Hadronic b→c decays at Belle

($B^+ \to D^{(*)}K$ Dalitz, $B^0 \to D_s^{(*)}h$, $B^- \to \bar{p}\Lambda D$)

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Outline

Efforts put

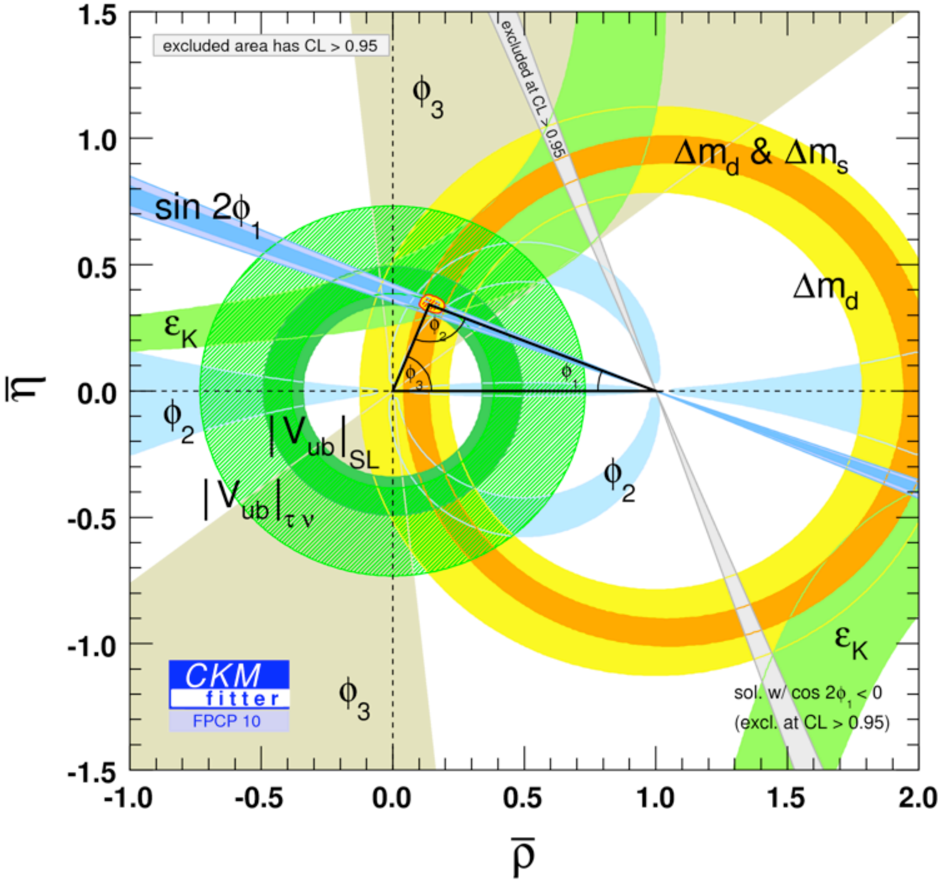
- in the direct determination of φ_3
  - $B^{\pm}\to D^{(*)}K^{\pm}$ Dalitz or GGSZ (ref: Giri *et al, Phys. Rev. D,* **68**, 054018 (2003))
- towards indirect determination of φ_3
  - $B^0\to D_s^{(*)}h$ in $B^0\to D^{(*)}\pi$ TCPV (ref: Dunietz *et al, Phys. Rev. D,* **65**, 054025 (2002))
- in testing of the *generalized factorization*
  - $B^-\to \bar{p}\Lambda D$ (ref: C. Chen, *Phys. Rev. D,* **78**, 054016 (2008))

CKM matrix and Φ_3 (γ) Angle

- Current CKM picture, as shown in FPCP10 by the *CKMfitter* group

$$\phi_1 = (21.15^{+0.90}_{-0.88})$$
$$\phi_2 = (89.0^{+4.4}_{-4.2})$$
$$\phi_3 = (70^{+14}_{-21})$$

(in degree)



Angle φ_3 needs more efforts and is more difficult to estimate

Event Selection

- charged tracks:
  - $|dr| < 0.2$ cm, $|dz| < 4$ cm
- photon:
  - $E_\gamma > 100$ MeV
- charged hadron (K/π):
  - $\mathcal{L}_{Total} = \mathcal{L}_{CDC} \times \mathcal{L}_{TOF} \times \mathcal{L}_{ACC}$
  - $\mathcal{L}(K/\pi) > 0.6$ for a kaon
  - efficiency ~ 85%, fake rate ~ 10%
- K_S^0 :
  - reconstructed from $\pi^+\pi^-$
  - quality check based on vertex topology
  - $| M(K_S^0) - M_{PDG} | < 10$ MeV/c^2

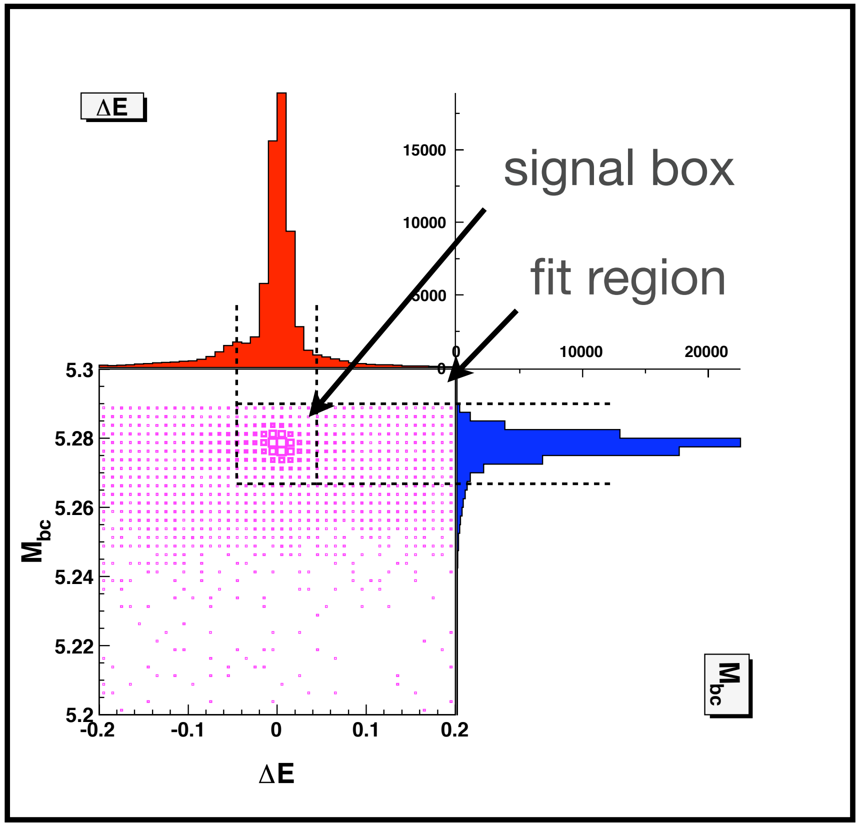
Continuum suppression:

Likelihood based on event topology

- Fisher $\mathcal{F}$,
- *B* meson thrust angle $\cos\theta_{th}$,
- *B* meson polar angle $\cos\theta_B$

B meson Reconstruction:

- B^0 candidate selection based on kinematically uncorrelated ΔE and M_{bc} variables



$$M_{\rm bc} = \sqrt{E^2_{\rm beam} - (\sum_i p^*_i)^2}$$

$$\Delta E = \sum_i E^*_i - E_{\rm beam}$$

where,

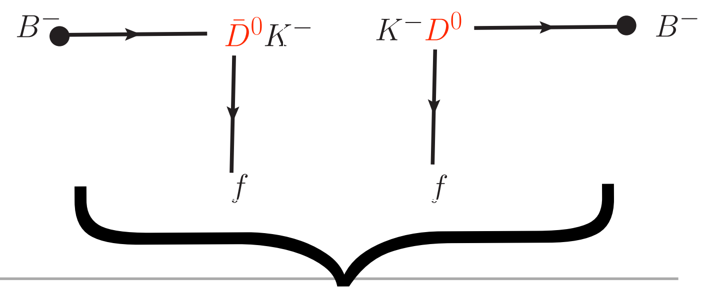
(E_i^*, p_i^*) are the i^{th} final-state 4-momentum in the center-of-mass frame, and

E_{beam} is the beam energy

All results on 657 M $B\bar{B}$ events!

$B^{\pm} \to D^{(*)} K^{\pm}$

(Dalitz)



interfere

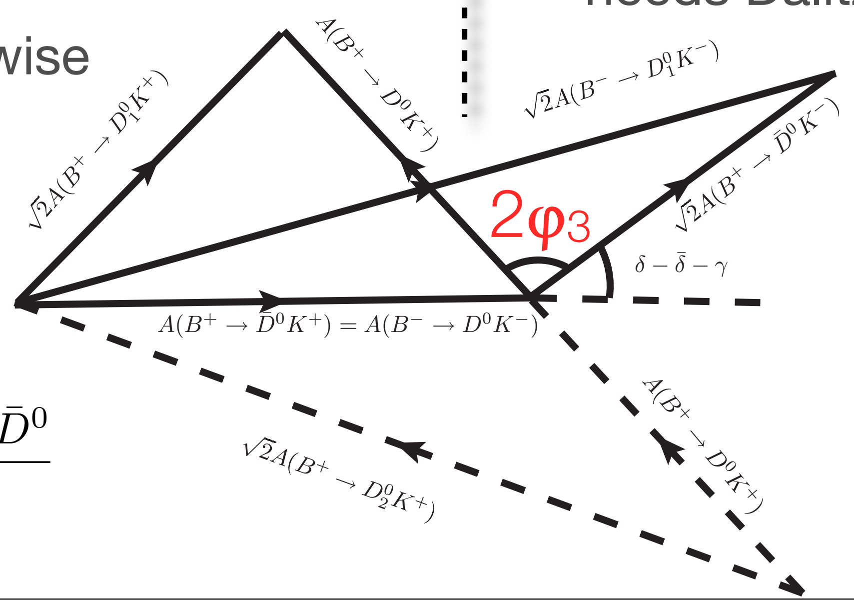
$B^\pm \rightarrow DK^\pm$

ADS

- f = $K^+\pi^-$
- col. sup. x Cabibbo allowed ~ col. allowed x Cabibbo sup.
- no control over strong phases
- statistically limited
- simpler analysis-wise

Dalitz

- f = $K_S^0\pi^+\pi^-$
- Cabibbo allowed modes
- large strong phases due to resonances
- most sensitive
- needs Dalitz analysis



$$D_{1,2}^0 = \frac{D^0 \pm \bar{D}^0}{\sqrt{2}}$$

<u>model dependent/ independent</u>
dependency:
D^0 decay model (Isobar, BW)

(ref: A. Poluektov *et al*, *Phy. Rev. D* **81**, 112002(2010))

$B \to D^{(*)}K$ Dalitz (model dependent)

- Amplitude for $B^\pm \to DK^\pm$ process can be expressed as

$$M_\pm = f(m^2_\pm, m^2_\mp) + r_\pm e^{\pm i\phi_3 + i\delta} f(m^2_\mp, m^2_\pm)$$

$$m^2_\pm = m^2_{K^0_S \pi^\pm}$$

$r_\pm$: ratio of magnitudes of interfering amplitudes (expected ~ 1%)

f: amplitude of $\overset{(-)}{D^0} \to K_S^0 \pi^+ \pi^-$ decay :

1. determined from Dalitz plot of large continuum data,
2. flavor-tagged by soft pion charge in $D^{*\pm} \to D\pi_s^\pm$
3. assuming isobar model, BW shapes for resonances

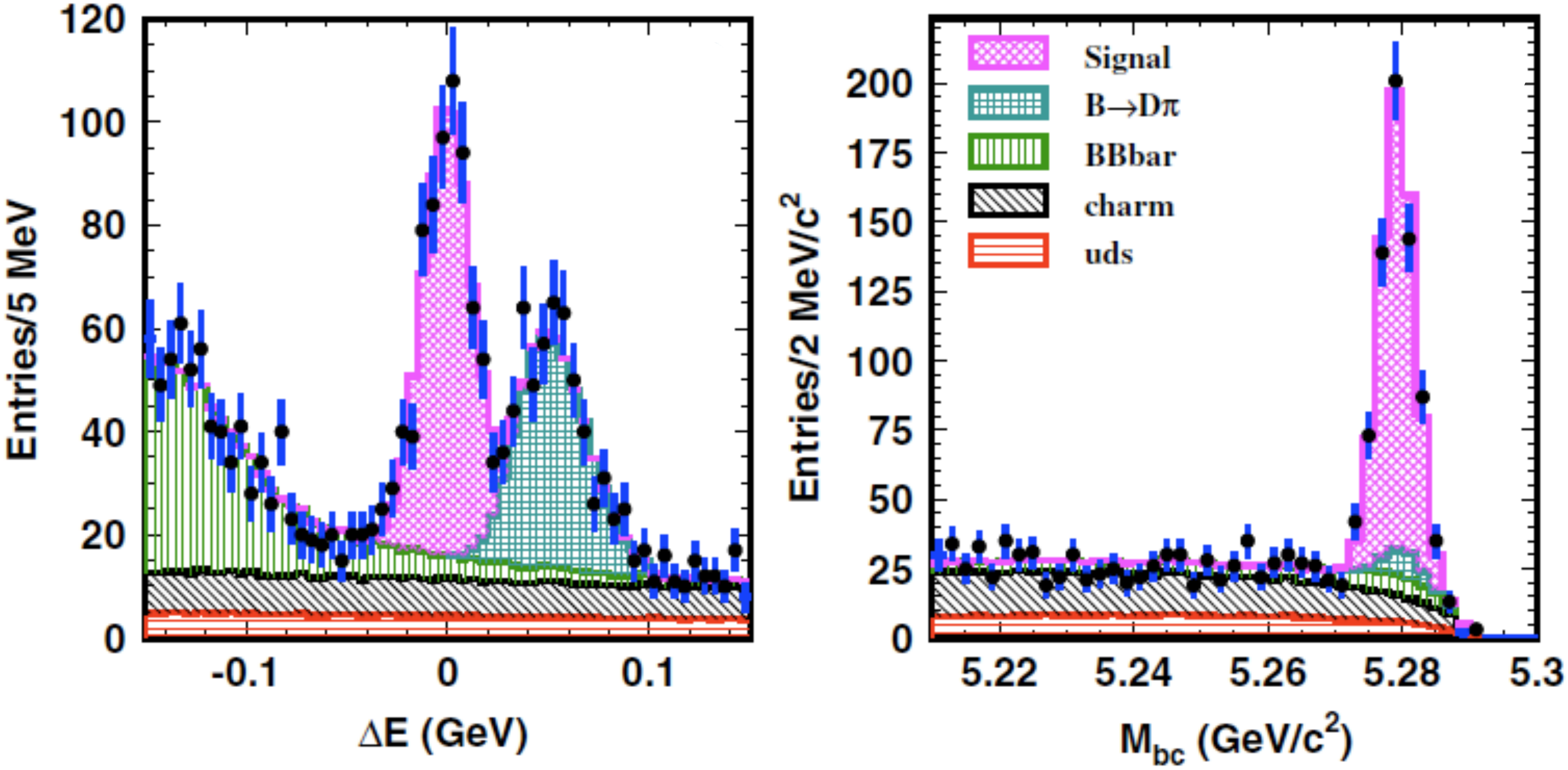
Analysis procedure:

- first step: background fractions are obtained from ΔE-M_{bc} 2D unbinned maximum likelihood (UML) fit
- Second step: Dalitz, with likelihoods (continuum separation) inside the fit using $x_\pm = r_\pm \cos(\pm\varphi_3 + \delta)$ and $y_\pm = r_\pm \sin(\pm\varphi_3 + \delta)$

(ref: A. Poluektov *et al*, *Phy. Rev. D* **81**, 112002(2010))

B→DK ΔE-M_{bc}

A 2D UML fit with free parameters: background relative fractions



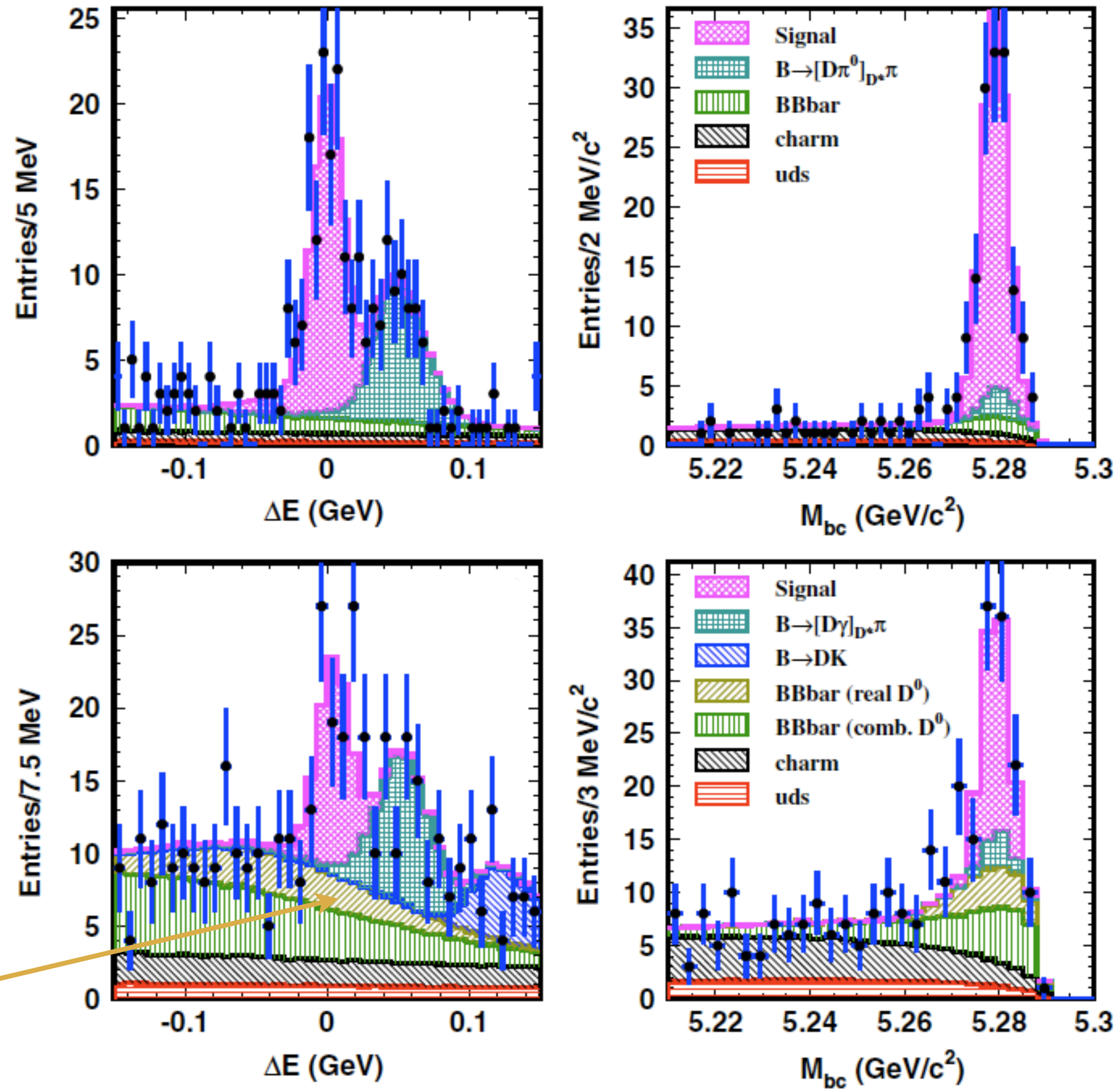
Note: continuum background is separated into **charm** and u,d,s components

(ref: A. Poluektov *et al*, *Phy. Rev. D* **81**, 112002(2010))

$B \to D^{*}K$ ΔE-M_{bc}

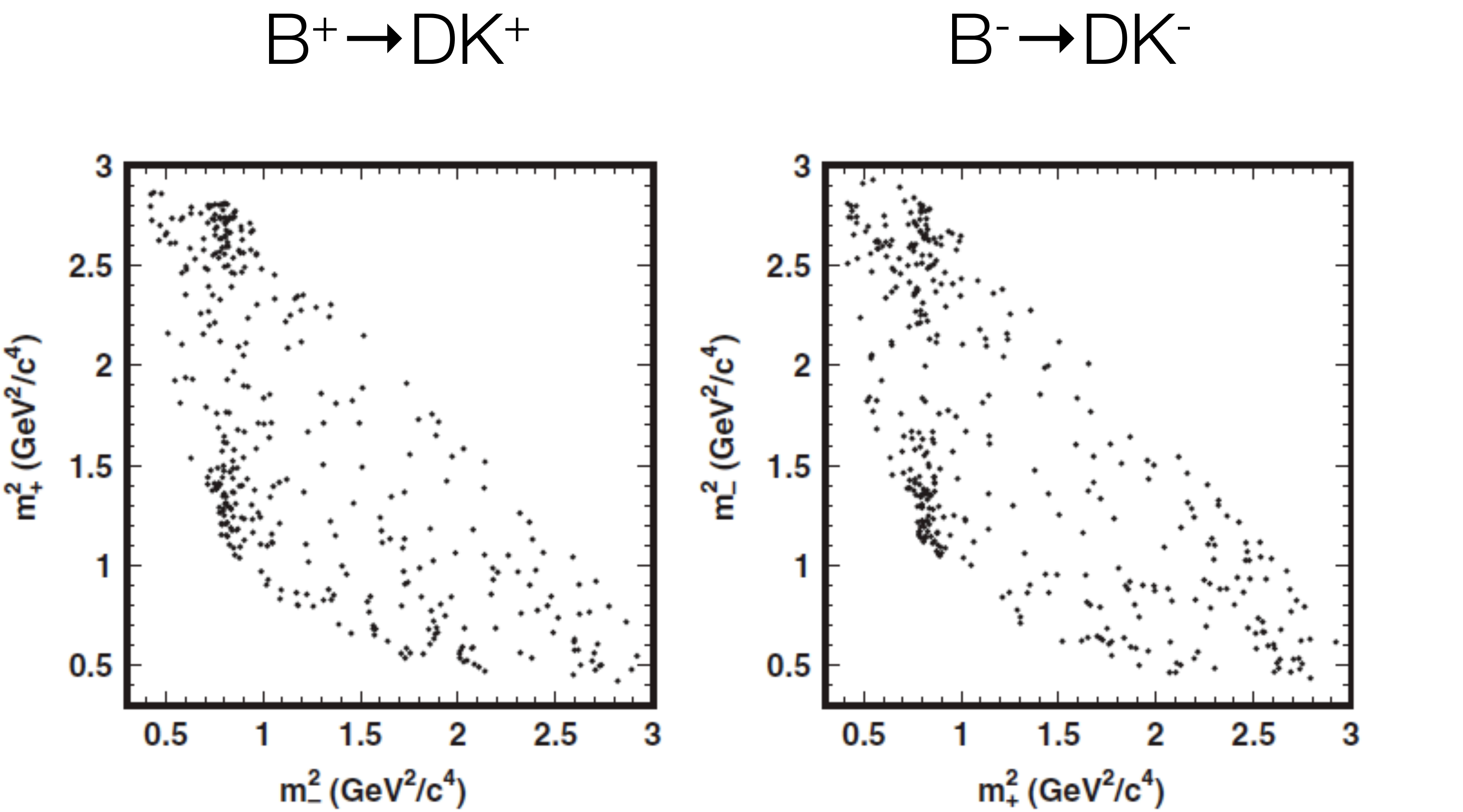
- $D^{*} \to D\pi^0$
- $D^{*} \to D\gamma$

photon cross-feed



(ref: A. Poluektov *et al*, *Phy. Rev. D* **81**, 112002(2010))

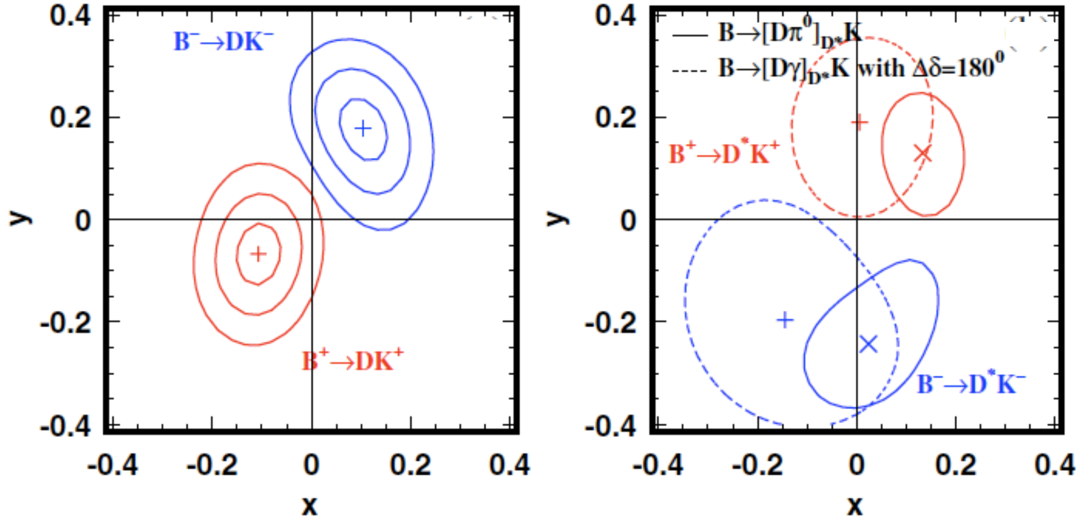
B→DK Dalitz



(ref: A. Poluektov *et al*, *Phy. Rev. D* **81**, 112002(2010))

$B \to D^{(*)}K$ Dalitz (model dependent)

To improve sensitivity, combine various $B^{\pm} \to D^{(*)}K^{\pm}$ modes



- combined $B^{\pm} \to D^{(*)}K^{\pm}$ results:

Parameter	1σ interval	2σ interval	Systematic error	Model uncertainty
ϕ_3	$(78.4^{+10.8}_{-11.6})°$	$54.2° < \phi_3 < 100.5°$	$3.6°$	$8.9°$
r_{DK}	$0.160^{+0.040}_{-0.038}$	$0.084 < r_{DK} < 0.239$	0.011	$+0.050 - 0.010$
r_{D^*K}	$0.196^{+0.072}_{-0.069}$	$0.061 < r_{D^*K} < 0.271$	0.012	$+0.062 - 0.012$
δ_{DK}	$(136.7^{+13.0}_{-15.8})°$	$102.2° < \delta_{DK} < 162.3°$	$4.0°$	$22.9°$
δ_{D^*K}	$(341.9^{+18.0}_{-19.6})°$	$296.5° < \delta_{D^*K} < 382.7°$	$3.0°$	$22.9°$

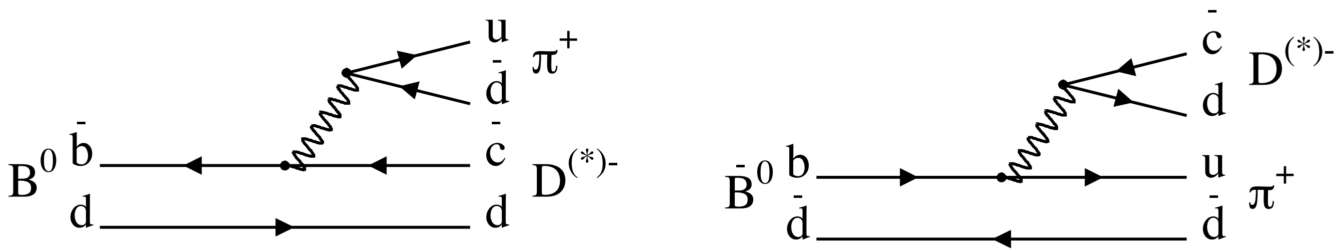
possible to remove model uncertainty:
perform a fit in the momentum-binned Dalitz plot
(much along the original idea of GGSZ)

$B \to D_s^{(*)} h$
$(h = K/\pi)$

Time dependent CP Analysis

$$B^0 \to D^{(*)\mp}\pi^{\pm}$$

- theoretically cleanliest method of extracting the $\sin(2\varphi_1 + \varphi_3)$ and hence the φ_3
- Initial state B^0 can be found in the state $D^{*-}\pi^+$ state in two ways: either through CFD or via mixing followed by DCSD



(a) CFD (b) DCSD

- The DCSD involves b→u transition, and the phase φ_3 shows up due to the interference between the two as,

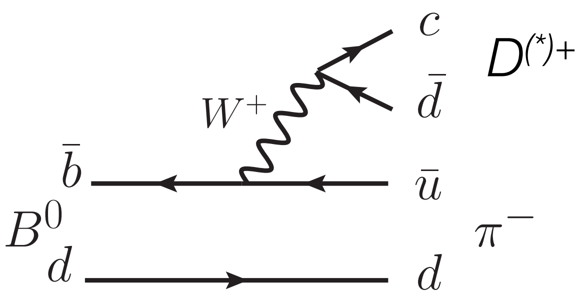
$$R_{D^{(*)}\pi}\sin(2\phi_1 + \phi_3)$$

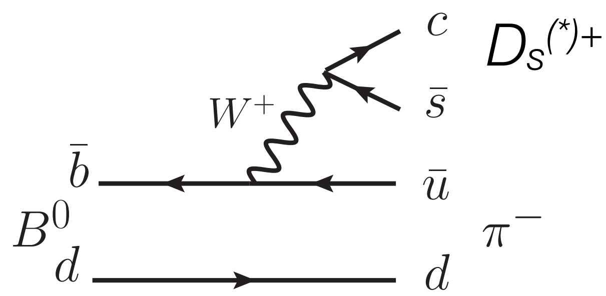
where, $R_{D^*\pi}$ is the ratio of magnitude of DCSD and CFD amplitude and must be provided externally.

$B^0 \to D_s^{(*)} h$

- $B^0 \to D_s^{*+} \pi^-$ is related to $B^0 \to D^{*+} \pi^-$ (DCSD) by SU(3) symmetry

DCSD





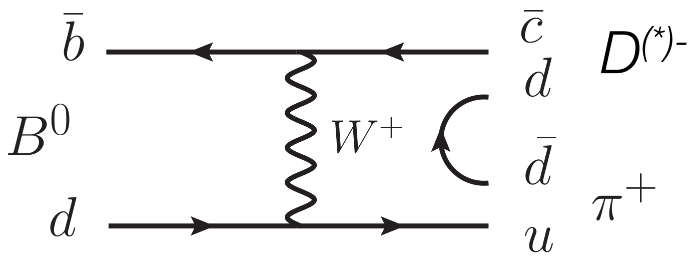
$D_s^{(*)+} \pi^-$

which means, $\mathcal{R}_{D^{(*)}\pi} = \tan\theta_C \frac{f_{D^{(*)}}}{f_{D_s^{(*)}}} \sqrt{\frac{\mathcal{B}(B^0 \to D_s^{(*)+} \pi^-)}{\mathcal{B}(B^0 \to D^{(*)-} \pi^+)}}$

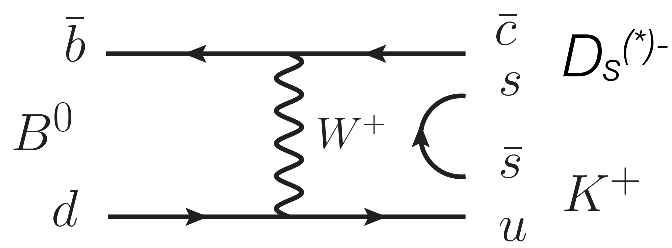
<u>Theory predicts</u>
$R_{D(*)\pi}$ ~ 2%

$B^0 \rightarrow D_s^{(*)}h$

- $B^0 \rightarrow D_s^{*-}K^+$ is related to CFD *W*-exchange by SU(3) symmetry



CFD *W*-exchange



$B^0 \rightarrow D_s^{*-}K^+$

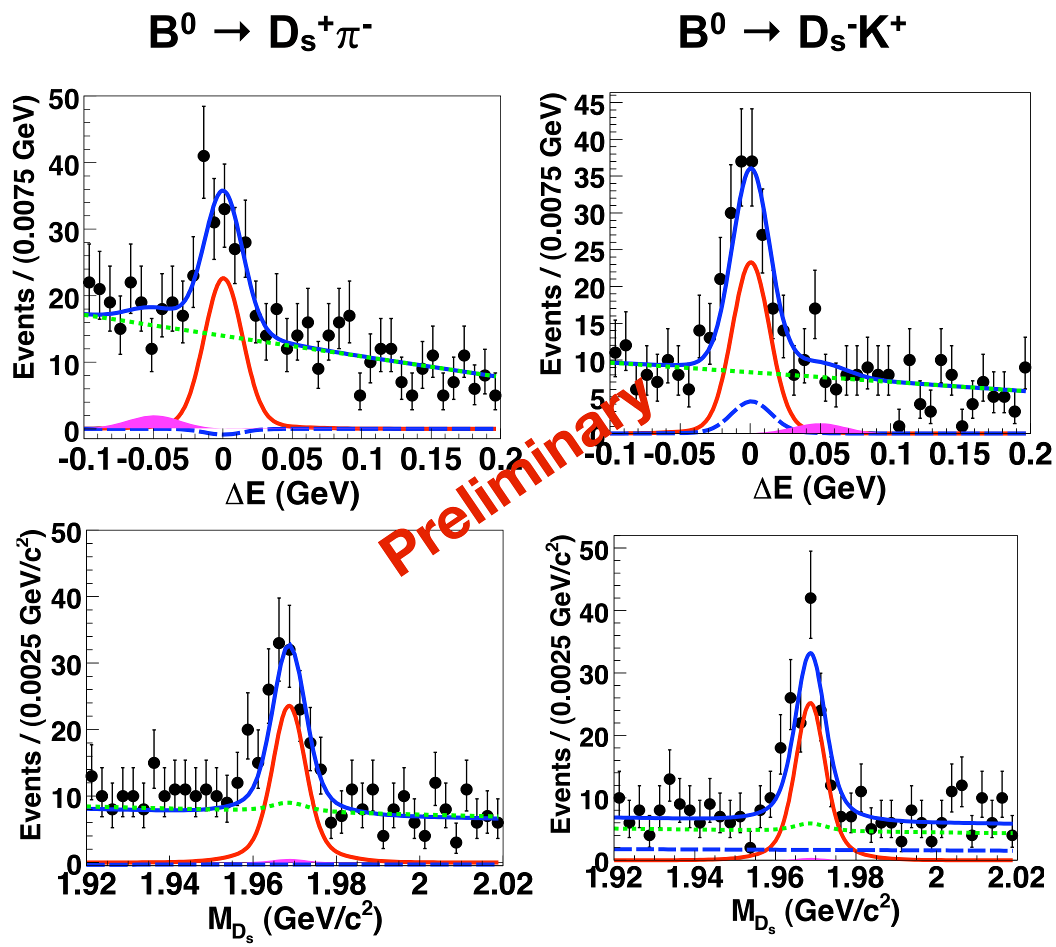
- $B^0 \rightarrow D_s^{*-}K^+$ is expected to be enhanced due to re-scattering effects ⇒ needs check!

(ref: Phys. Rev. Lett., **78**, 3999 (1997)
Phys. Lett. B, **666**, 185 (2008))

$B^0 \to D_s h$

A ΔE-M_{D_s} 2D UML fit is performed

- signal is reconstructed in three D_s^+ decay channels: $\varphi\pi$, $K^*(892)^0K$, K_S^0K
- $B^0 \to D_s^+\pi^-$ and $B^0 \to D_s^+K^-$ cross-feed each other
- data fitted simultaneously in 3 x 2 mutually exclusive samples



We obtained,

$$\mathcal{B}(B^0 \to D_s^+\pi^-) = (1.99 \pm 0.26 \pm 0.18) \times 10^{-5}$$

and

$$\mathcal{B}(B^0 \to D_s^-K^+) = (1.91 \pm 0.24 \pm 0.17) \times 10^{-5}$$

with significances 8.0σ and 9.2σ, respectively.

$$\mathcal{R}_{D\pi} = [1.71 \pm 0.11(\text{stat}) \pm 0.09(\text{syst}) \pm 0.02(\text{th})]\%$$

(ref: N. J Joshi *et al*, *Phy. Rev. D* **81**, 031101(2010))

$B^0 \to D_s^* h$

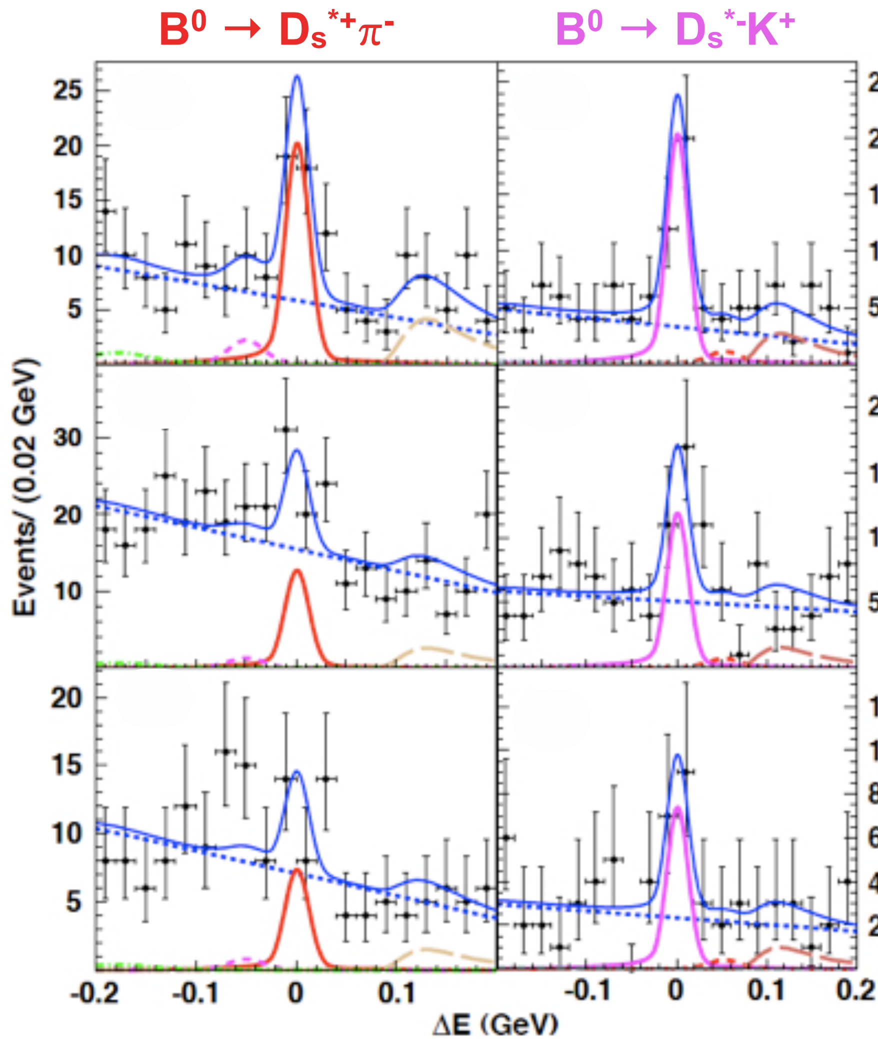
An UML fit to ΔE is performed to six exclusive samples

$\lvert M_{Ds} - M_{PDG}\rvert < 15$ MeV/c^2
132 MeV/c^2 < ΔM < 168 MeV/c^2

$D_s^+ \to \varphi\pi^+$

$D_s^+ \to K^{*0}K^+$

$D_s^+ \to K_S^0K^+$



We obtain,

$$\mathcal{BR}(B^0 \to D_s^{*+}\pi^-) = (1.75^{+0.32}_{-0.34}) \times 10^{-5}$$

and

$$\mathcal{BR}(B^0 \to D_s^{*-}K^+) = (2.02^{+0.33}_{-0.31}) \times 10^{-5}.$$

with significances 6.1σ and 8.0σ, respectively

$$\mathcal{R}_{D^*\pi} = [1.58 \pm 0.15(\mathrm{stat}) \pm 0.10(\mathrm{syst}) \pm 0.03(\mathrm{th})]\%$$

$B^- \to \bar{p}\Lambda D$

$B^- \to \bar{p}\Lambda D$: A test for *generalized factorization*

- The vertex (and the penguin correction thereof) of the hadronic matrix elements of four quark operators can be absorbed in the effective Wilson coefficients c^{eff}, so that the momentum dependence is smeared out

- Under generalized factorization:

<u>three body amplitudes</u>

1. current type
2. transition type
3. hybrid

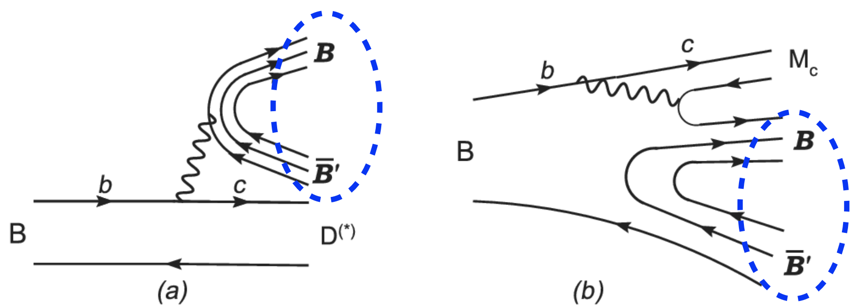


FIG. 1. Two types of the $B \to \mathbf{B}\bar{\mathbf{B}}'M_c$ decay process: (a) current type and (b) transition type.

- Under generalized factorization approximation, one predicts the decay amplitude

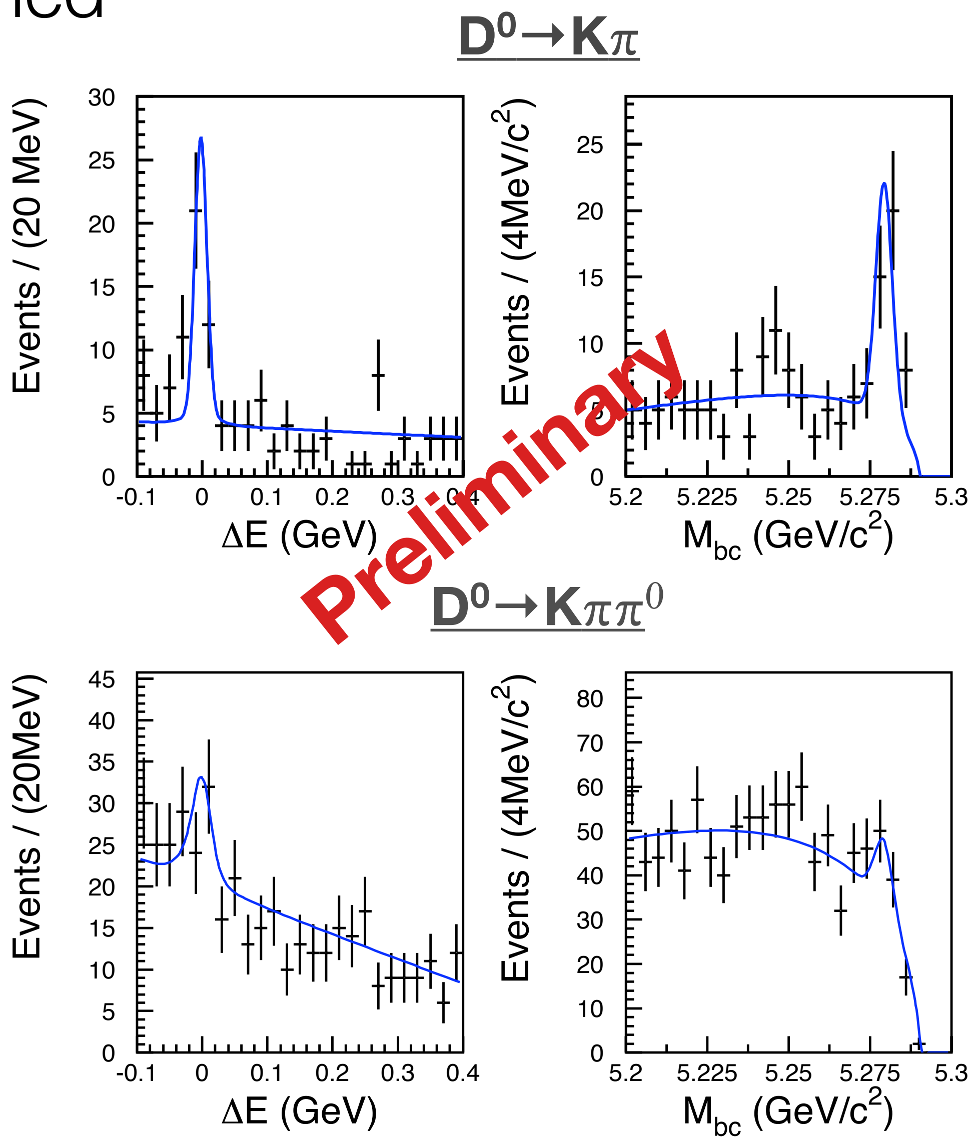
$$\mathcal{B}(B^- \to \bar{p}\Lambda D^0) \sim 1.1 \times 10^{-5}$$

proceeding via **threshold** enhancement.

$B^- \to \bar{p}\Lambda D^0$

An UML fit to ΔE-M_{bc} is performed

- $\mathscr{L}(p/h) > 0.6$ for a proton
- Λ selection
  1. quality check vertex topology
  2. 1.111 GeV/c^2 < M_Λ < 1.121 GeV/c^2
- D meson is reconstructed in two decay channels
  1. $D^0 \to K\pi$
  2. $D^0 \to K\pi\pi^0$



We report,

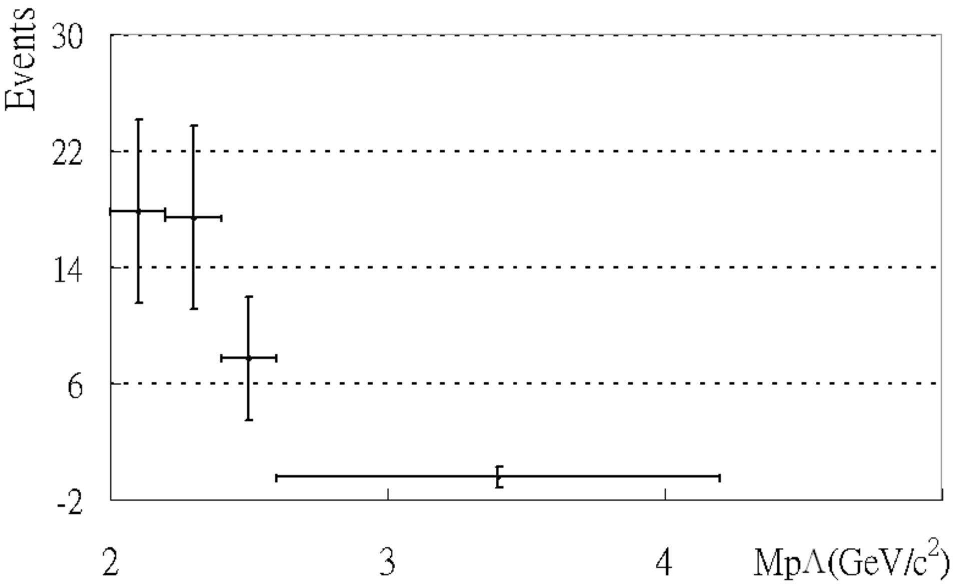
$$\mathcal{B}(B^- \to \bar{p}\Lambda D^0) = (1.40^{+0.27}_{-0.24} \pm 0.16) \times 10^{-5}$$

with a significance of 8.6σ.

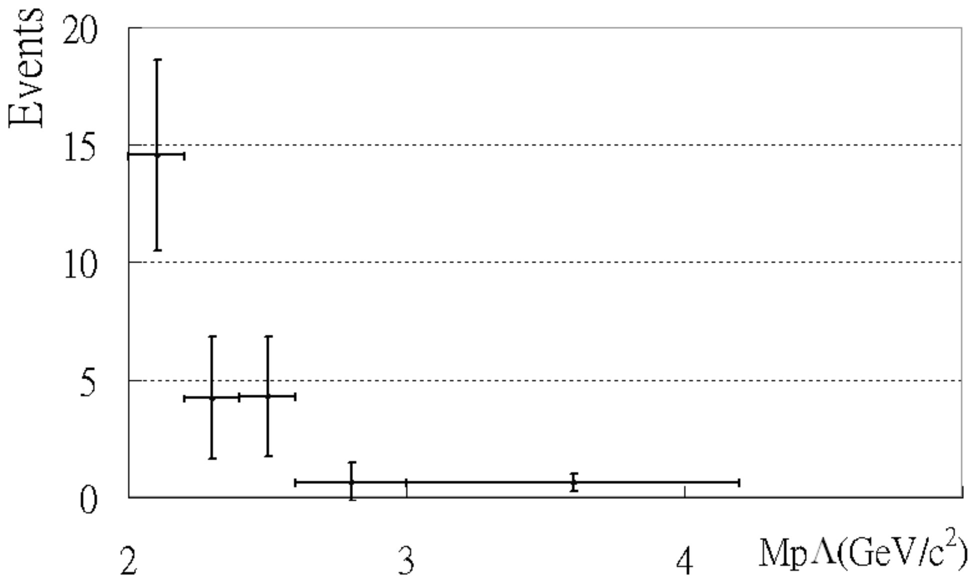
$B^- \to p\Lambda D$

We also observe $p\Lambda$ threshold enhancement near 2 GeV/c^2

$D^0 \to K\pi$



$D^0 \to K\pi\pi^0$



Conclusion

- We report results from $B^{\pm}\rightarrow D^{(*)}K^{\pm}$ Dalitz analysis done using isobar model, as

$$\phi_3 = (78.4^{\circ}{}^{+10.8^{\circ}}_{-11.6^{\circ}} \pm 3.6^{\circ}(\mathrm{syst}) \pm 8.9^{\circ}(\mathrm{model}))$$

- A model-independent study is undertaken to reduce the model-uncertainties.

- $B^0\rightarrow D_s h$ measurements yield $R_{D\pi}$ = [1.71 ± 0.11 (stat) ± 0.09 (syst) ± 0.02 (th)]% , consistent with the theoretical predictions of 2%

- $B^0\rightarrow D_s^* h$ measurements yield $R_{D^*\pi}$ = [1.58 ± 0.15 (stat) ± 0.10 (syst) ± 0.03 (th)]%

- $B^-\rightarrow p\Lambda D^0$ study shows agreement with the expectations from the *generalized factorization* approach

Back up

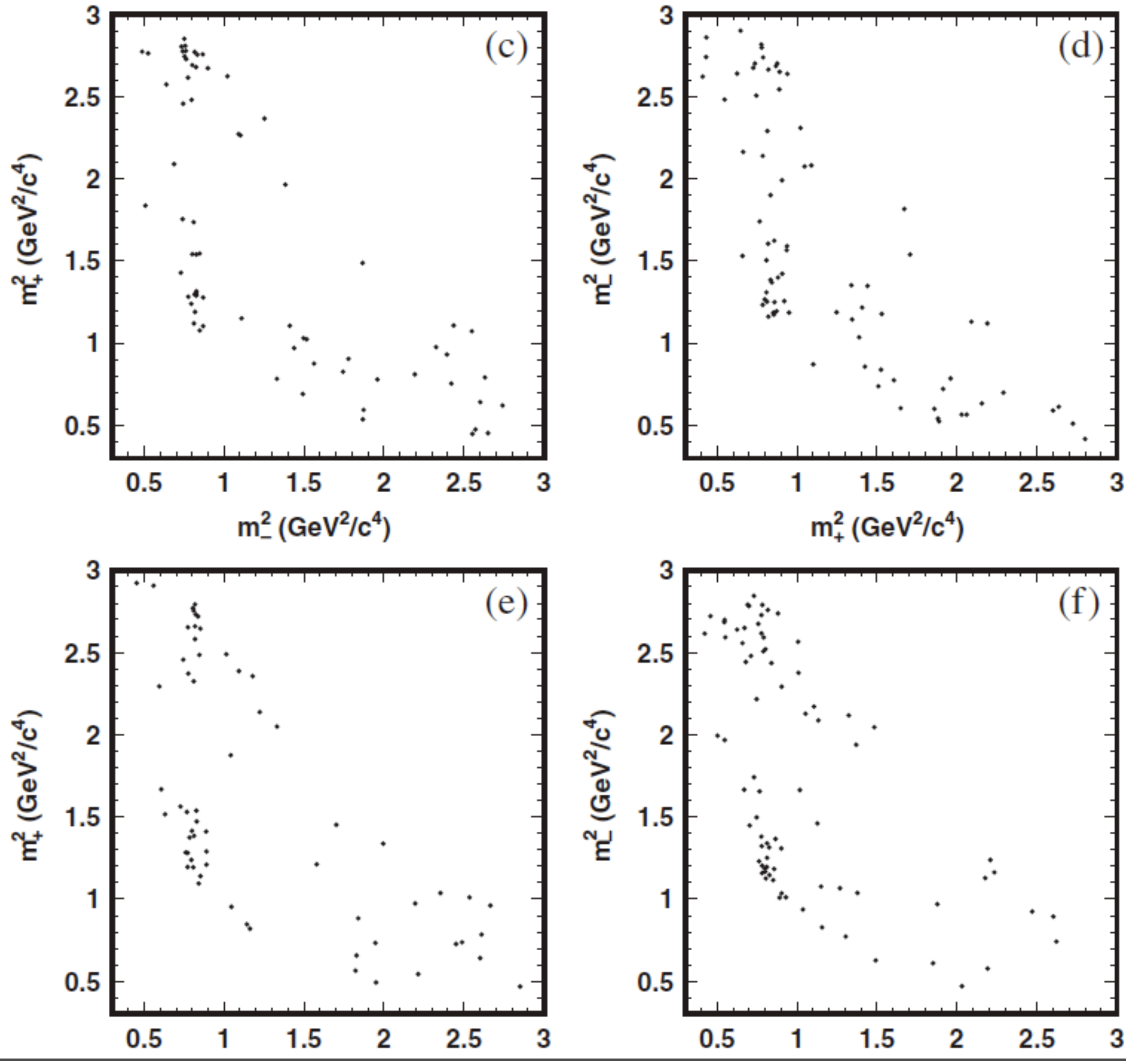
(ref: *Phy. Rev. D* **81**, 112002(2010))

$B \to D^* K$ Dalitz

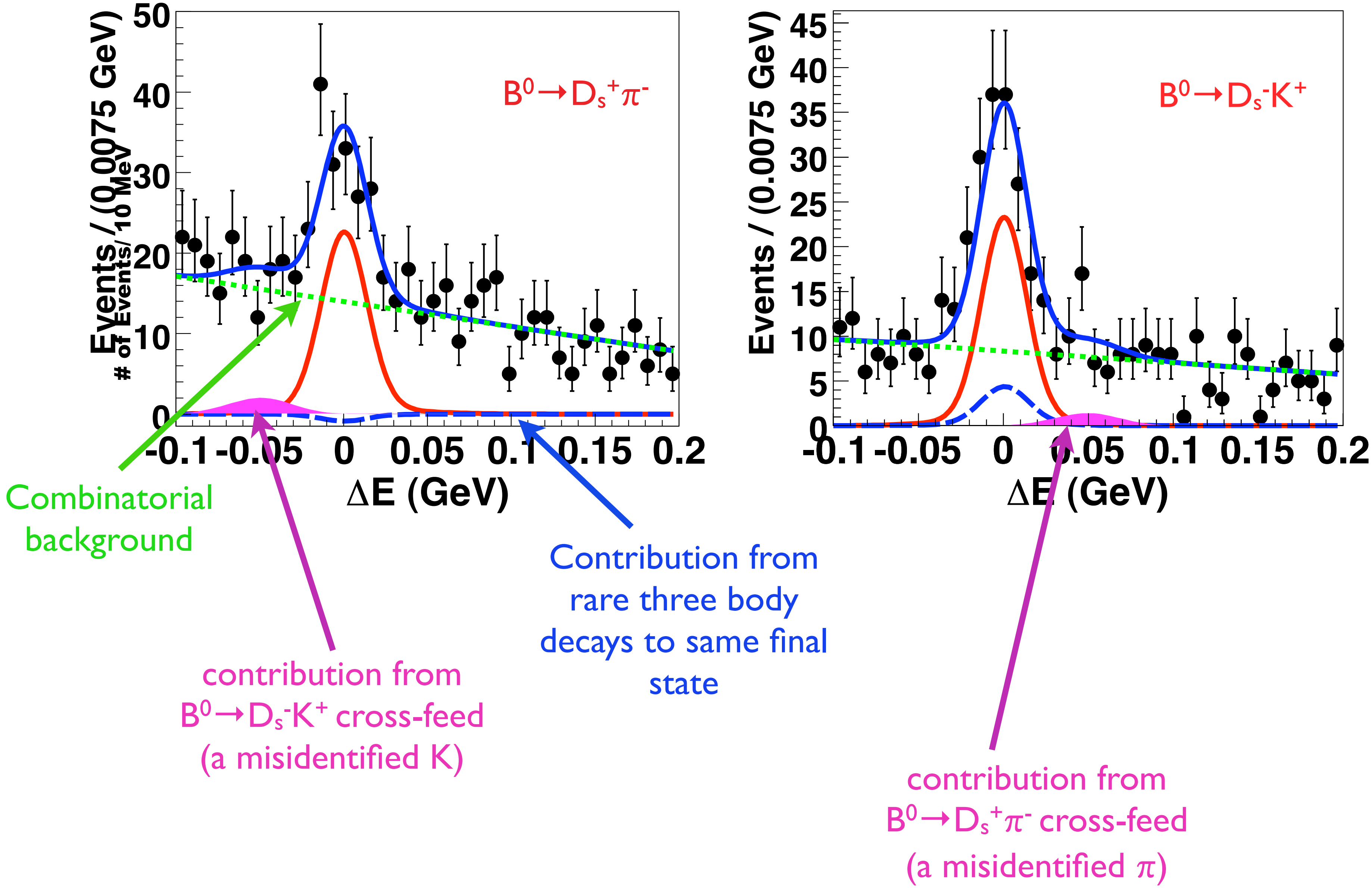
$B^+ \to D^* K^+$ | **$B^- \to D^* K^-$**

$D^* \to D\pi^0$

$D^* \to D\gamma$



Result:
Fit Explained



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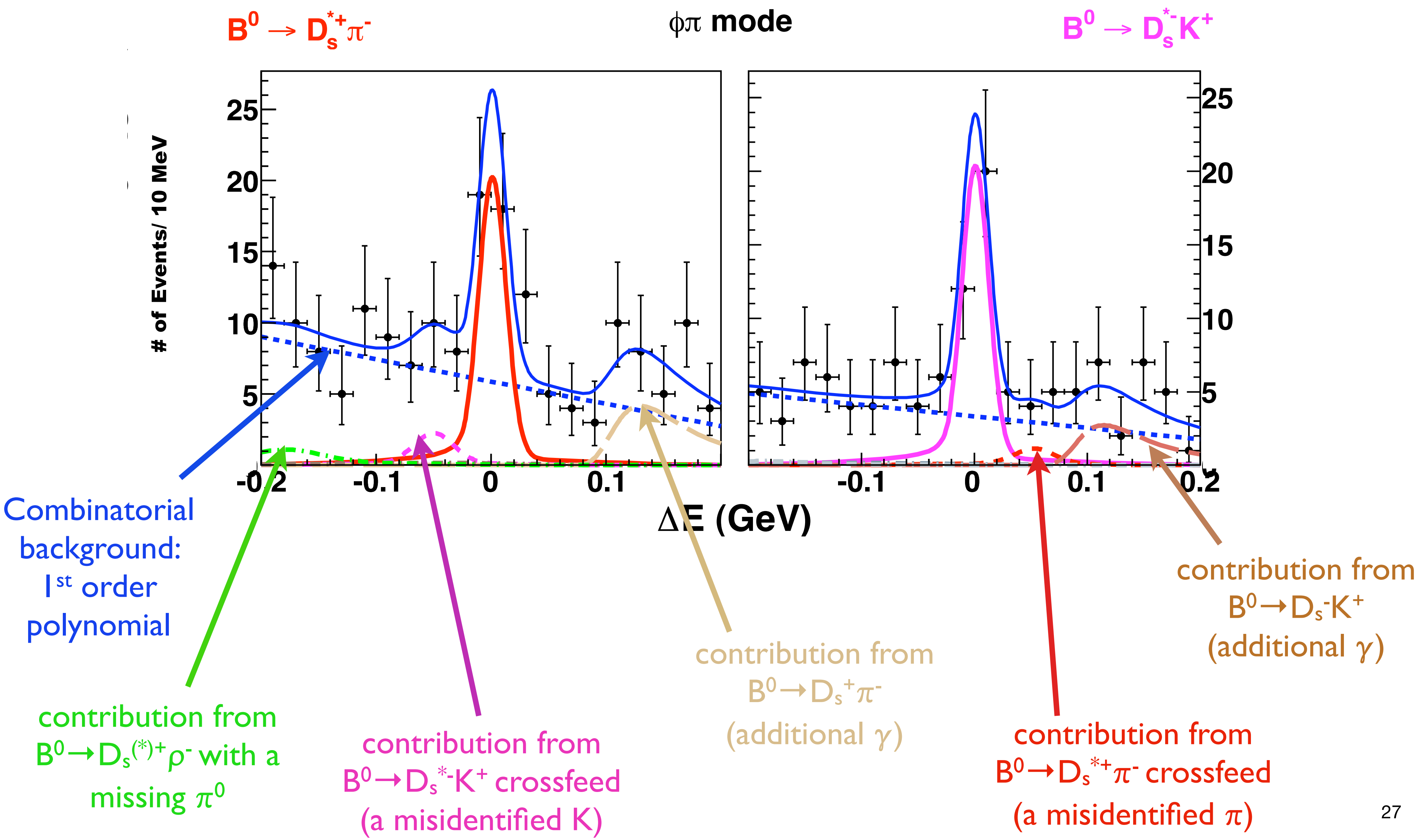

Individual branching fractions of $B^{-} \to p\Lambda D$

$D^0 \to K\pi$

$$\mathcal{B}(B^- \to \bar{p}\Lambda D^0(K\pi)) = (1.43^{+0.34}_{-0.30} \pm 0.14) \times 10^{-5}$$

with a significance of 7.70σ.

$D^0 \to K\pi\pi^0$

$$\mathcal{B}(B^- \to \bar{p}\Lambda D^0(K\pi\pi^0)) = (1.35^{+0.44}_{-0.40} \pm 0.18) \times 10^{-5}$$

with a significance of 3.85σ.