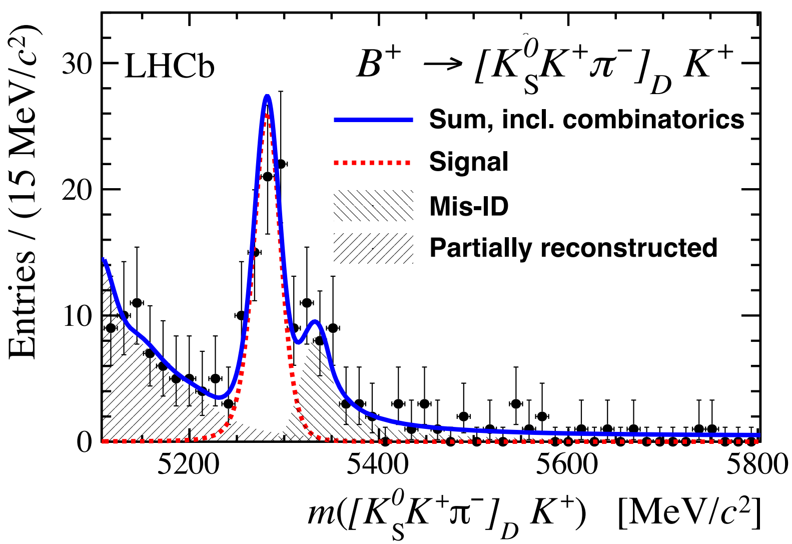
Same sign $B^\pm \to D(K_S K \pi) h^\pm$

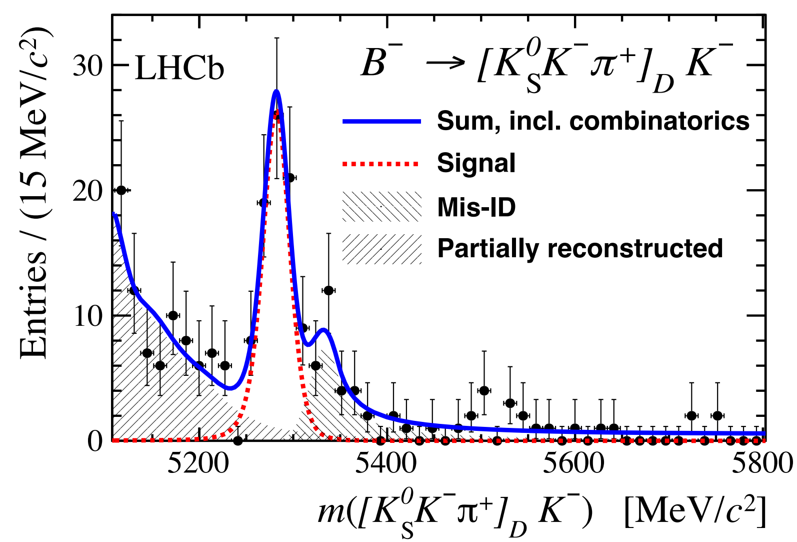
Phys. Lett. B 733C (2014) 36





1841 ± 47

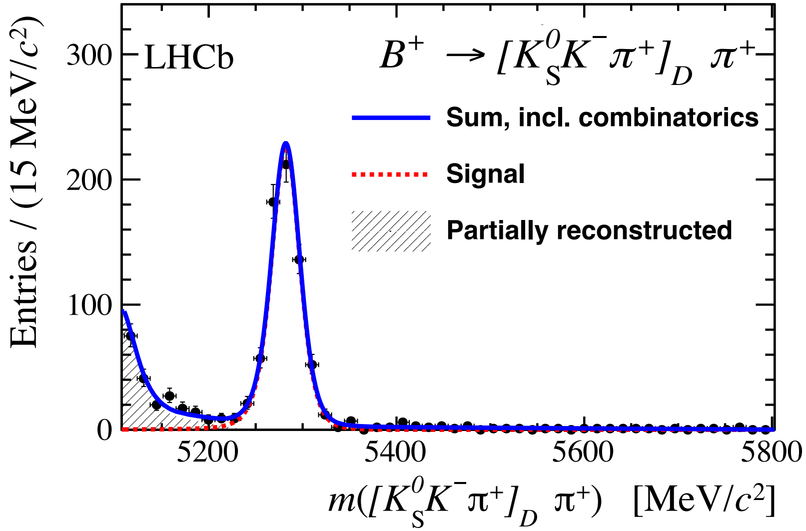


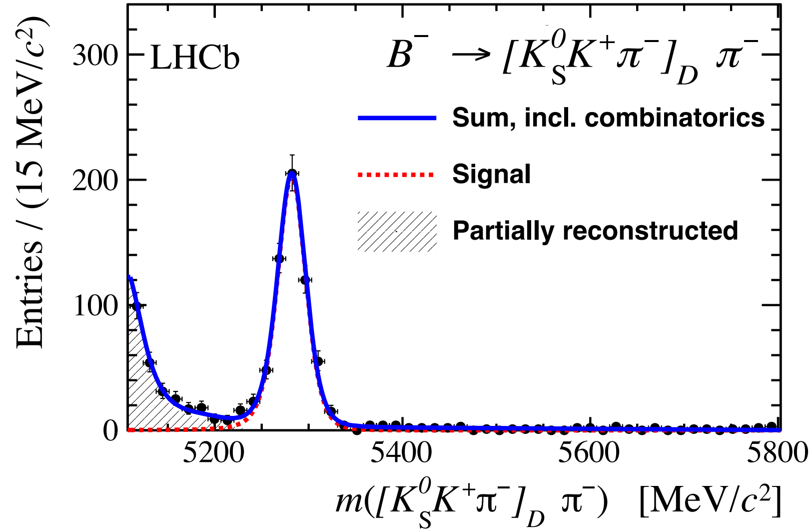


145 ± 15

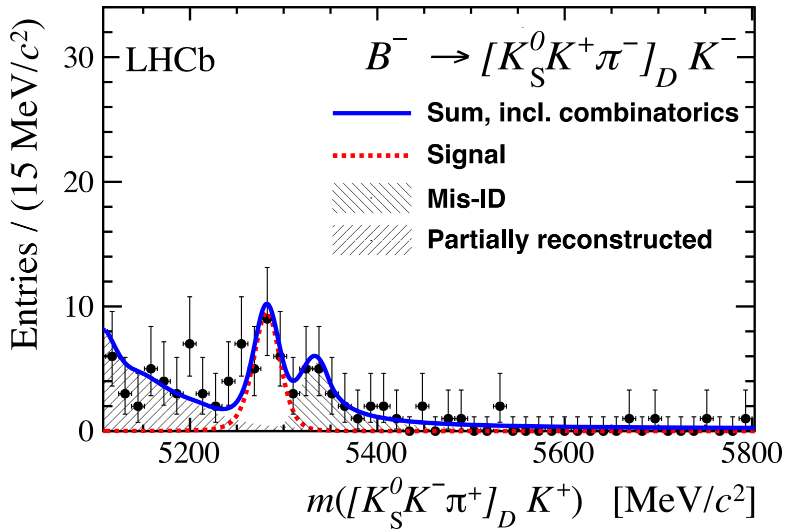
Opposite sign $B^{\pm} \to D(K_S K \pi) h^{\pm}$

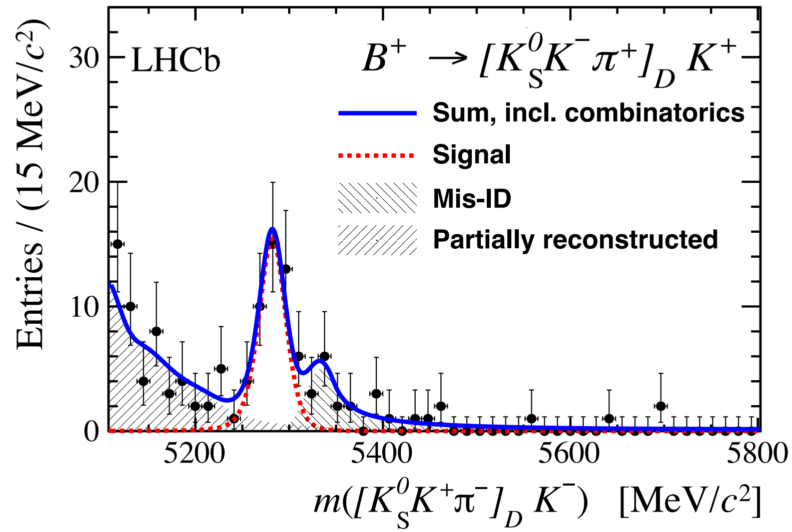
Phys. Lett. B 733C (2014) 36





1267 ± 37





71 ± 10

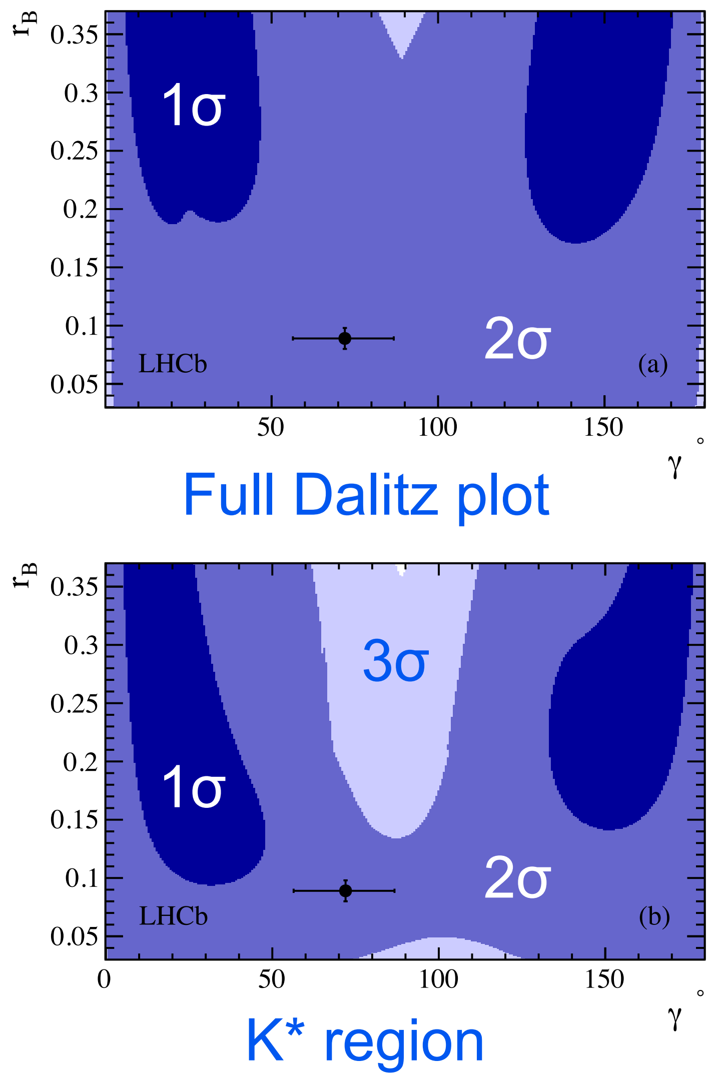
$B^\pm \to D(K_S K \pi) h^\pm$

Phys. Lett. B 733C (2014) 36

- 7 observables calculated from the 8 yields
  - 3 yield ratios and 4 asymmetries

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

- Higher sensitivity in the K* region
  - As expected from larger coherence factor
  - Good future prospects

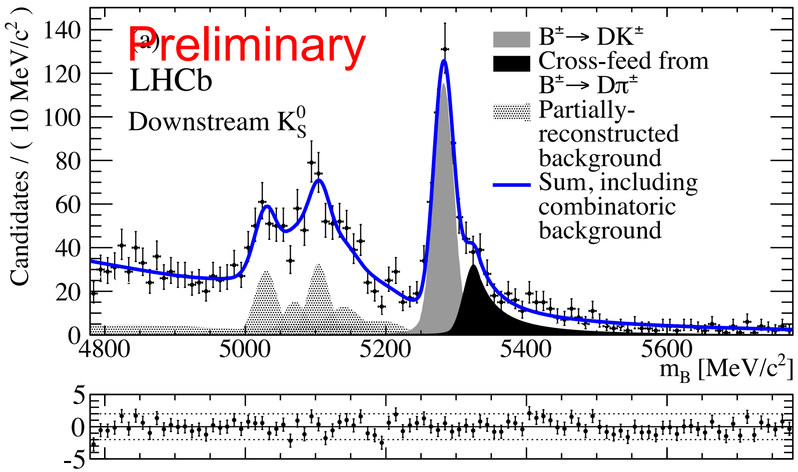


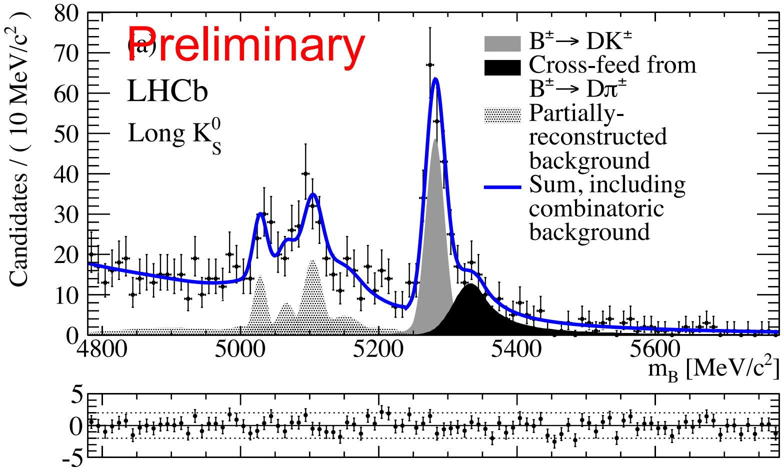
$B^\pm \to D(K_S\pi\pi)h^\pm$

LHCb-PAPER-2014-017

- Model dependent GGSZ amplitude analysis
  - Use Babar model for the fit to the D decay
  - $1fb^{-1}$ data sample
- Fit B mass to extract signal and backgrounds yields
  - Define signal region as ± $50MeV/c^2$
  - Downstream and Long refer to track types used to make the K_S

420±27





217±17

$B^{\pm} \to D(K_S\pi\pi)h^{\pm}$

LHCb-PAPER-2014-017

- Dalitz plot fit
  - K*(892) dominates
  - Split B+ and B-
  - Backgrounds
  - Efficiency
- Cartesian parameters
  - D^0 mixing negligible

$$x_- = +0.027 \pm 0.044 \,^{+0.010}_{-0.008} \pm 0.001$$

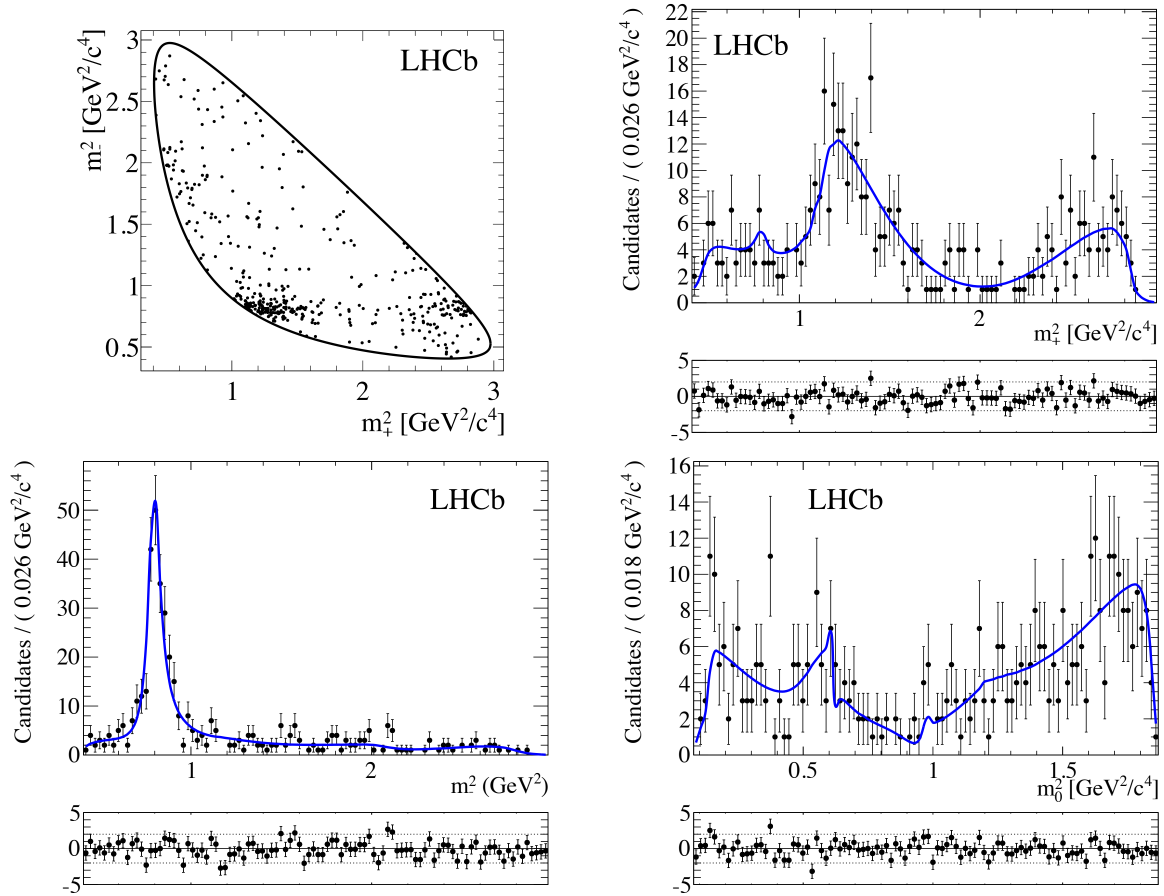
$$y_- = +0.013 \pm 0.048 \,^{+0.008}_{-0.006} \pm 0.003$$

$$x_+ = -0.084 \pm 0.045 \pm 0.009 \pm 0.003$$

$$y_+ = -0.032 \pm 0.048 \pm 0.009 \pm 0.007$$

Preliminary

Preliminary



B- only, $m_+ = m(K_S\pi_+)$

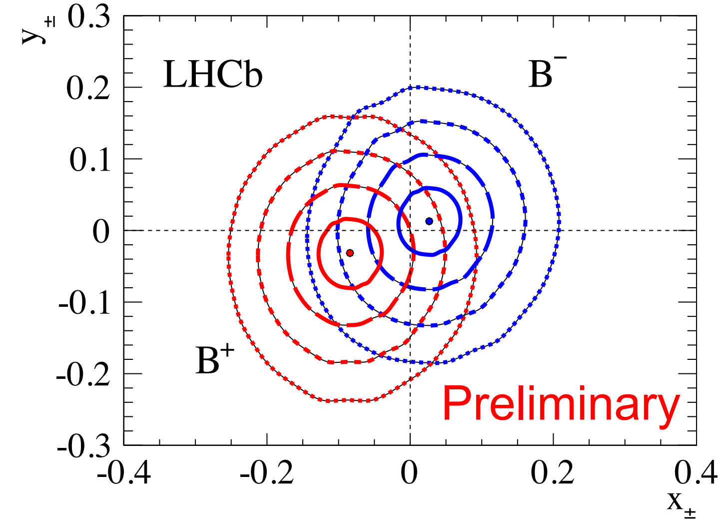
$B^\pm \rightarrow D(K_S\pi\pi)h^\pm$

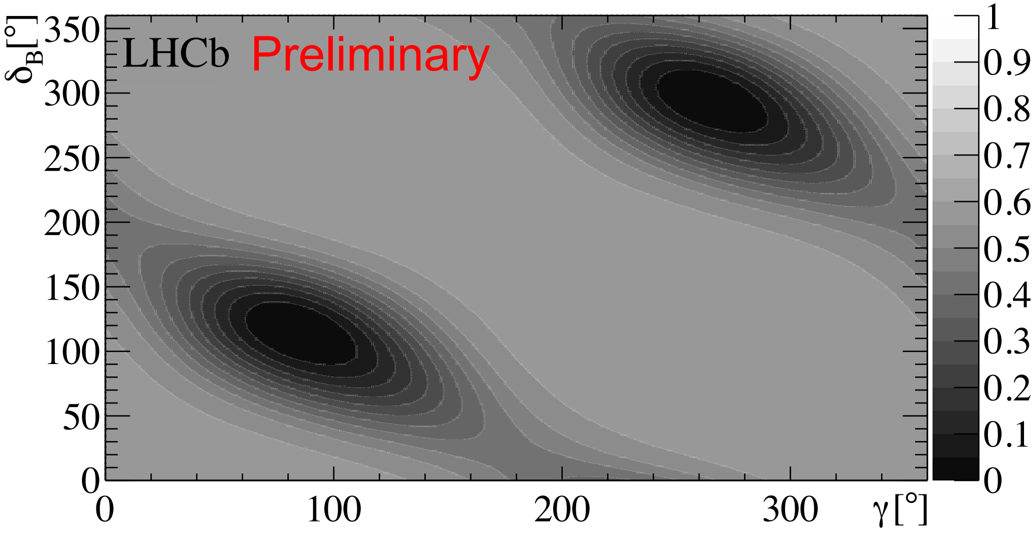
LHCb-PAPER-2014-017

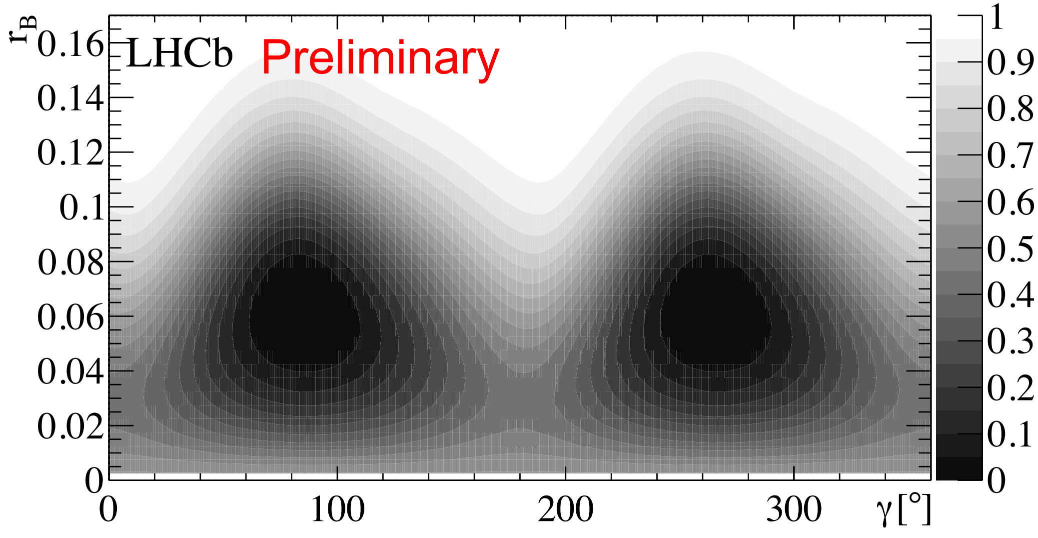
- Convert the Cartesian parameters

$$\gamma = (84^{+49}_{-42})^\circ$$ Preliminary

  - Includes all uncertainties
  - Choose solution < 180°



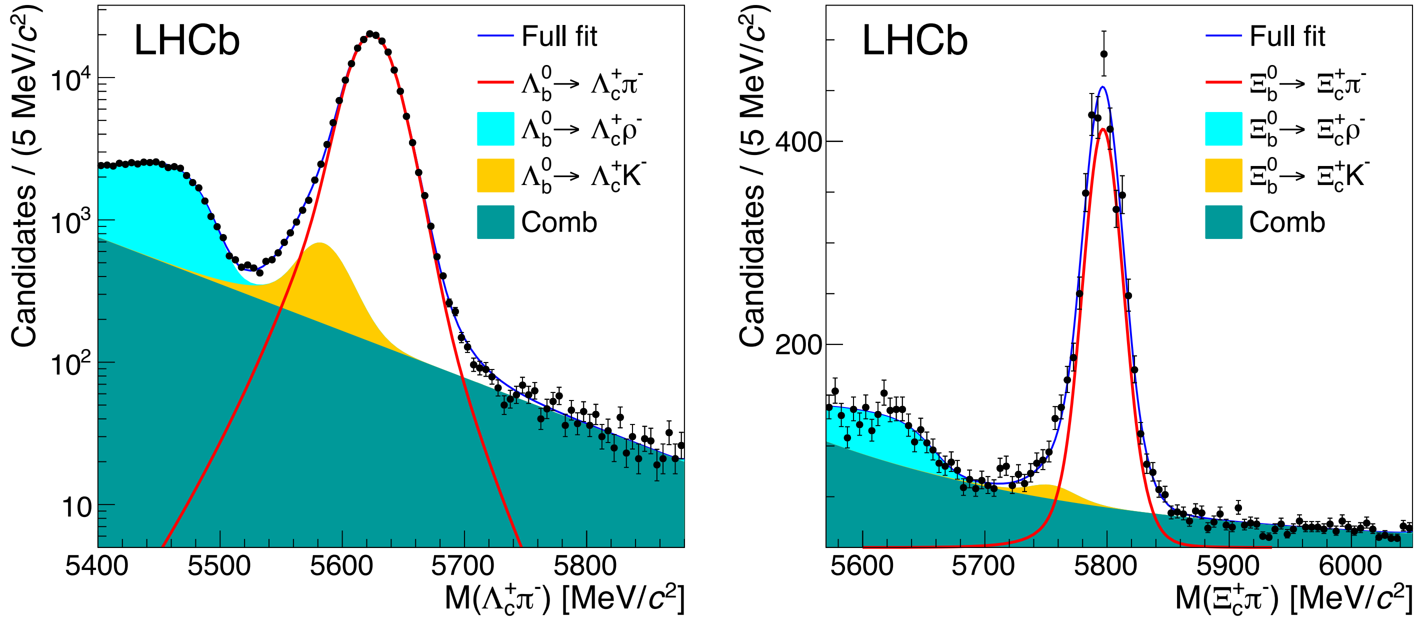




$\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$

arXiv:1405.7223

- Aim to measure the mass and lifetime of Ξ_b
  - Lifetime expected to be equal to that of Λ_b (Leading order HQE)
  - Large sample of ~3800 decays available from 3fb-1 data set
  - $\Lambda_b \rightarrow \Lambda_c \pi$ provides the ideal control channel, kinematics are ~identical
  - Decays of Λ_c and Ξ_c to the same final state of pKπ



$\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$

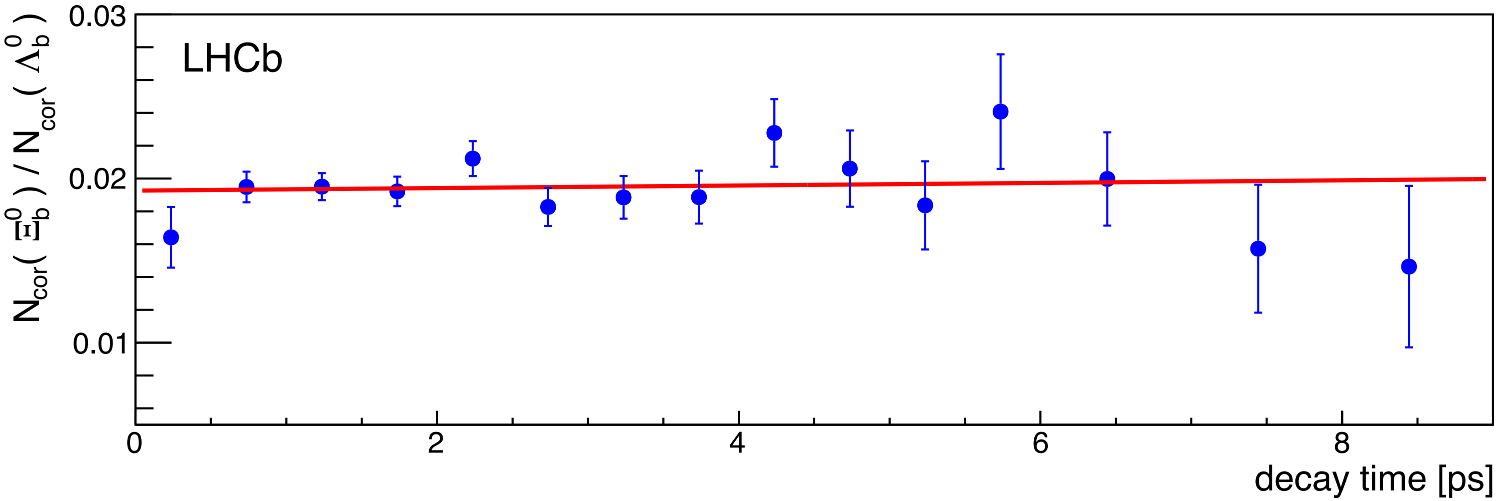
arXiv:1405.7223

- Float the mass difference in the fit to data

$$M(\Xi_b^0) - M(\Lambda_b^0) = 172.44 \pm 0.39\,(\mathrm{stat}) \pm 0.17\,(\mathrm{syst})\ \mathrm{MeV}/c^2$$

$$M(\Xi_b^0) = 5791.80 \pm 0.39\,(\mathrm{stat}) \pm 0.17\,(\mathrm{syst}) \pm 0.26\,(\Lambda_b^0)\ \mathrm{MeV}/c^2$$

- Measure lifetime from yield ratio as a function of decay time
  - Fit with the function $e^{\beta t}$ where $\beta = 1/\tau_{\Lambda_b^0} - 1/\tau_{\Xi_b^0}$
  - Efficiency corrected



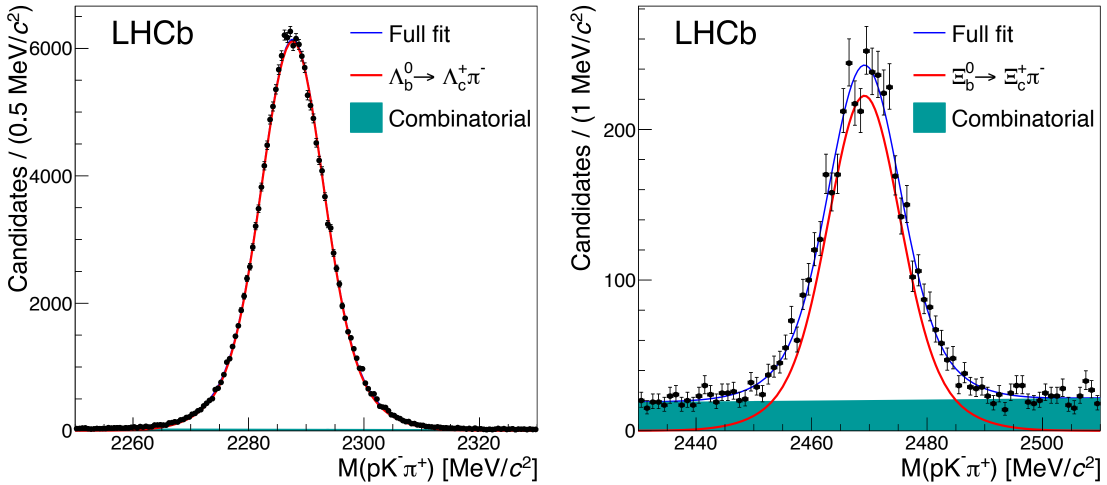
$\Xi_b^0 \to \Xi_c^+ \pi^-$

arXiv:1405.7223

- World first lifetime measurement

$$\frac{\tau_{\Xi_b^0}}{\tau_{\Lambda_b^0}} = 1.006 \pm 0.018\,(\mathrm{stat}) \pm 0.010\,(\mathrm{syst})$$

$$\tau_{\Xi_b^0} = 1.477 \pm 0.026\,(\mathrm{stat}) \pm 0.014\,(\mathrm{syst}) \pm 0.013\,(\Lambda_b^0)\ \mathrm{ps}$$



- Two world best mass measurements

$$M(\Xi_b^0) = 5791.80 \pm 0.39\,(\mathrm{stat}) \pm 0.17\,(\mathrm{syst}) \pm 0.26\,(\Lambda_b^0)\ \mathrm{MeV}/c^2$$

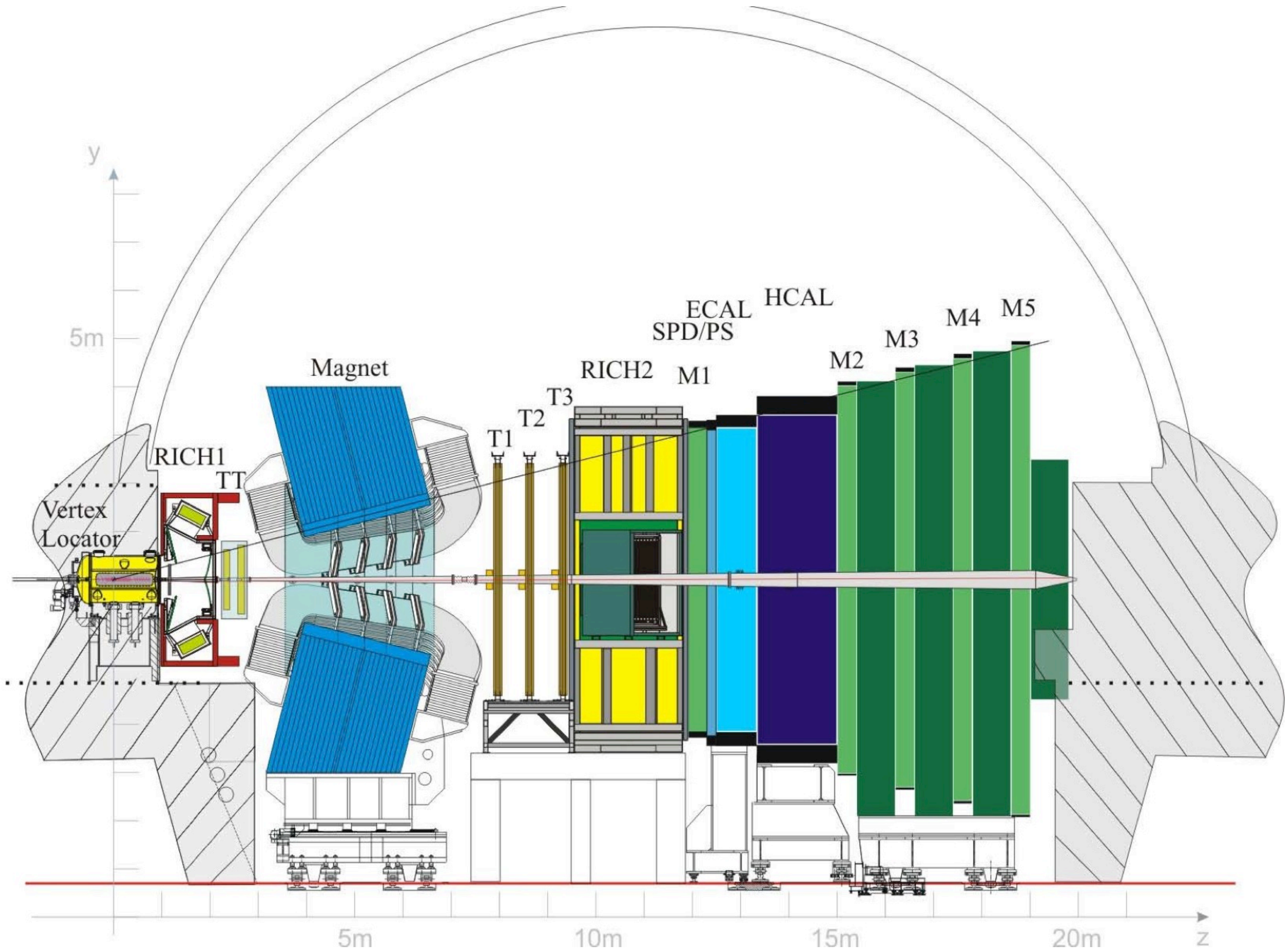
$$M(\Xi_c^+) = 2467.97 \pm 0.14\,(\mathrm{stat}) \pm 0.10\,(\mathrm{syst}) \pm 0.14\,(\Lambda_c^+)\ \mathrm{MeV}/c^2$$

Summary

- Latest updates from $B^{\pm} \to DK^{\pm}$ γ studies
  - Using a new D decay mode, $D \to K_S K \pi$
  - First model dependent GGSZ results
- Much more still to come on γ
  - Update all $1fb^{-1}$ analyses to the full $3fb^{-1}$ data sample
  - Other B decays e.g. $B^0 \to DK\pi$ and $B^0 \to DK^*$, $B_s \to D_s K$ and $B^{\pm} \to DK^{\pm}\pi\pi$
- Progress on b-Baryon decays
  - Precise lifetime and mass measurements of the Ξ_b
- Stay tuned for all of our new results in this sector

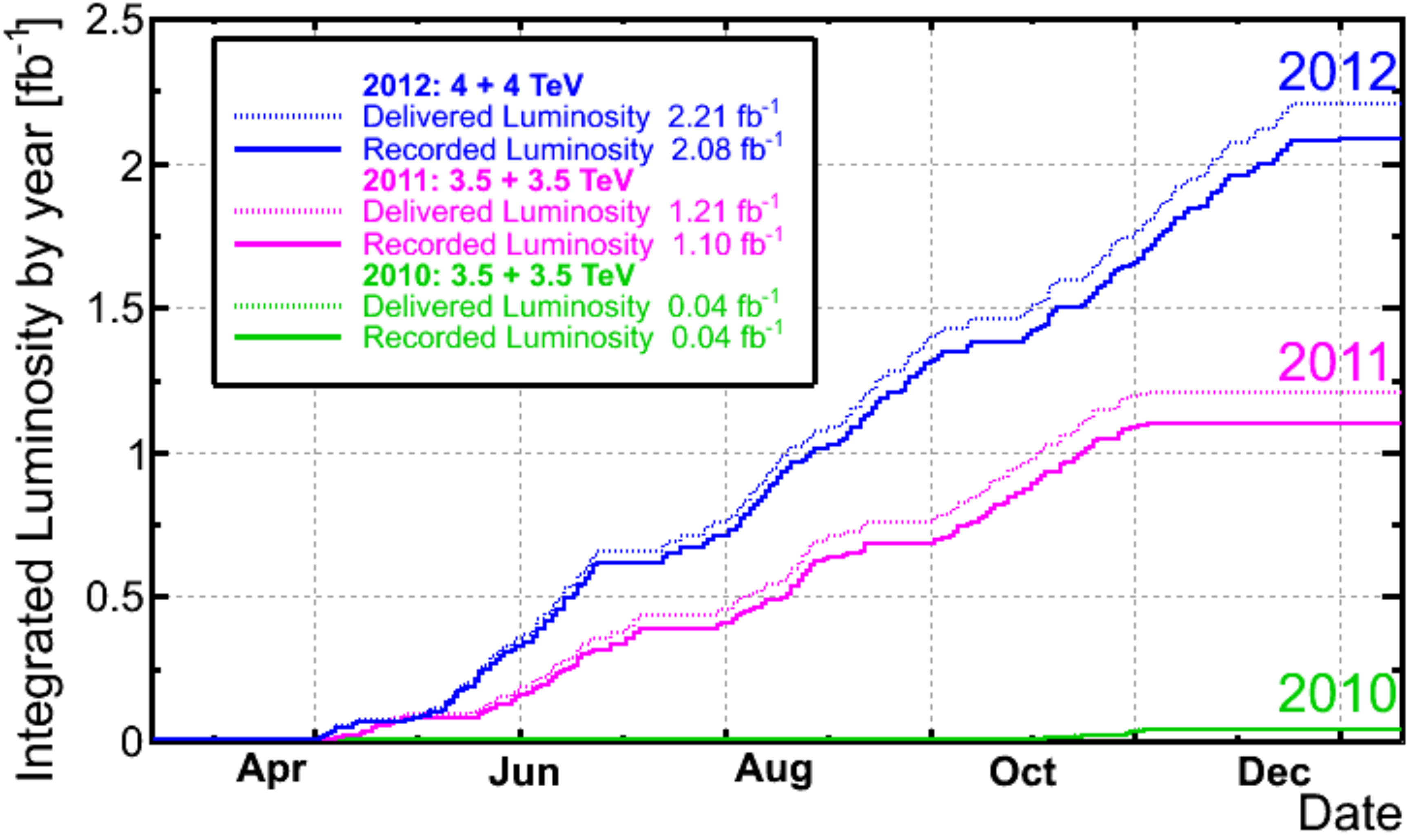
Back ups

Detector



y
5m
Magnet
RICH1
TT
Vertex
Locator
T1
T2
T3
RICH2
M1
SPD/PS
ECAL
HCAL
M2
M3
M4
M5
5m
10m
15m
20m
z

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

Methods to measure γ

- GLW
  - CP eigenstate D decays
  - Eg: D→KK, D→ππ

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

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

Phys. Lett. B 253 (1991) 483, Phys. Lett. B 265 (1991) 172

- ADS
  - Quasi flavour specific decays
  - Eg: D→Kπ, D→Kπππ

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

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

Phys. Rev. Lett. 78 (1997) 3257, Phys. Rev. D 63 (2001) 036005

- GGSZ
  - 3 body self conjugate decays
  - Eg: D→K_Sππ

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

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

Phys. Rev. D 68 (2003) 054018

$1fb^{-1}$ γ combination

Phys. Lett. B 726 (2013) 151

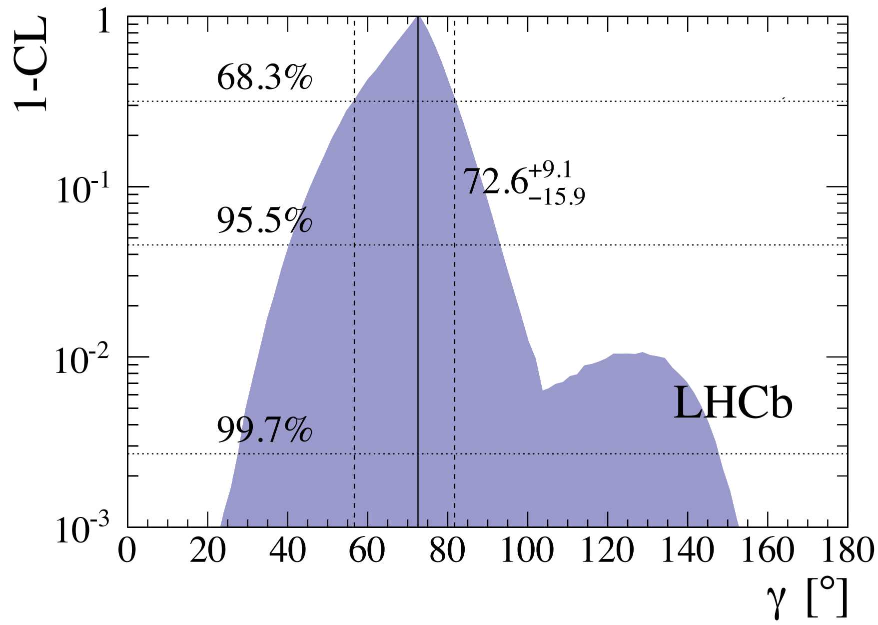
- Combination includes the following results
  - 2 body GLW/ADS (D→KK, Kπ, ππ) Phys. Lett. B 712 (2012) 203
  - 4 body ADS (D→Kπππ) Phys. Lett. B 723 (2013) 44
  - GGSZ (D→K_Sππ, K_SKK) Phys. Lett. B 718 (2012) 43
  - Information on the strong phase from CLEO Phys. Rev. D 80 (2009) 031105 Phys. Rev. D 80 (2009) 032002

- Additionally:
  - D^0 mixing, CPV in charm decays

$$\gamma = (72.0^{+14.7}_{-15.6})^\circ \text{ at } 68\% \text{ CL}$$

  - B→Dπ decays also used

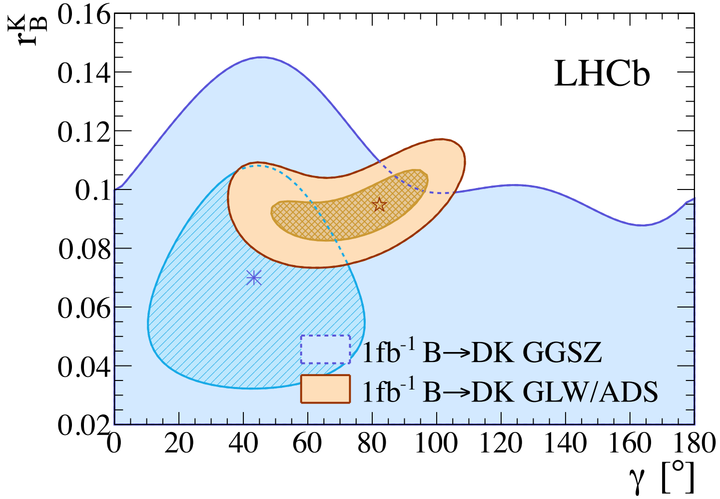
$$\gamma = (72.6^{+9.1}_{-15.9})^\circ \text{ at } 68\% \text{ CL}$$

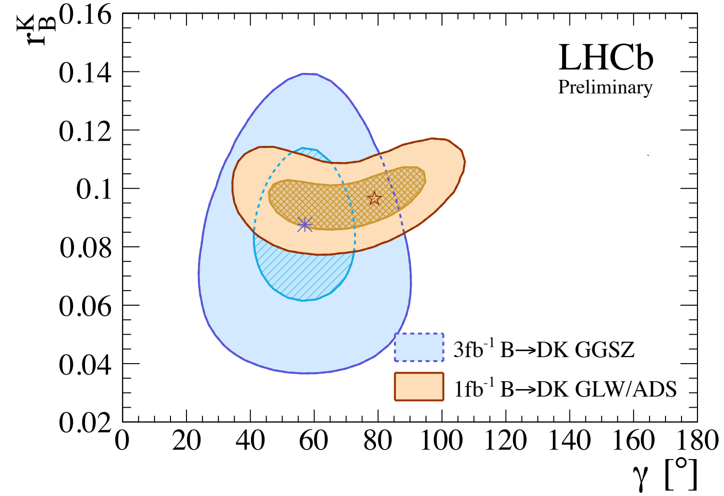


$1fb^{-1}$ γ combination + $2fb^{-1}$ GGSZ

LHCb-CONF-2013-006

- Update to include 2012 GGSZ result LHCb-CONF-2013-004

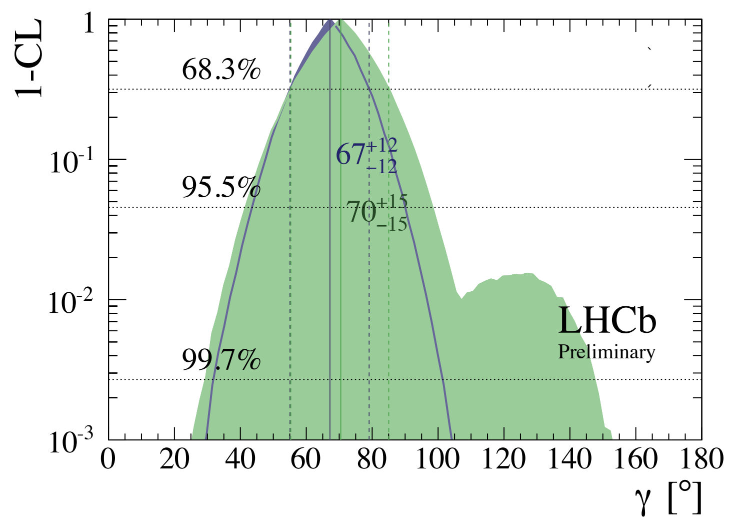




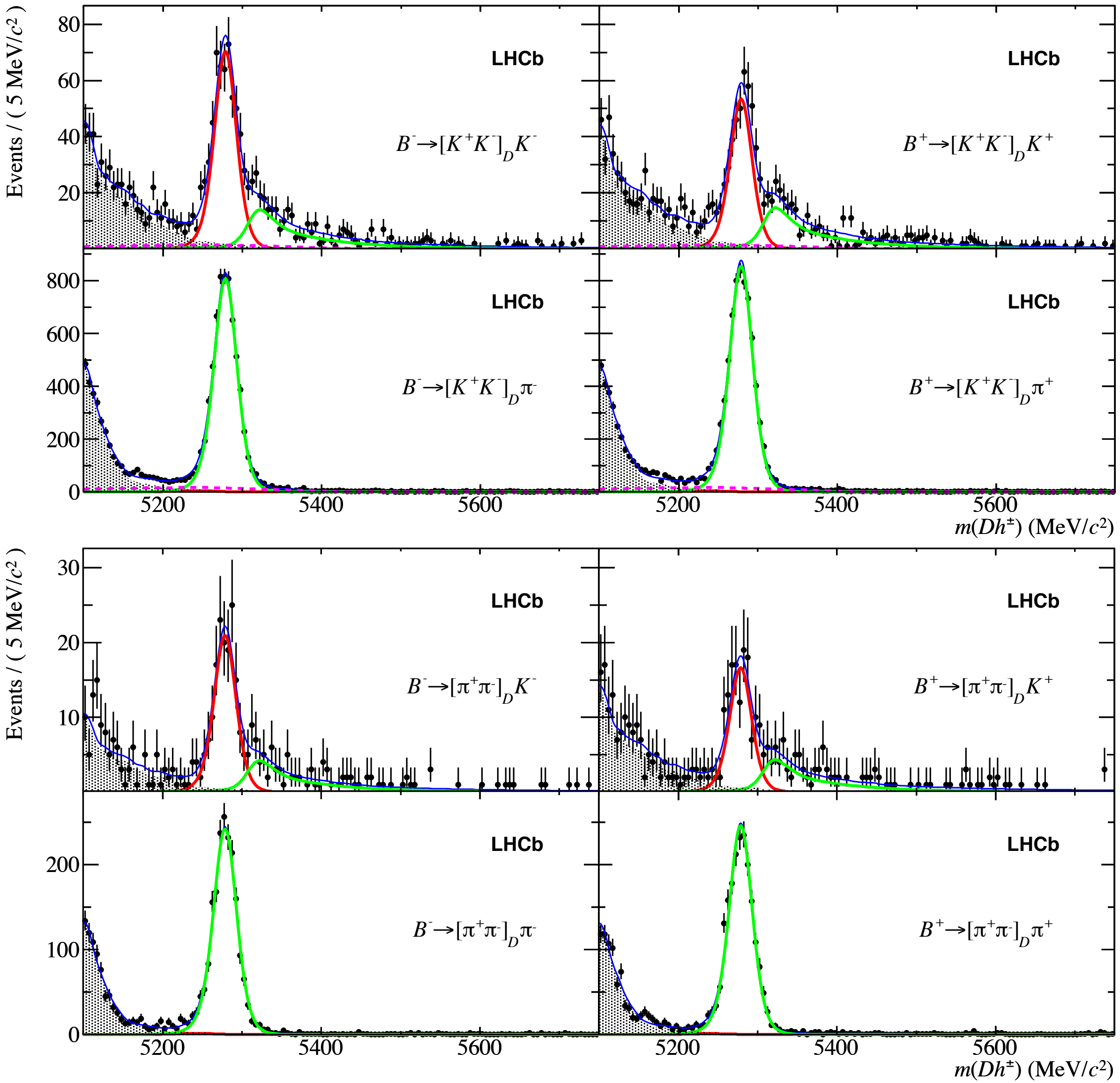
- B→DK only here
  - Green is the old B→DK curve
  - Purple shows the updated interval

$$\gamma = (67 \pm 12)^{\circ} \text{ at } 68\% \text{ CL}$$

Preliminary

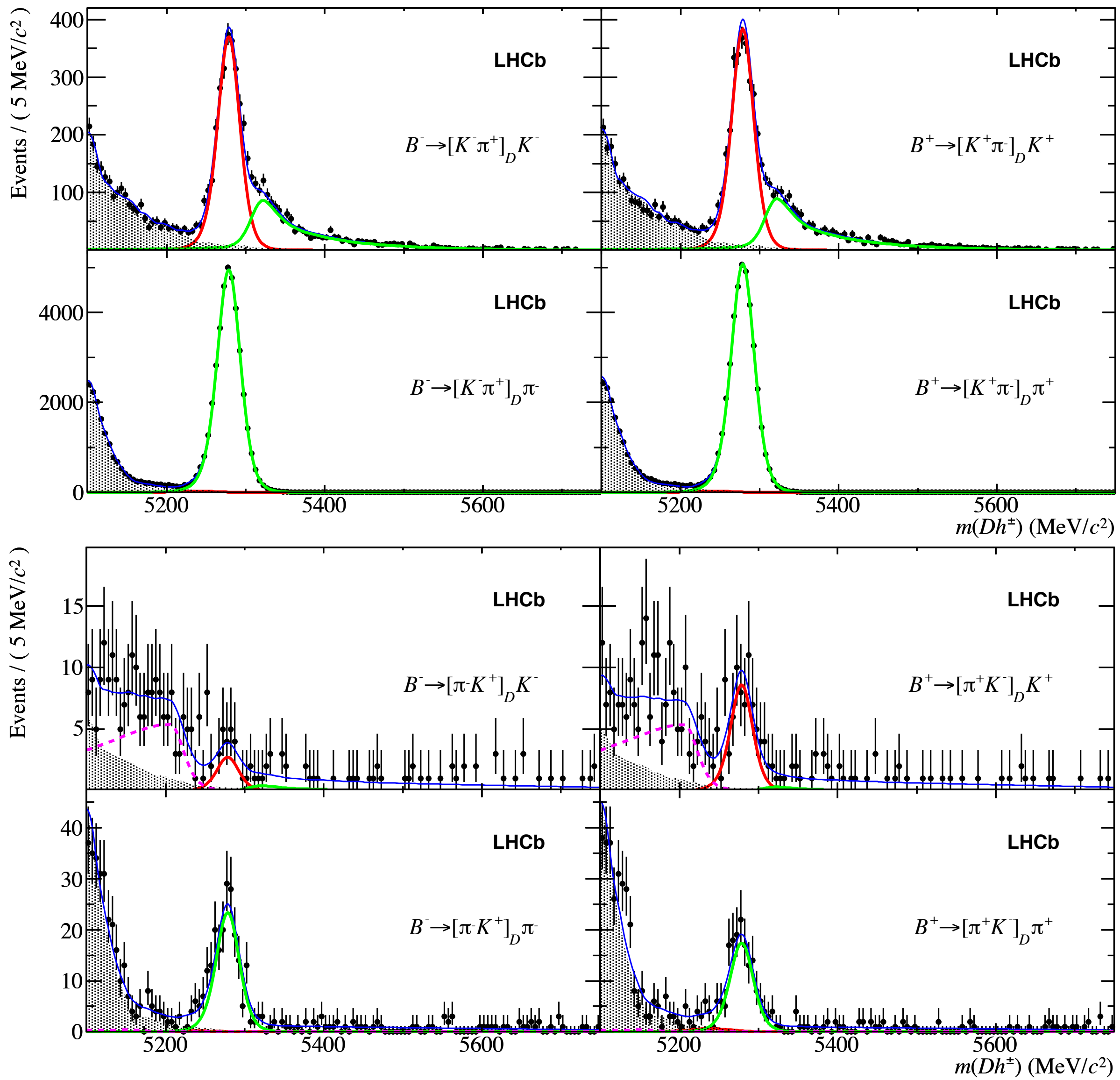


2 body GLW



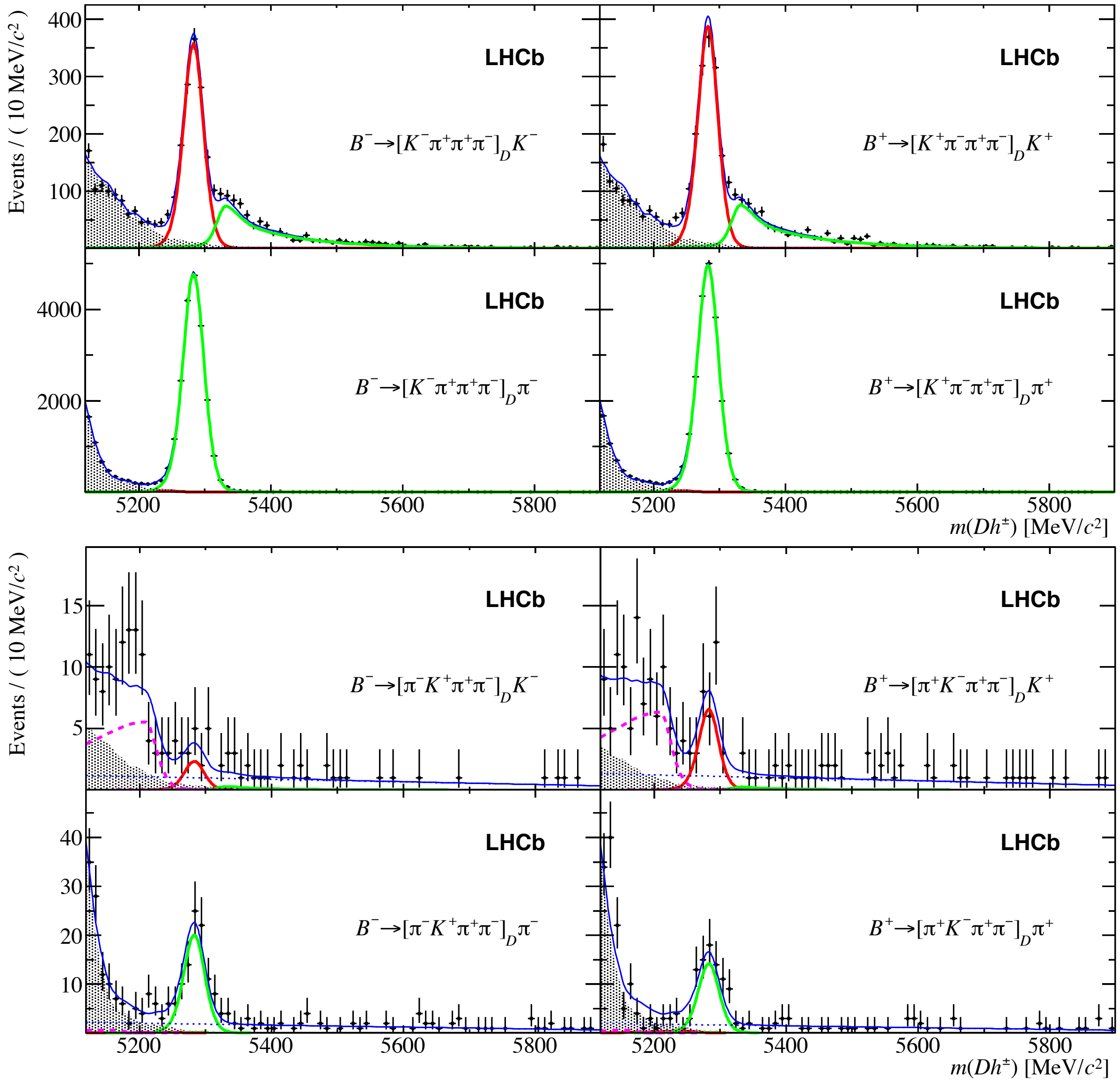
LHCb
$B^- \to [K^+K^-]_D K^-$
$B^+ \to [K^+K^-]_D K^+$
$B^- \to [K^+K^-]_D \pi^-$
$B^+ \to [K^+K^-]_D \pi^+$
$B^- \to [\pi^+\pi^-]_D K^-$
$B^+ \to [\pi^+\pi^-]_D K^+$
$B^- \to [\pi^+\pi^-]_D \pi^-$
$B^+ \to [\pi^+\pi^-]_D \pi^+$
Events / (5 MeV/c^2)
$m(Dh^{\pm})$ (MeV/c^2)
5200
5400
5600

2 body ADS



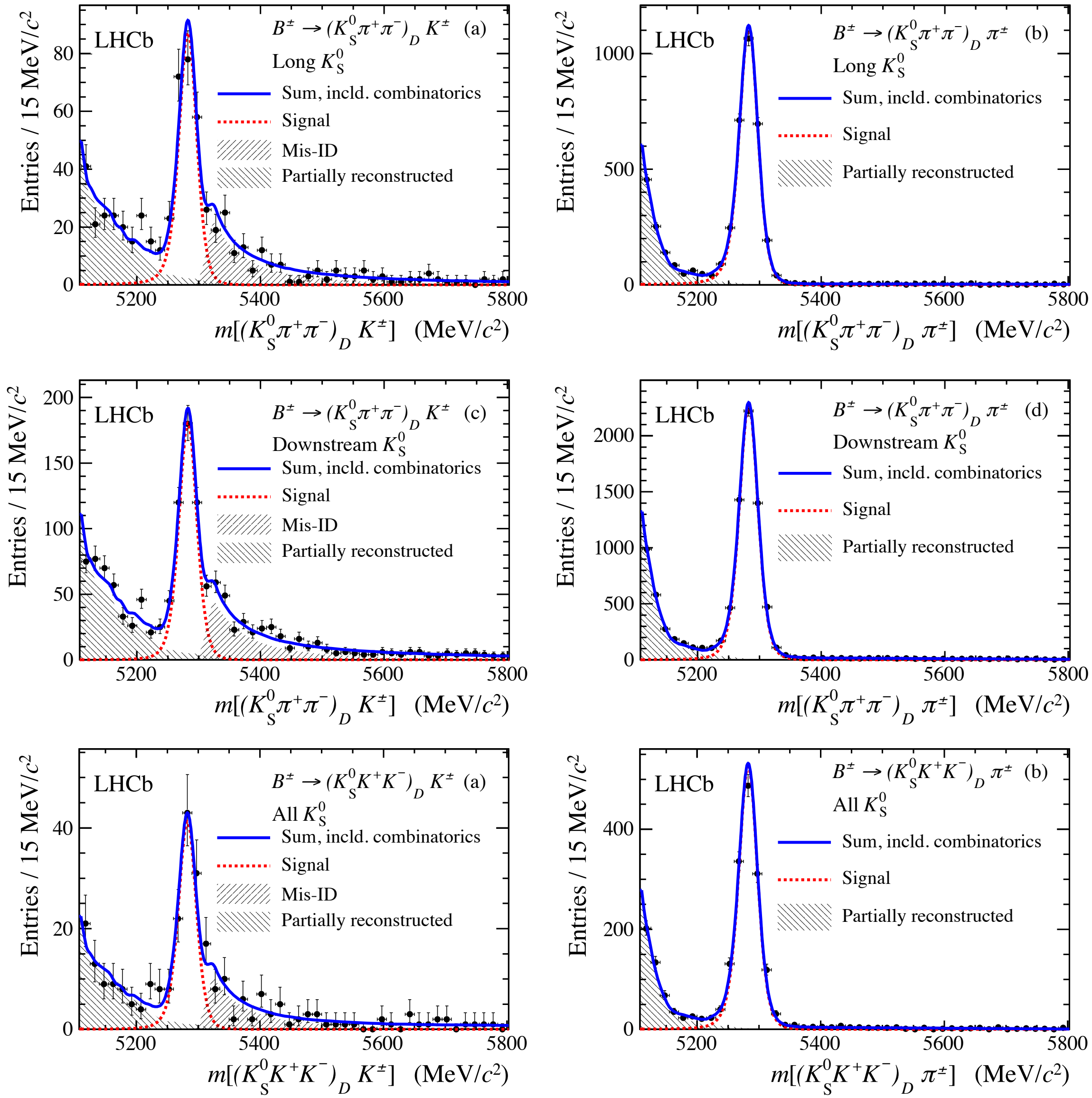
Events / (5 MeV/c^2)
LHCb
$B^- \to [K^-\pi^+]_D K^-$
$B^+ \to [K^+\pi^-]_D K^+$
$B^- \to [K^-\pi^+]_D \pi^-$
$B^+ \to [K^+\pi^-]_D \pi^+$
$B^- \to [\pi^- K^+]_D K^-$
$B^+ \to [\pi^+ K^-]_D K^+$
$B^- \to [\pi^- K^+]_D \pi^-$
$B^+ \to [\pi^+ K^-]_D \pi^+$
$m(Dh^\pm)$ (MeV/c^2)

4 body ADS

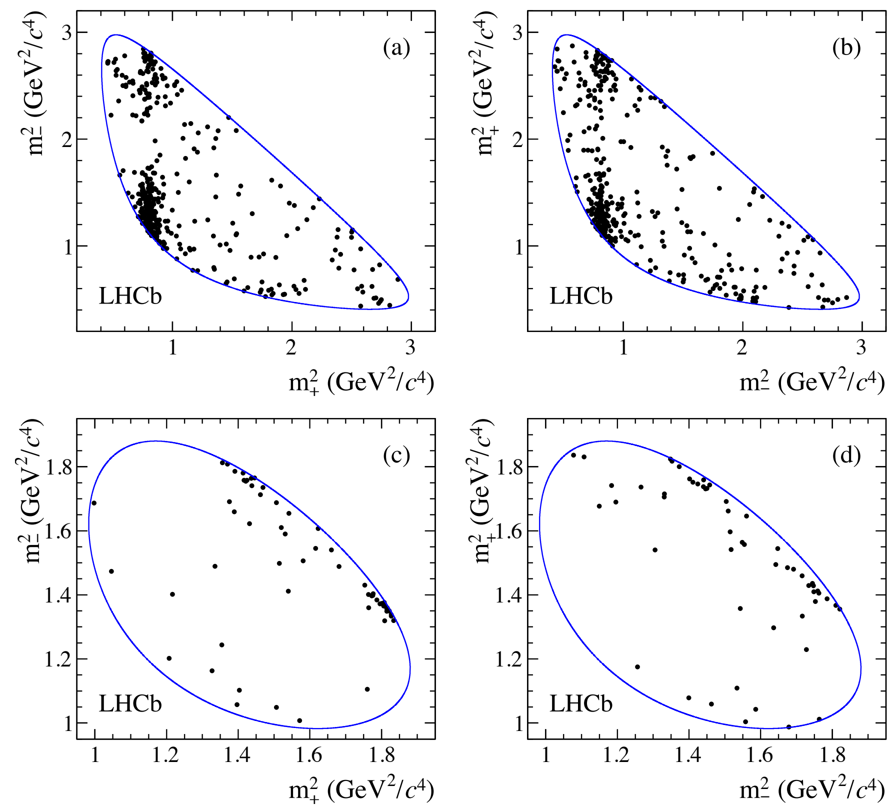


Events / (10 MeV/c^2)
LHCb
$B^-\to[K^-\pi^+\pi^+\pi^-]_D K^-$
$B^+\to[K^+\pi^-\pi^+\pi^-]_D K^+$
$B^-\to[K^-\pi^+\pi^+\pi^-]_D \pi^-$
$B^+\to[K^+\pi^-\pi^+\pi^-]_D \pi^+$
$m(Dh^\pm)$ [MeV/c^2]
$B^-\to[\pi^-K^+\pi^+\pi^-]_D K^-$
$B^+\to[\pi^+K^-\pi^+\pi^-]_D K^+$
$B^-\to[\pi^-K^+\pi^+\pi^-]_D \pi^-$
$B^+\to[\pi^+K^-\pi^+\pi^-]_D \pi^+$

1fb-1 MI GGSZ

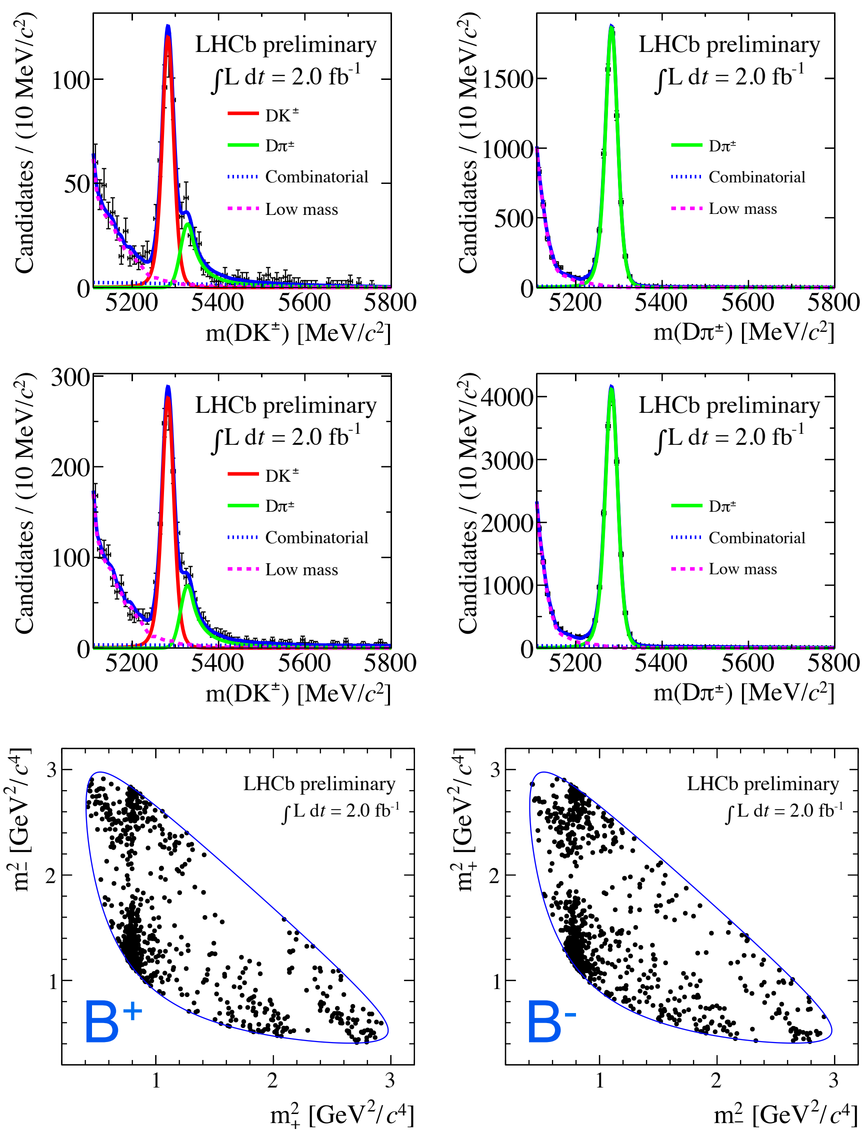


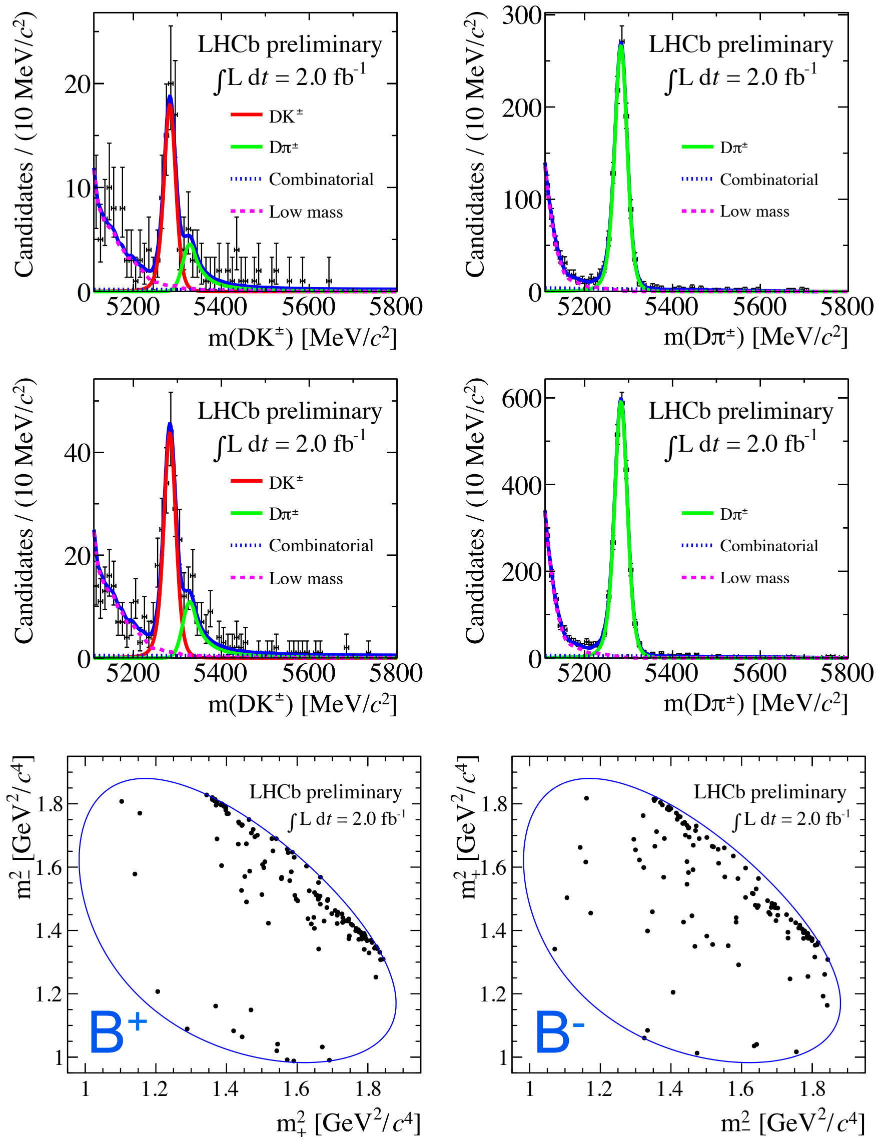
LHCb
$B^\pm \to (K^0_S\pi^+\pi^-)_D K^\pm$ (a)
Long K^0_S
Sum, incld. combinatorics
Signal
Mis-ID
Partially reconstructed
$B^\pm \to (K^0_S\pi^+\pi^-)_D \pi^\pm$ (b)
Long K^0_S
$B^\pm \to (K^0_S\pi^+\pi^-)_D K^\pm$ (c)
Downstream K^0_S
$B^\pm \to (K^0_S\pi^+\pi^-)_D \pi^\pm$ (d)
Downstream K^0_S
$B^\pm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



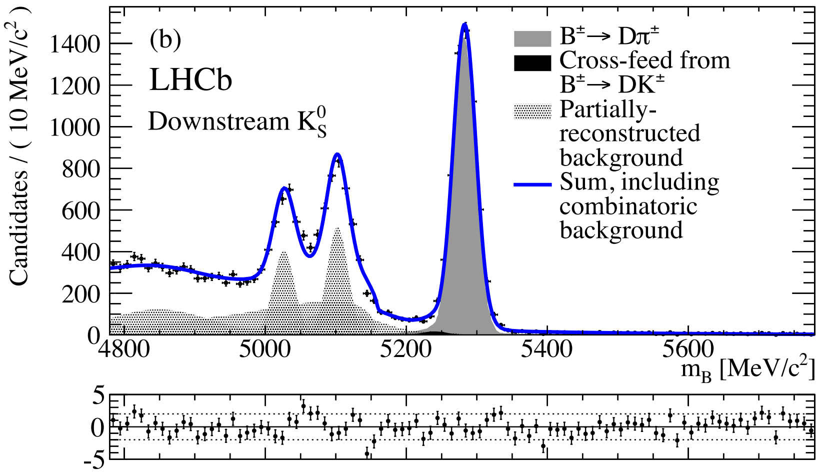
(a)
(b)
(c)
(d)
LHCb
m^2_- (GeV$^2/c^4$)
m^2_+ (GeV$^2/c^4$)

2fb-1 MI GGSZ

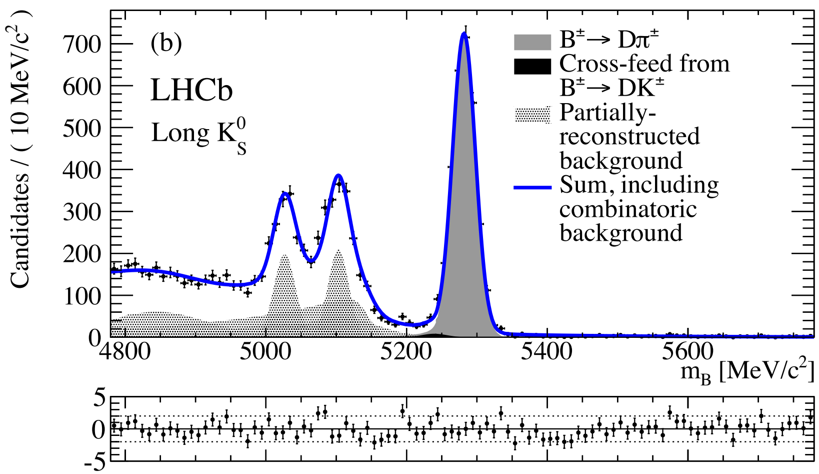

LHCb preliminary
∫L dt = 2.0 fb-1
DK±
Dπ±
Combinatorial
Low mass
Candidates / (10 MeV/c²)
m(DK±) [MeV/c²]
m(Dπ±) [MeV/c²]
m²₋ [GeV²/c⁴]
m²₊ [GeV²/c⁴]
B+
B-


LHCb preliminary
∫L dt = 2.0 fb-1
DK±
Dπ±
Combinatorial
Low mass
Candidates / (10 MeV/c²)
m(DK±) [MeV/c²]
m(Dπ±) [MeV/c²]
m²₋ [GeV²/c⁴]
m²₊ [GeV²/c⁴]
B+
B-

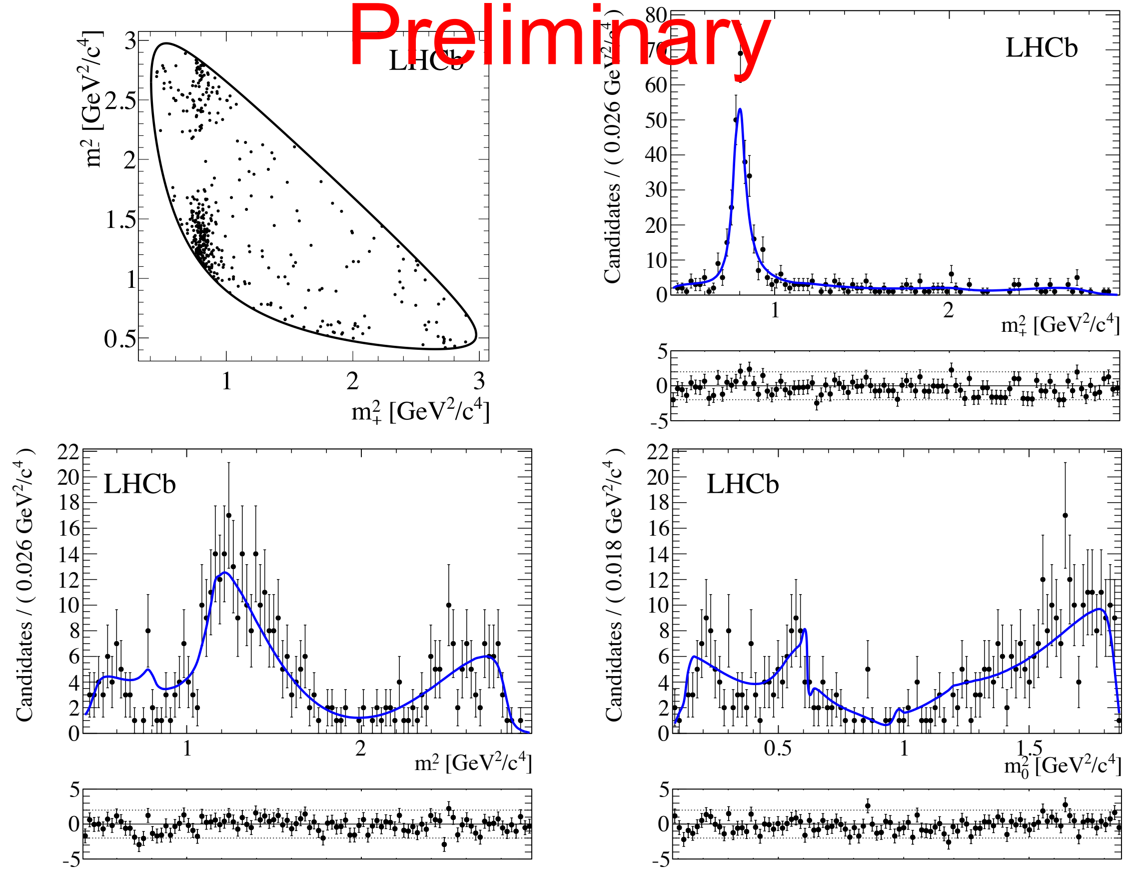
1fb-1 MD GGSZ



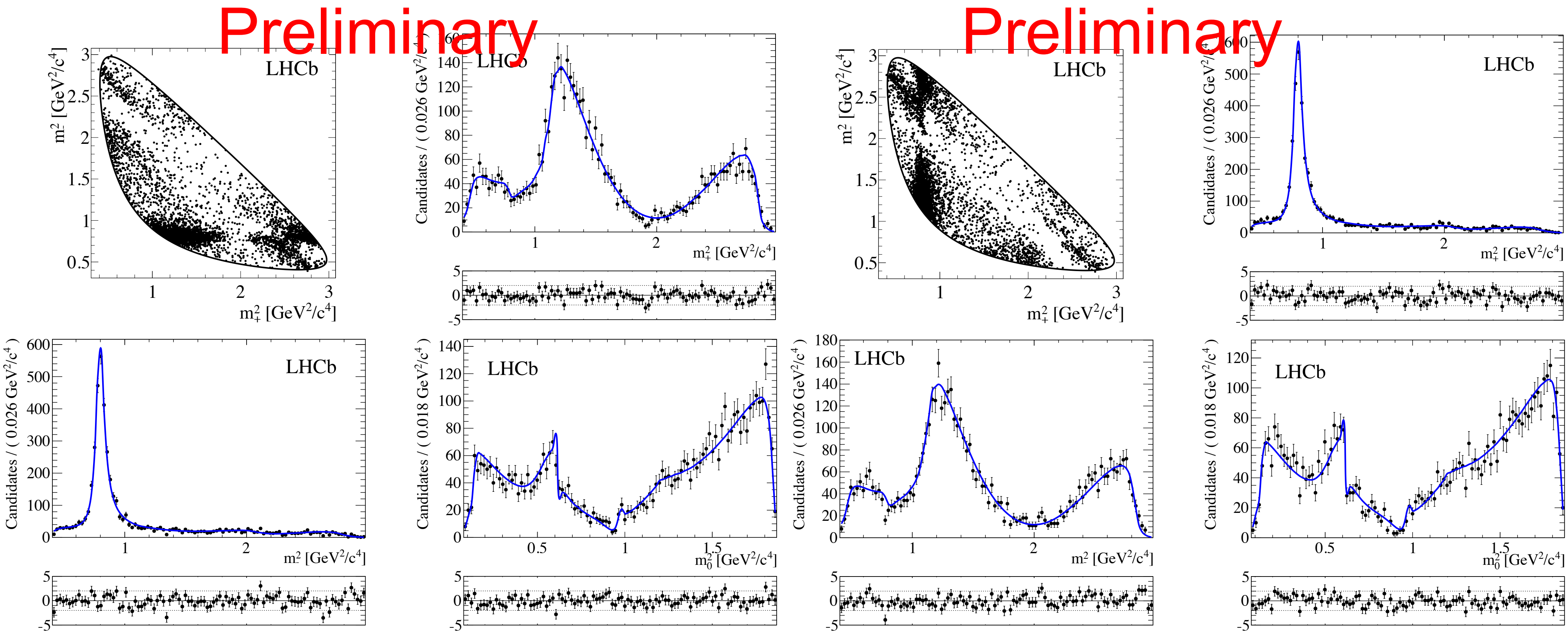
Preliminary



Preliminary



1fb-1 MD GGSZ



Preliminary
Preliminary
LHCb
LHCb
LHCb
LHCb
LHCb
LHCb
LHCb
LHCb