Belle Results on Time-dependent CP Asymmetry for $B \to D^{*-}\pi^+$ and Search for $B \to D^{*+}\pi^0$ Decay

Masaya Iwabuchi

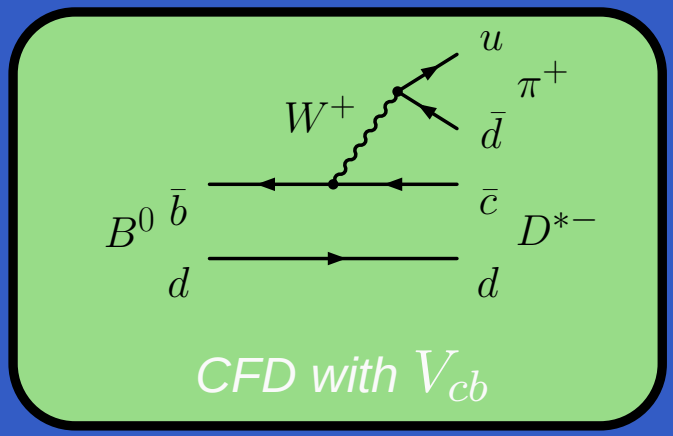
iwabuchi@post.kek.jp

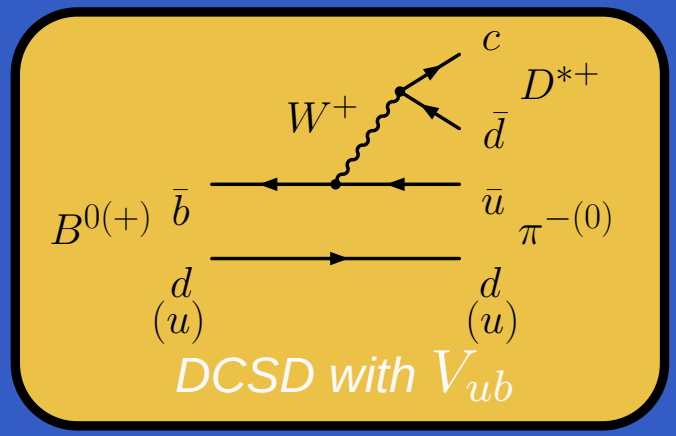
The Graduate University for Advanced Studies (Sokendai)

Tsukuba, Japan

Introduction

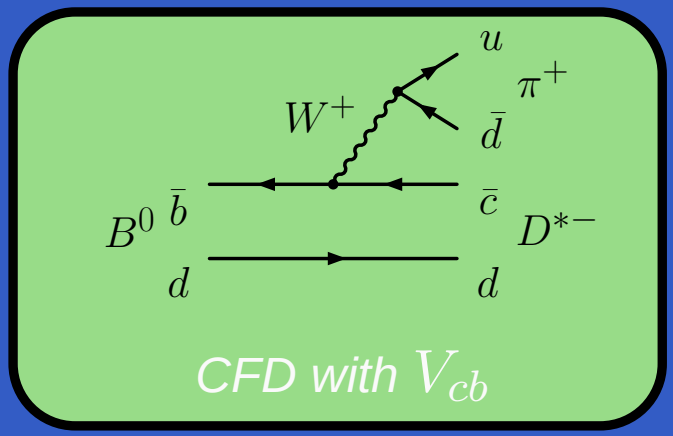
- Interference of different tree diagrams with V_{ub} ($\rightarrow \phi_3$) through $B\overline{B}$ mixing ($\rightarrow 2\phi_1$)

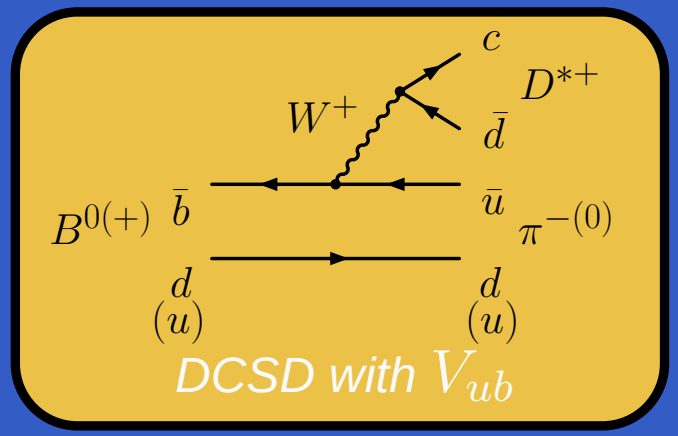




Introduction

- Interference of different tree diagrams with V_{ub} ($\rightarrow \phi_3$) through $B\overline{B}$ mixing ($\rightarrow 2\phi_1$)



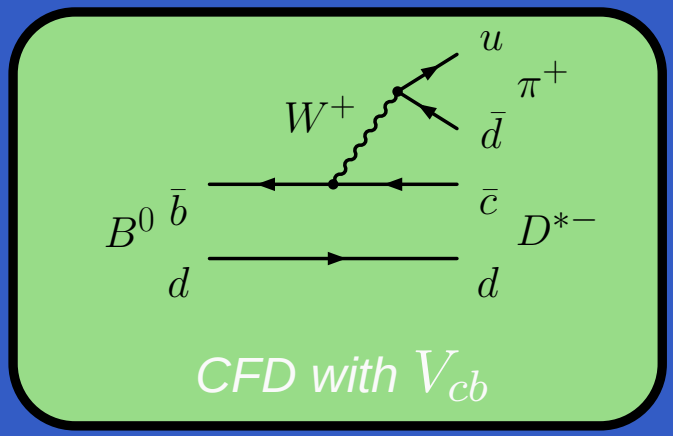


- Time-dependent asymmetry can be derived using the relation,

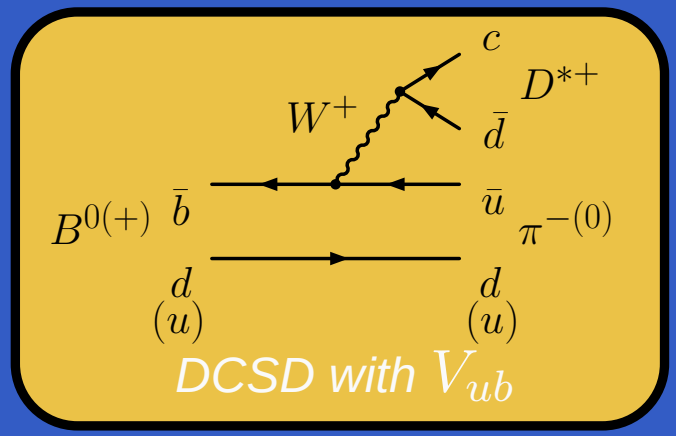
$$\frac{\Gamma(\overline{B}^0(\Delta t \rightarrow f)) - \Gamma(B^0(\Delta t \rightarrow f))}{\Gamma(\overline{B}^0(\Delta t \rightarrow f)) + \Gamma(B^0(\Delta t \rightarrow f))} = S \sin(\Delta m_d) - C \cos(\Delta m_d)$$

Introduction

- Interference of different tree diagrams with V_{ub} ($\rightarrow \phi_3$) through $B\overline{B}$ mixing ($\rightarrow 2\phi_1$)



CFD with V_{cb}



DCSD with V_{ub}

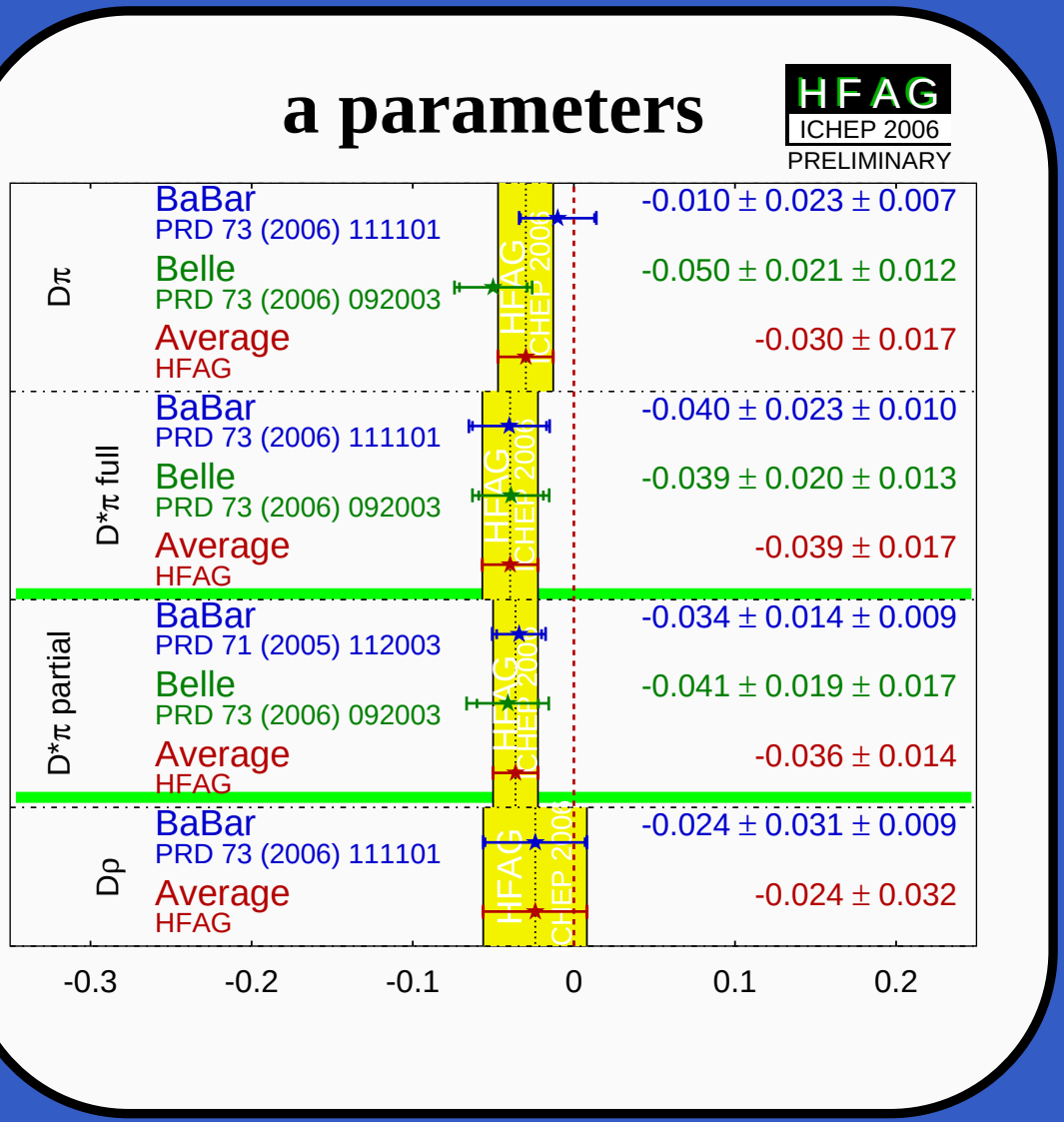
- Time-dependent asymmetry can be derived using the relation,

$$\frac{\Gamma(\overline{B}^0(\Delta t\rightarrow f))-\Gamma(B^0(\Delta t\rightarrow f))}{\Gamma(\overline{B}^0(\Delta t\rightarrow f))+\Gamma(B^0(\Delta t\rightarrow f))} = S\sin(\Delta m_d) - C\cos(\Delta m_d)$$

$$S^{\pm} = -2\,R\sin(2\phi_1 + \phi_3 \pm \delta) \qquad C = \pm 1$$

for $B \rightarrow D^{*\pm}\pi^{\mp}$ final states $\quad (|C| = (1-R^2)/(1+R^2) \simeq 1)$

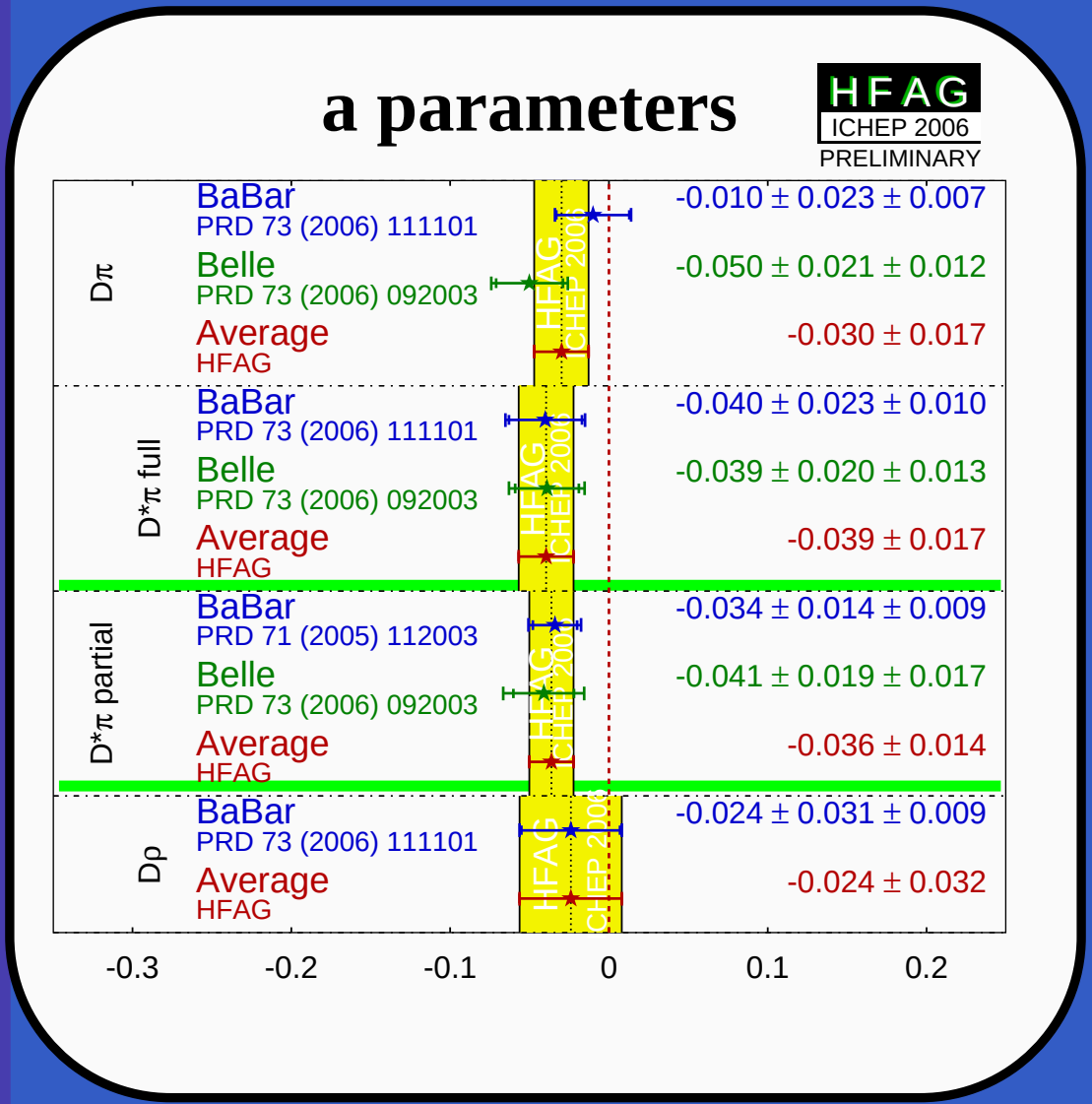
Introduction (Cont'd)



HFAG notation:

$$a = -\frac{S^+ + S^-}{2},\ c = -\frac{S^+ - S^-}{2}$$

Introduction (Cont'd)



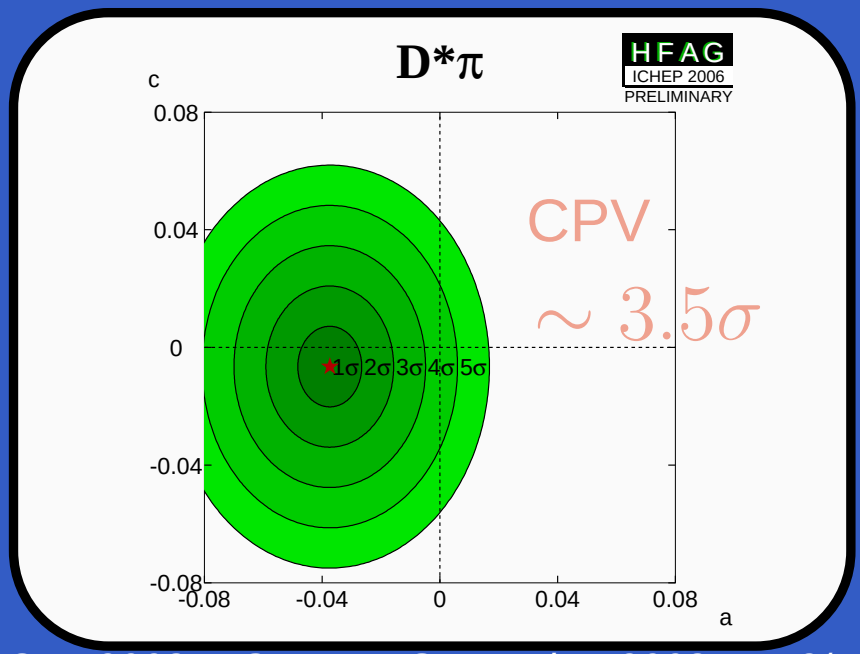
HFAG notation:

$$a = -\frac{S^+ + S^-}{2},\ c = -\frac{S^+ - S^-}{2}$$

HFAG average for $D^*\pi$ [2006]:
(full and partial, Babar and Belle)

$$a = -0.037 \pm 0.011$$

$$c = -0.006 \pm 0.014$$



Introduction (Cont'd)

- AD: CFD fraction $\mathcal{B}(B^0 \to D^{*-}\pi^+)$ is large (2.76×10^{-3}).
  DA: the amplitude ratio is not sizable,
  $$R \equiv \mathcal{A}(B^0 \to D^{*+}\pi^-)/\mathcal{A}(B^0 \to D^{*-}\pi^+) \simeq 0.02.$$
  : $B^0 \to \overline{B}^0 \to D^{*+}\pi^-$ (CFD) is large compared to the DCSD amplitude.

Introduction (Cont'd)

- AD: CFD fraction $\mathcal{B}(B^0 \to D^{*-}\pi^+)$ is large (2.76×10^{-3}).
  DA: the amplitude ratio is not sizable,
  $$R \equiv \mathcal{A}(B^0 \to D^{*+}\pi^-)/\mathcal{A}(B^0 \to D^{*-}\pi^+) \simeq 0.02.$$
  : $B^0 \to \overline{B}^0 \to D^{*+}\pi^-$ (CFD) is large compared to the DCSD amplitude.

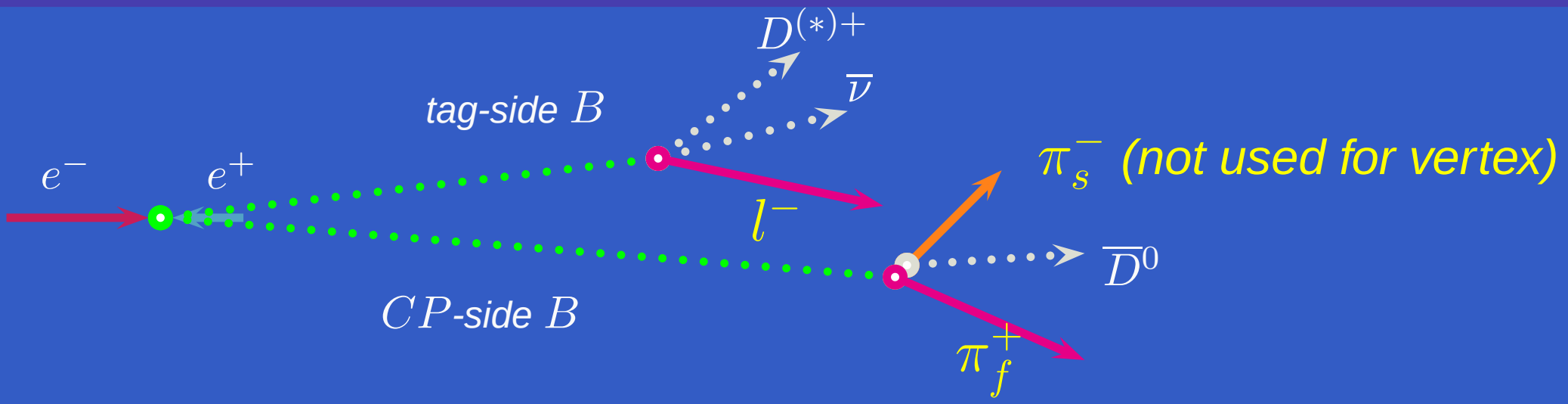
- Two possible ways for reaching R :
  - $R = \tan\theta_c \dfrac{f_{D^*}}{f_{D_s^*}} \sqrt{\dfrac{\mathcal{B}(B^0 \to D_s^{*+}\pi^-)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)}}$
    allowing the error from the assumption of SU(3) symmetry.
  - $R = \sqrt{\dfrac{\tau_{B^0}}{\tau_{B^+}} \dfrac{2\mathcal{B}(B^+ \to D^{*+}\pi^0)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)}}$
    as suggested by Duniez, PLB 427 (1998), using the isospin relation.

$B^0 \to D^*\pi$ partial reconstruction

$B^0 \to D^*\pi$ partial reconstruction

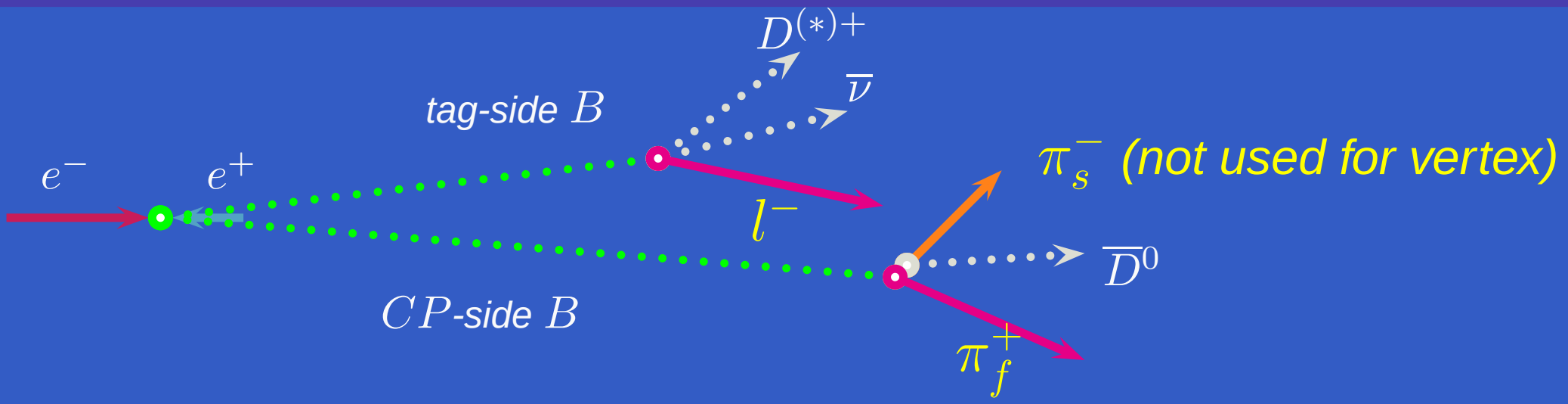
- High-momentum lepton is required in tag-side.

$B^0 \to D^*\pi$ partial reconstruction



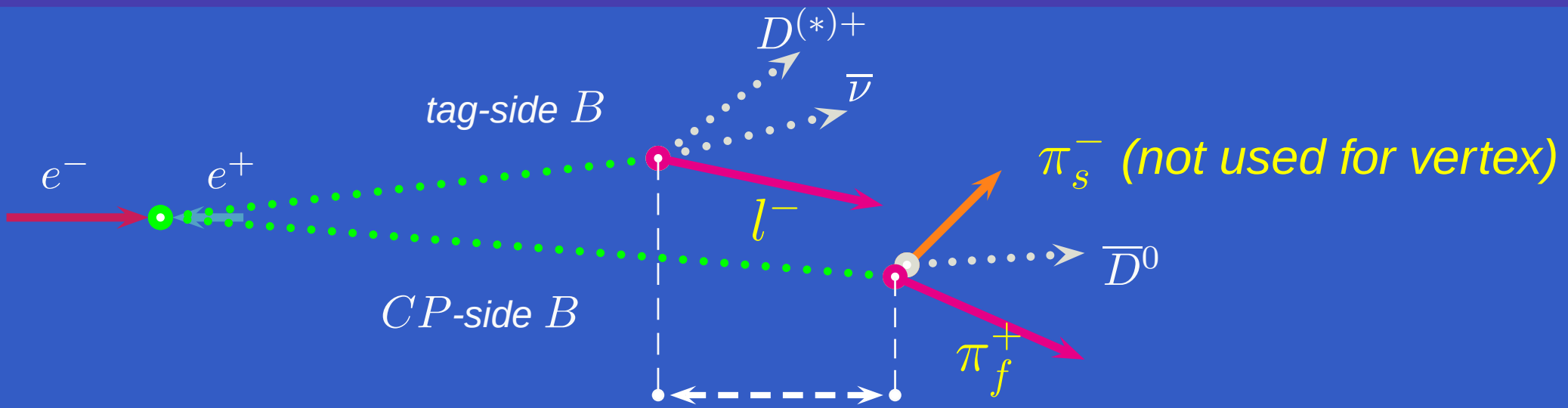
- High-momentum lepton is required in tag-side.
- Two charged pions must have high and low momentum.

$B^0 \to D^*\pi$ partial reconstruction



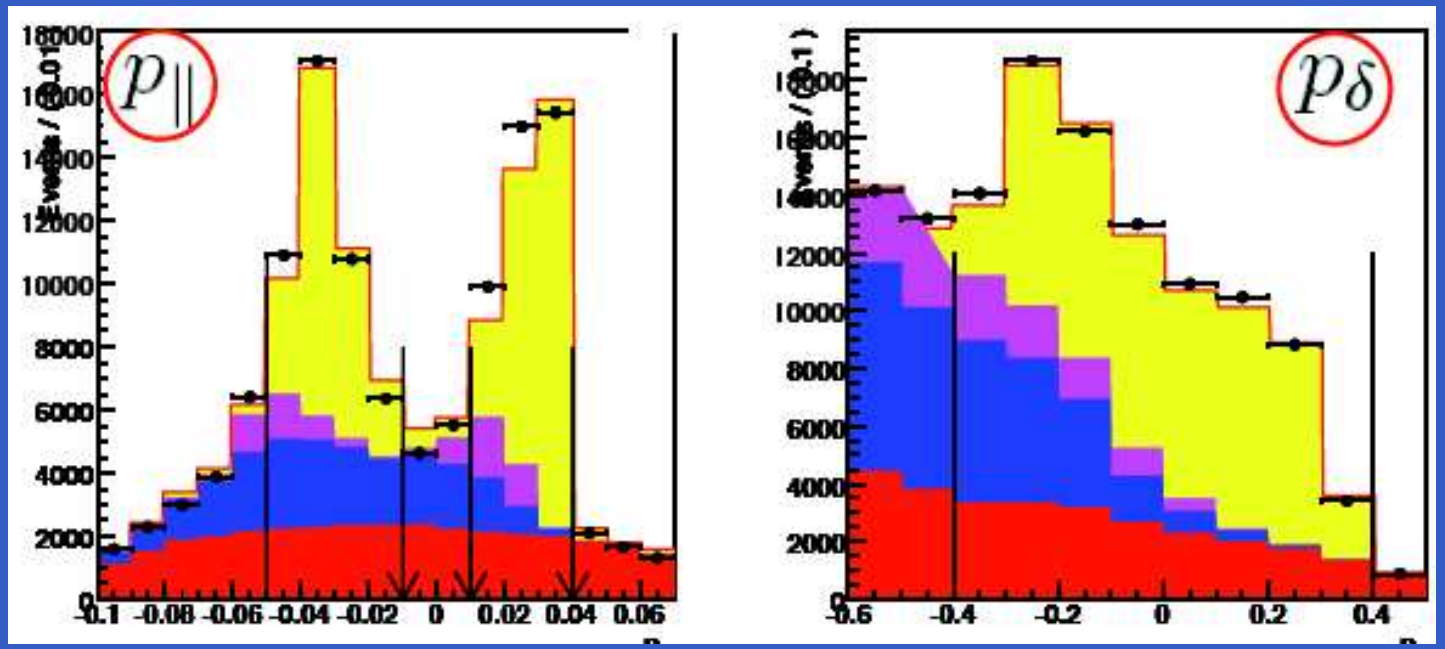
- High-momentum lepton is required in tag-side.
- Two charged pions must have high and low momentum.
- Vertex positions are obtained from single tracks.

$B^0 \to D^*\pi$ partial reconstruction



- High-momentum lepton is required in tag-side.
- Two charged pions must have high and low momentum.
- Vertex positions are obtained from single tracks.
- Proper-time difference can be derived from Δz.

Yield extraction for $B^0 \to D^*\pi$



- Fit in two kinematical dimensions: π_s momentum along the opposite direction of π_f ($p_{||}$) and momentum difference between π_f and D^* (p_δ).

Experiment	$N_{B\overline{B}}$	$N_{\rm sig}$ in signal region	$S/(S+B)$	cut for lepton
Belle (PRD 73, 092003 (2006))	386 M	$21,773 \pm 214$	66%	$> 1.2\,{\rm GeV}/c$
Belle 2008 Summer	657 M	$50,196 \pm 286$	59%	$> 1.1\,{\rm GeV}/c$

CP fit

- Unbinned ML fit :

  to minimize the quantity $-2\sum_i \ln \mathcal{L}_i$,

  $$\mathcal{L}_i = f_{D^*\pi}P_{D^*\pi} + f_{D^*\rho}P_{D^*\rho} + f_{\rm unco}P_{\rm unco} + f_{\rm corr}P_{\rm corr}$$

- Time-dependent decay rates :

  $$P(B^0 \to D^{*\pm}\pi^{\mp}) = (1/8\tau_{B^0})e^{-|\Delta t|}/\tau_{B0}[1 \mp C\cos(\Delta m\Delta t) - S^{\pm}\sin(\Delta m\Delta t)]$$
  $$P(\overline{B}^0 \to D^{*\pm}\pi^{\mp}) = (1/8\tau_{B^0})e^{-|\Delta t|}/\tau_{B0}[1 - C\cos(\Delta m\Delta t) \mp S^{\pm}\sin(\Delta m\Delta t)]$$

- Mistagging :

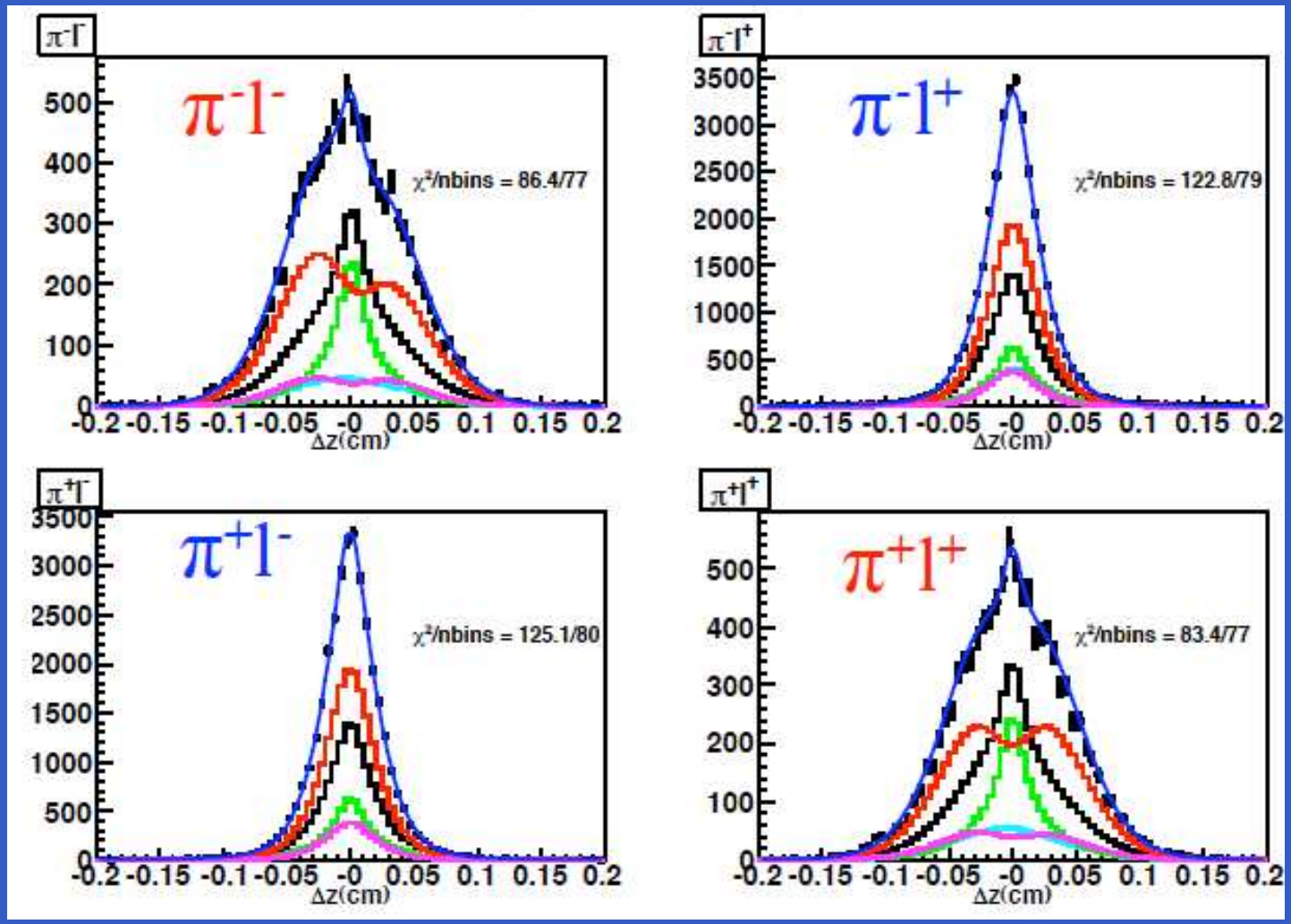
  taken into account in the fit,

  $$P(l,\pi_f) = (1-w_-)P(B^0 \to D^*\pi) + (1-w_+)P(\overline{B}^0 \to D^*\pi) \quad (w_{+/-} \sim 5\%)$$

- Detector resolution function :

  J/ψ events are analysed and $\Delta z = z_{\mu^+} - z_{\mu^-}$ is used.

Δz fi t results



$D^*\pi$ signal

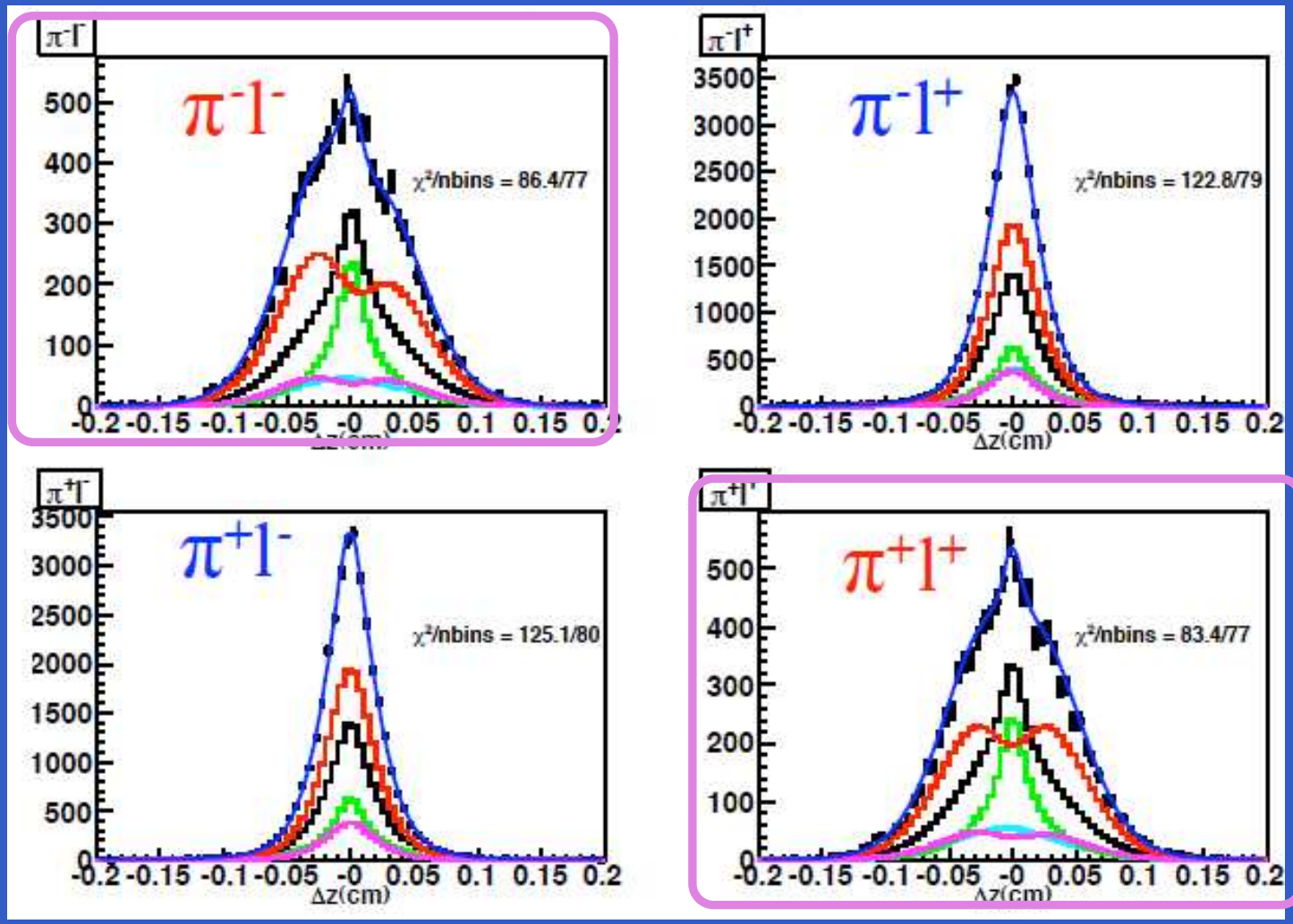
total background

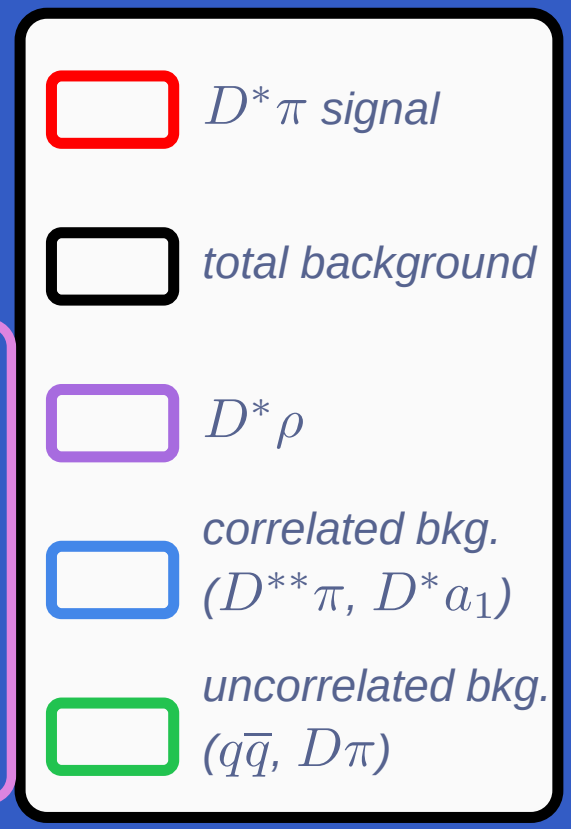
$D^*\rho$

correlated bkg. ($D^{**}\pi$, D^*a_1)

uncorrelated bkg. ($q\bar{q}$, $D\pi$)

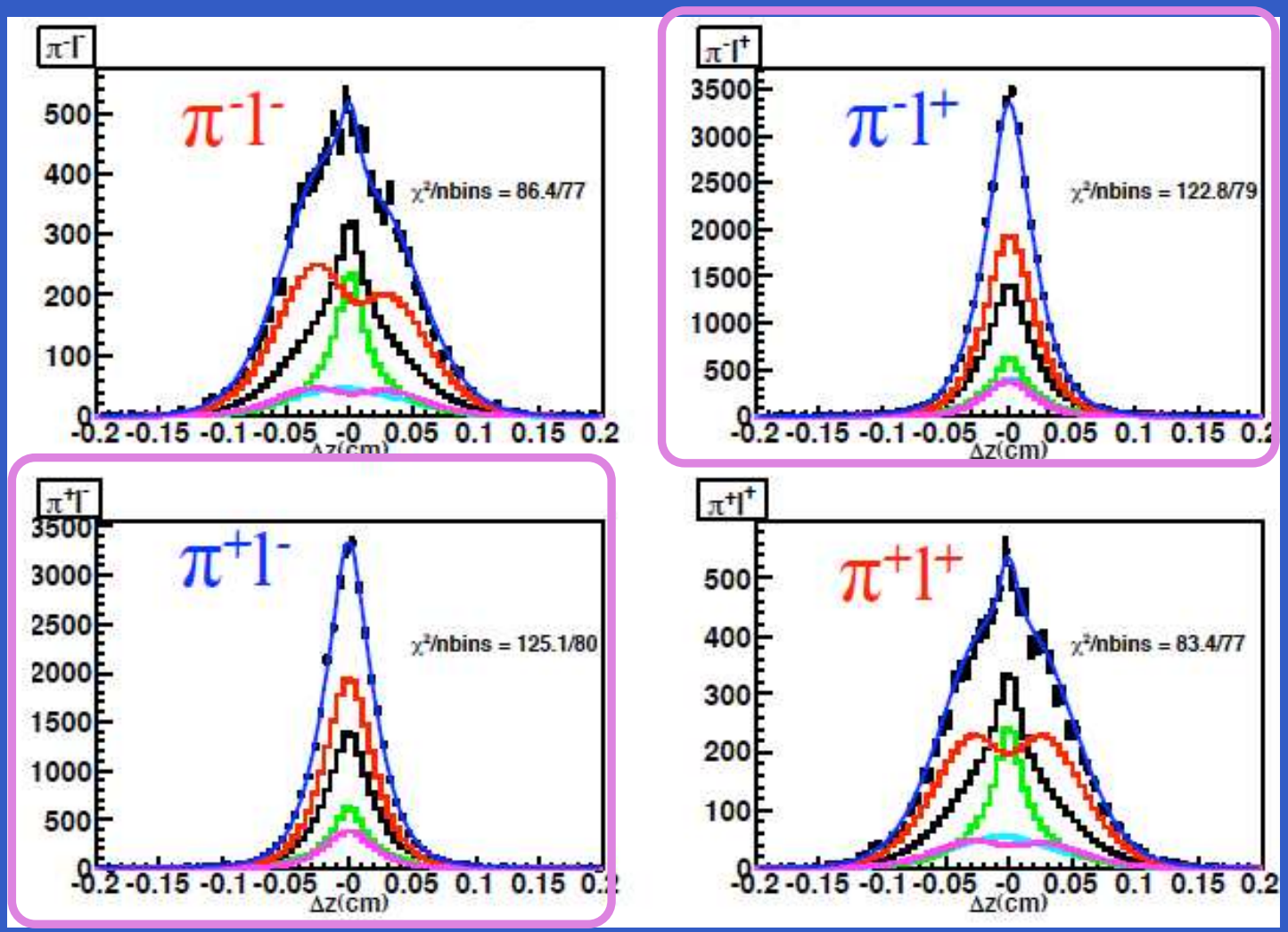
Δz fi t results

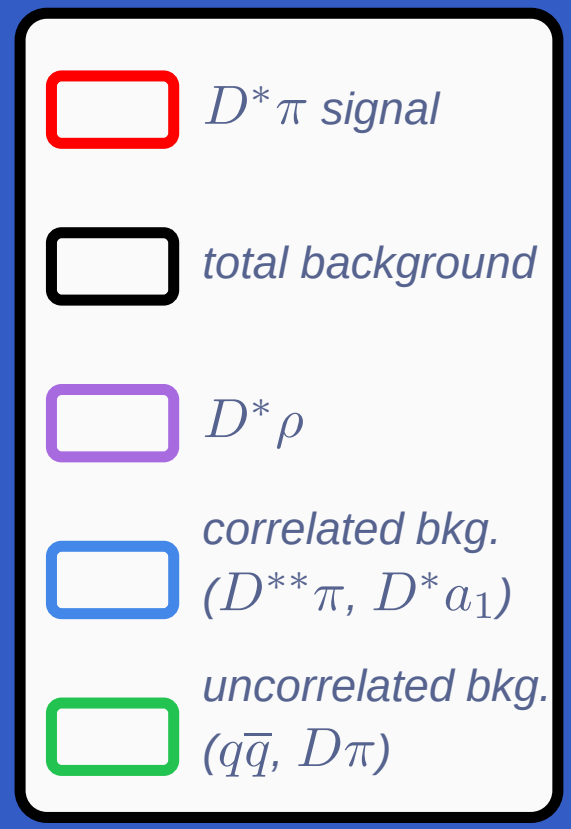




SF (same flavor)
: π_f and tagging lepton have same charge

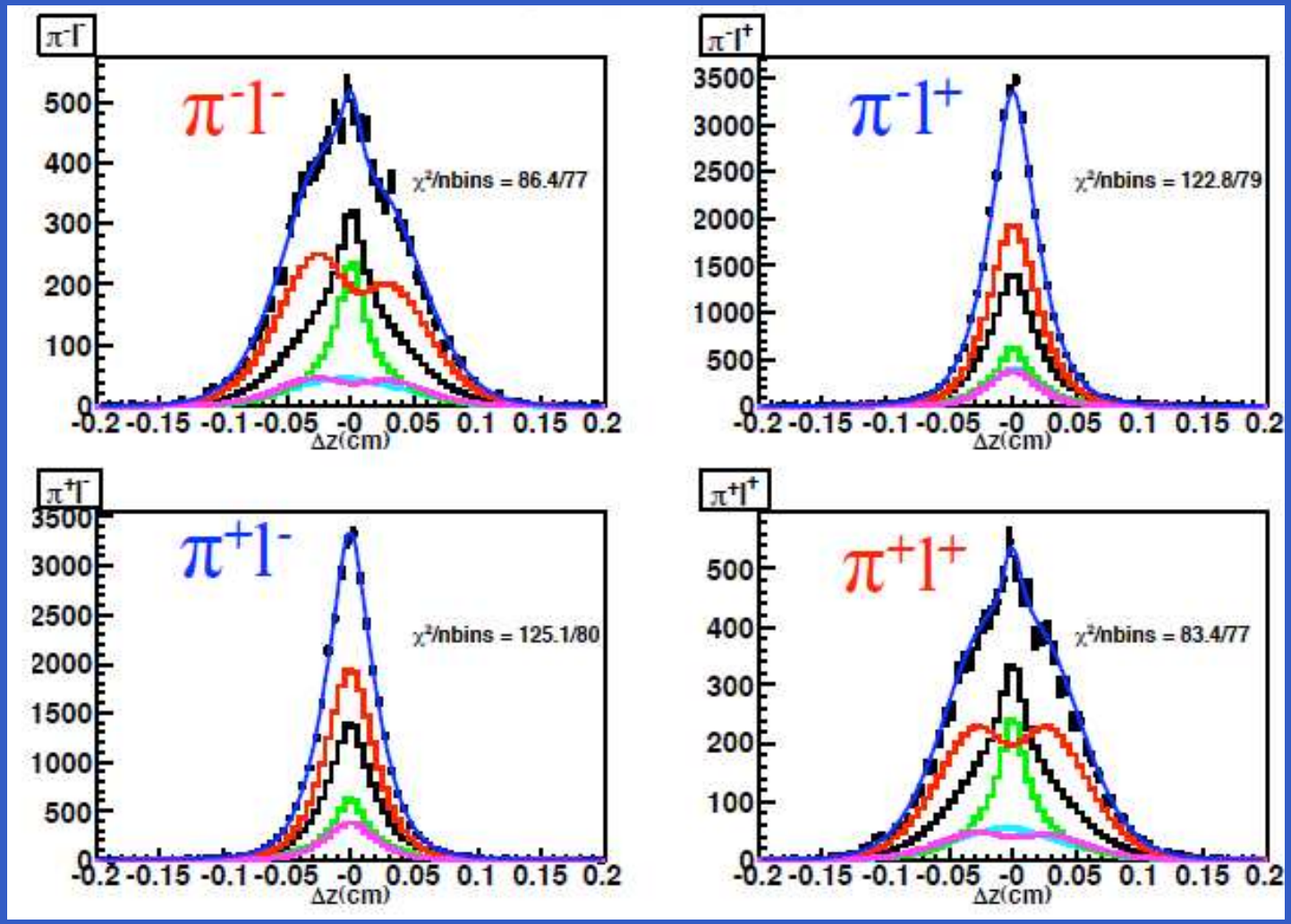
Δz fi t results





OF (opposite flavor)
: π_f and tagging lepton have opposite charge

Δz fi t results



$D^*\pi$ signal

total background

$D^*\rho$

correlated bkg. ($D^{**}\pi$, D^*a_1)

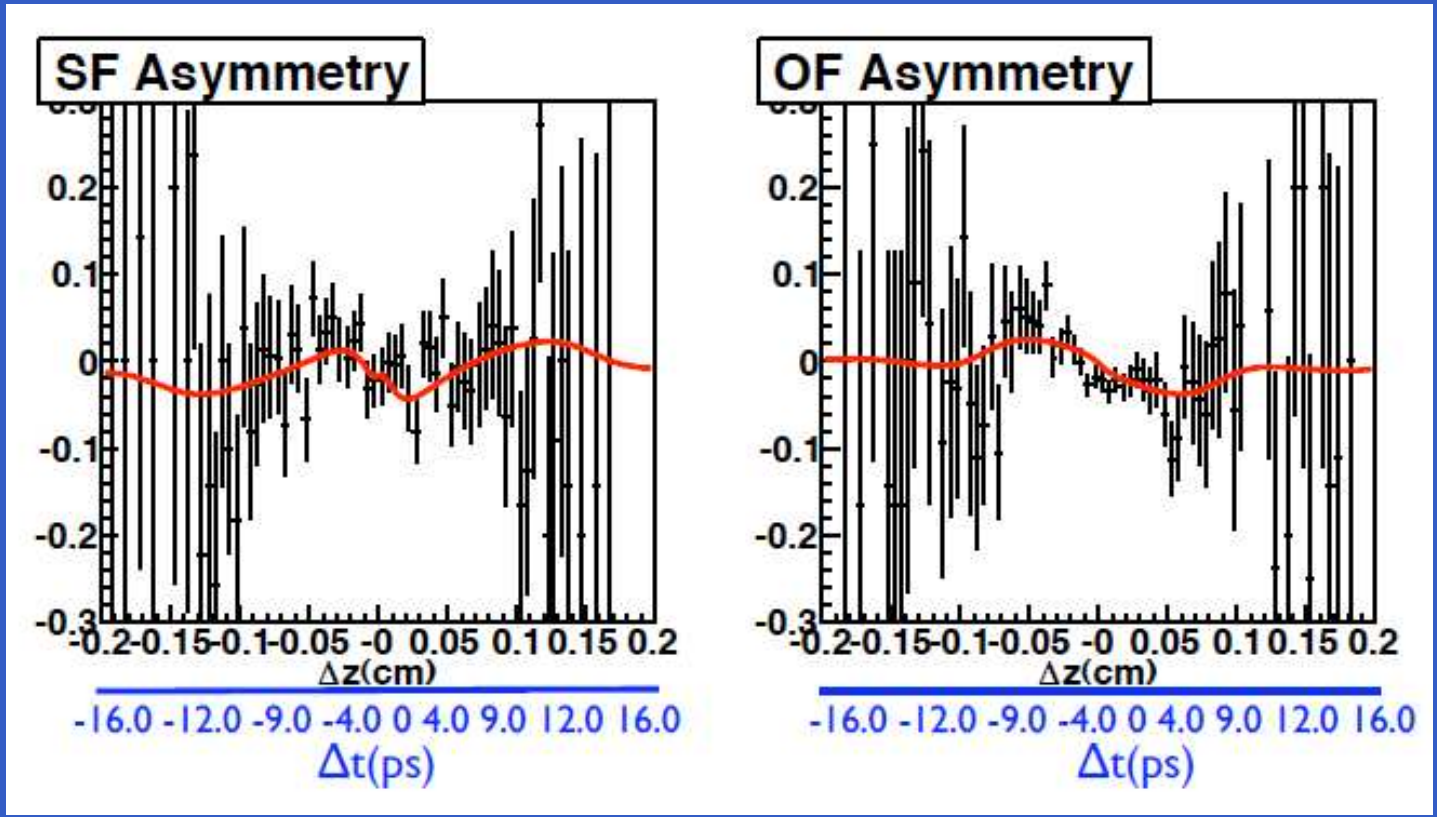
uncorrelated bkg. ($q\bar{q}$, $D\pi$)

- $S^+ = 0.057 \pm 0.019\,(\mathrm{stat.})$, $S^- = 0.038 \pm 0.020\,(\mathrm{stat.})$

preliminary

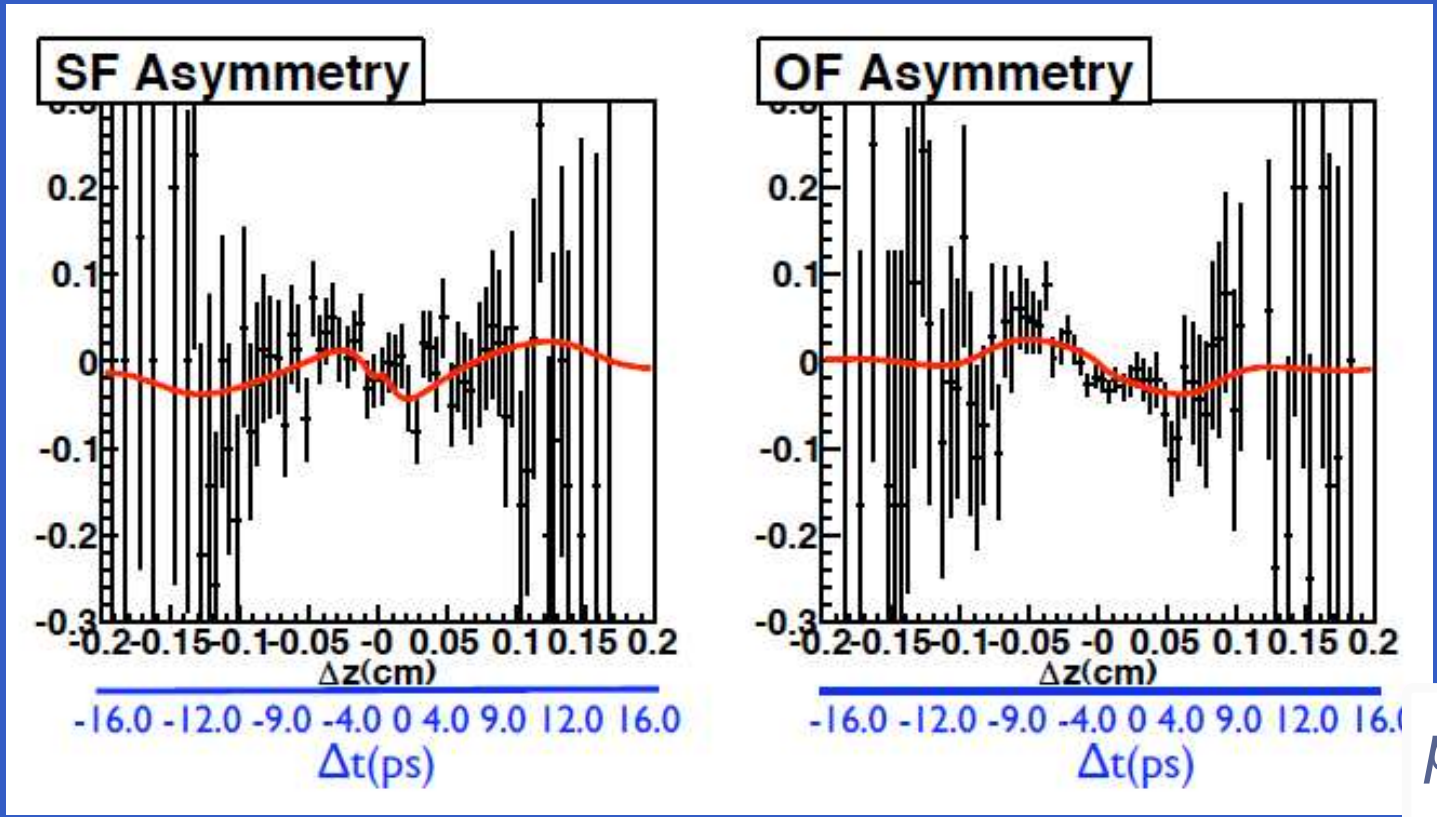
CP asymmetry

- $\mathcal{A} = \frac{N_{\pi^-l^-}(\Delta z) - N_{\pi^+l^+}(\Delta z)}{N_{\pi^-l^-}(\Delta z) + N_{\pi^+l^+}(\Delta z)}$ (SF) $\quad \mathcal{A} = \frac{N_{\pi^+l^-}(\Delta z) - N_{\pi^-l^+}(\Delta z)}{N_{\pi^+l^-}(\Delta z) + N_{\pi^-l^+}(\Delta z)}$ (OF)



CP asymmetry

- $\mathcal{A} = \frac{N_{\pi^-\ell^-}(\Delta z) - N_{\pi^+\ell^+}(\Delta z)}{N_{\pi^-\ell^-}(\Delta z) + N_{\pi^+\ell^+}(\Delta z)}$ (SF) $\quad \mathcal{A} = \frac{N_{\pi^+\ell^-}(\Delta z) - N_{\pi^-\ell^+}(\Delta z)}{N_{\pi^+\ell^-}(\Delta z) + N_{\pi^-\ell^+}(\Delta z)}$ (OF)

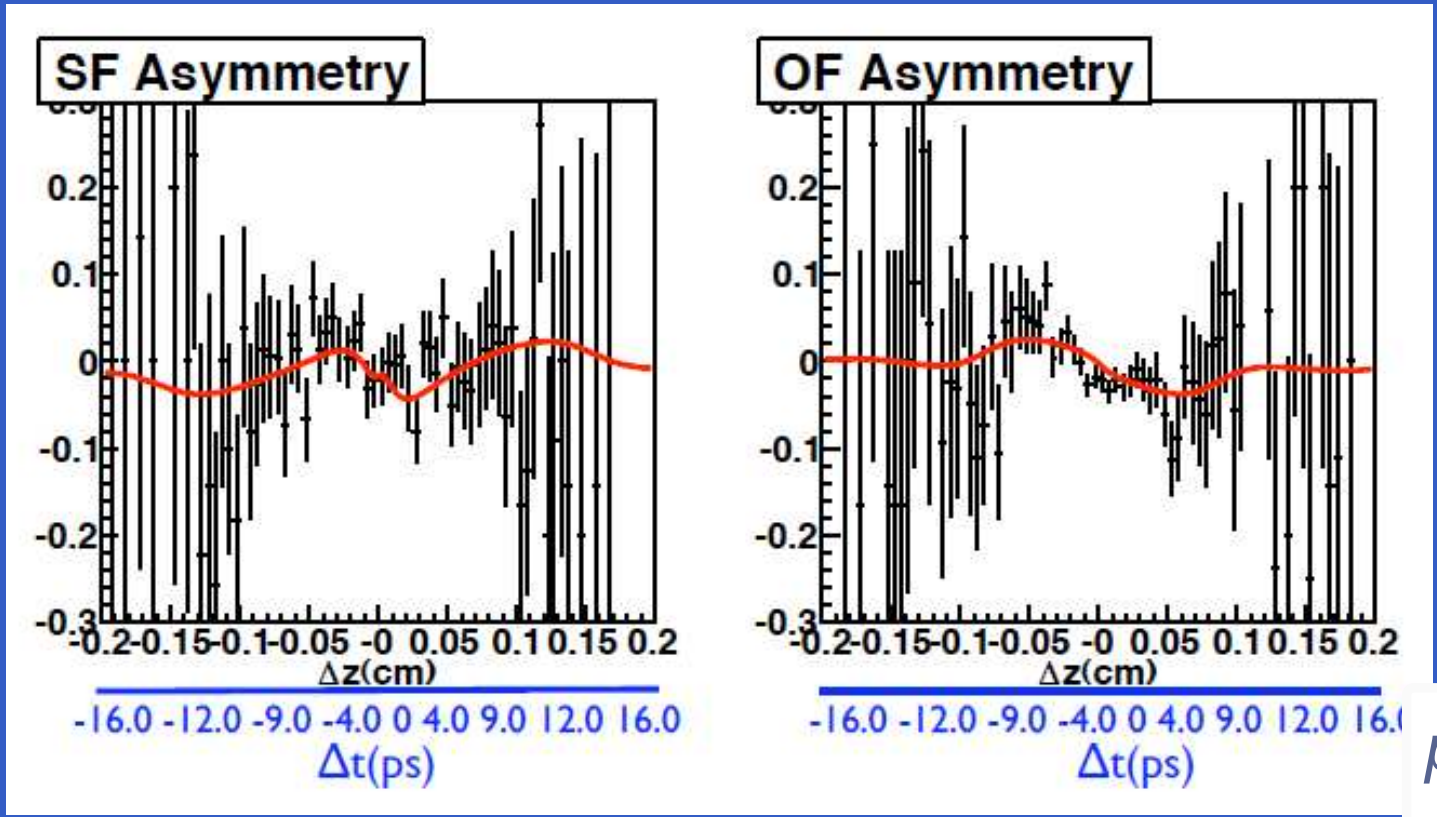


preliminary

$$S^+ = 0.057 \pm 0.019 \pm 0.012 \qquad a = 0.047 \pm 0.014 \pm 0.012$$
$$S^+ = 0.038 \pm 0.020 \pm 0.010 \qquad c = 0.009 \pm 0.014 \pm 0.012$$

CP asymmetry

- $\mathcal{A} = \frac{N_{\pi^-\ell^-}(\Delta z) - N_{\pi^+\ell^+}(\Delta z)}{N_{\pi^-\ell^-}(\Delta z) + N_{\pi^+\ell^+}(\Delta z)}$ (SF) $\quad \mathcal{A} = \frac{N_{\pi^+\ell^-}(\Delta z) - N_{\pi^-\ell^+}(\Delta z)}{N_{\pi^+\ell^-}(\Delta z) + N_{\pi^-\ell^+}(\Delta z)}$ (OF)



preliminary

$S^+ = 0.057 \pm 0.019 \pm 0.012$

$S^+ = 0.038 \pm 0.020 \pm 0.010$

$\Leftrightarrow$

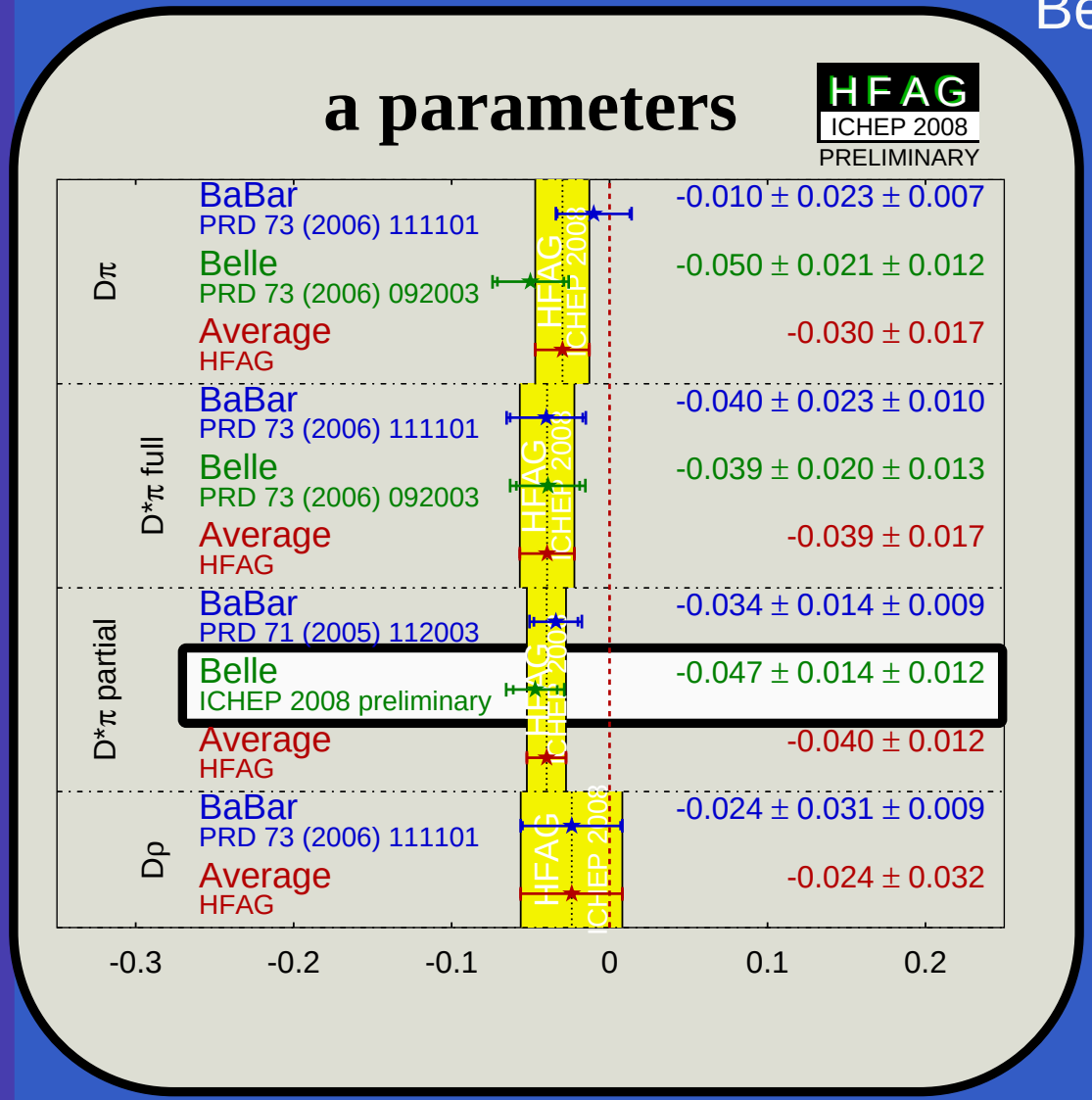
$a = 0.047 \pm 0.014 \pm 0.012$

significance of CPV is 2.6σ

Systematic uncertainties for $S^{\pm}$

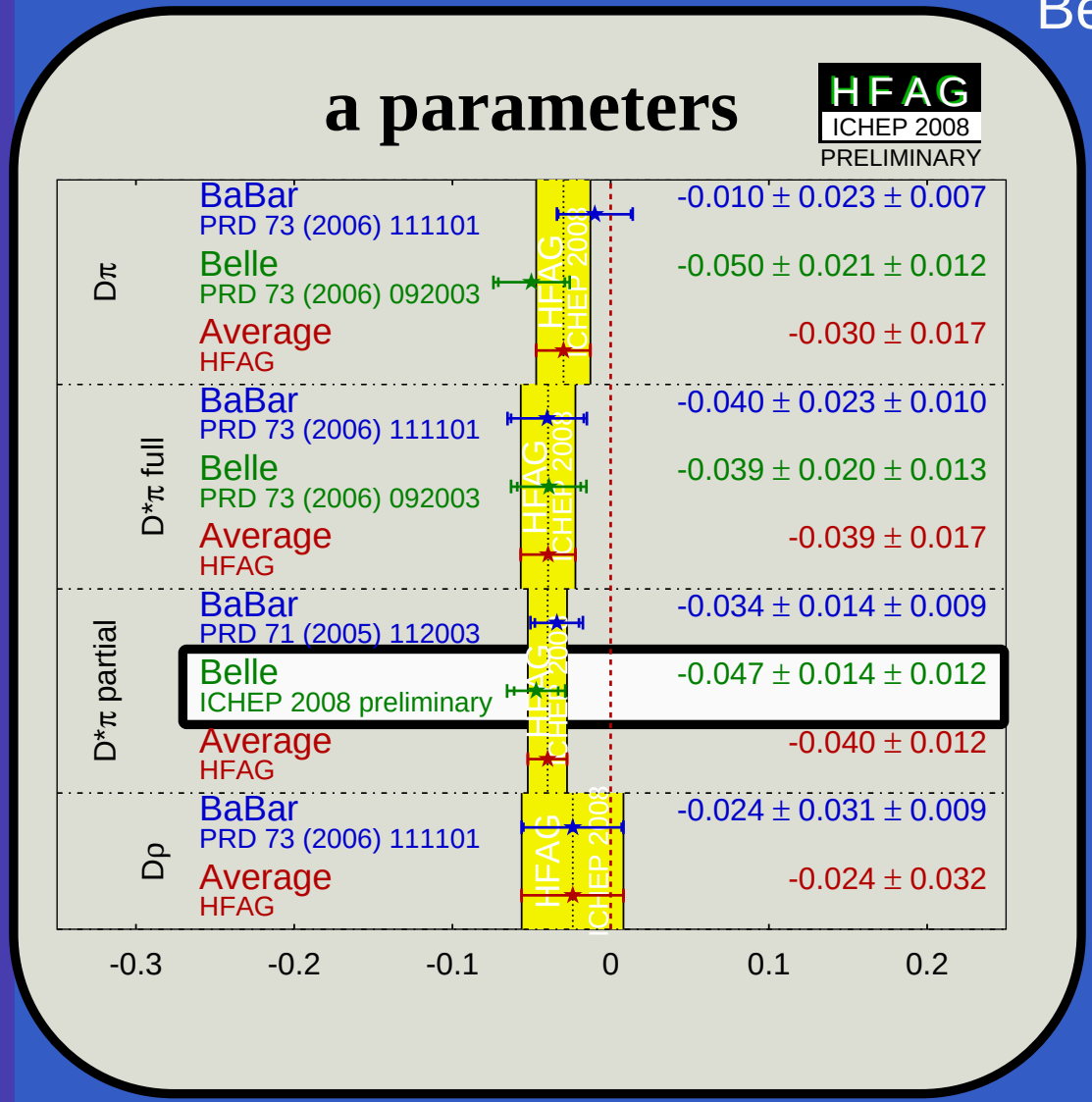
Source	S_+	S^-
Δz offsets	0.002	0.003
R_k	0.002	0.003
$R_{\rm det}$	0.002	0.002
$R_{\rm np}$	0.008	0.007
Background param.	0.004	0.004
Phys. param.	0.004	0.004
Yield fi t	0.003	0.003
Resol. model	0.006	0.002
Δz offsets fbated in bkg.	0.002	0.003
Total	0.012	0.010

Updated HFAG average



Belle result using partial reconstruction is updated from the previous plot

Updated HFAG average

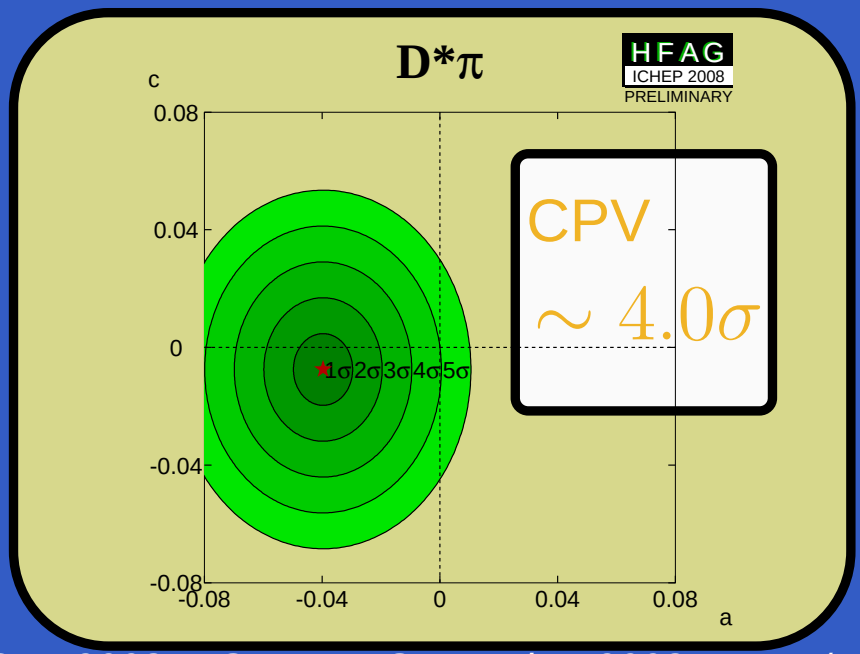


Belle result using partial reconstruction is updated from the previous plot

HFAG average for $D^*\pi$ [2008]:
(full and partial, Babar and Belle)

$$a = -0.040 \pm 0.010$$

$$c = -0.007 \pm 0.012$$



Estimate for R

- $2\phi_1 + \phi_3$ is to be derived from S using the relation, $S^{\pm} = -2\,R\sin(2\phi_1 + \phi_3 \pm \delta)$.
- $2\phi_1 + \phi_3$ results in Belle (PRD 73, 092003 (2006)) were assuming SU(3)-breaking effect as 30% on R.
- Very recent publication from Babar (PRD 78, 032005 (2008)) is mentioning the effect as $10\% - 15\%$.

Estimate for R

- $2\phi_1 + \phi_3$ is to be derived from S using the relation, $S^{\pm} = -2\,R\sin(2\phi_1 + \phi_3 \pm \delta)$.
- $2\phi_1 + \phi_3$ results in Belle (PRD 73, 092003 (2006)) were assuming SU(3)-breaking effect as 30% on R.
- Very recent publication from Babar (PRD 78, 032005 (2008)) is mentioning the effect as $10\% - 15\%$.
- Another way using isospin relation has not been tested for a decade due to its small amplitude.
  $\mathcal{B}(B^+ \to D^{*+}\pi^0) < 1.7 \times 10^{-4}$ $(90\%\ \mathrm{C.L.})$ was only available from CLEO's results, PRL 80, 2762 (1998).

Estimate for R

- $2\phi_1 + \phi_3$ is to be derived from S using the relation, $S^{\pm} = -2\,R\sin(2\phi_1 + \phi_3 \pm \delta)$.
- $2\phi_1 + \phi_3$ results in Belle (PRD 73, 092003 (2006)) were assuming SU(3)-breaking effect as 30% on R.
- Very recent publication from Babar (PRD 78, 032005 (2008)) is mentioning the effect as $10\% - 15\%$.
- Another way using isospin relation has not been tested for a decade due to its small amplitude. $\mathcal{B}(B^+ \to D^{*+}\pi^0) < 1.7 \times 10^{-4}$ $(90\%\ \mathrm{C.L.})$ was only available from CLEO's results, PRL 80, 2762 (1998).
- Assuming $R = 0.02$, and with $\mathcal{B}(B^0 \to D^{*-}\pi^+) = 2.76 \times 10^{-3}$ from PDG, $\mathcal{B}(B^+ \to D^{*+}\pi^0) = 5.9 \times 10^{-7}$.

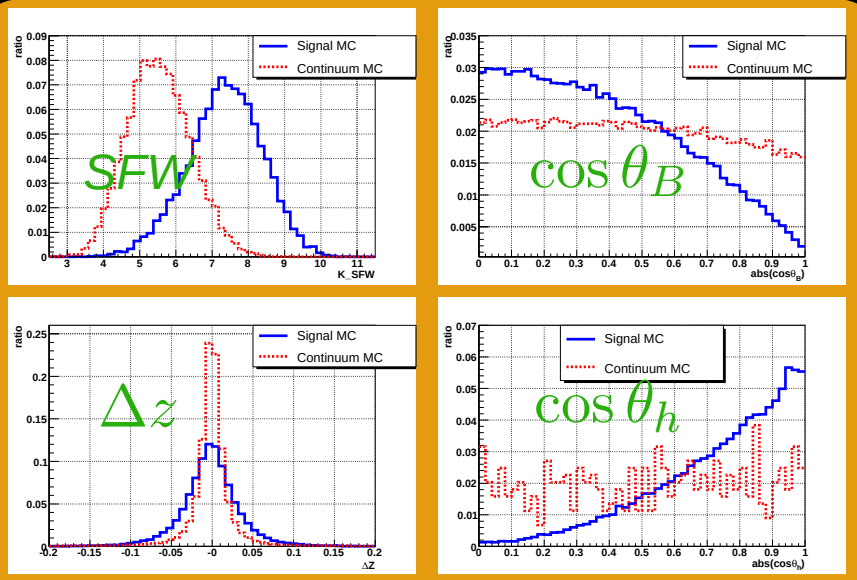
$B^+ \to D^{*+}\pi^0$ reconstruction

$B^+ \to D^{*+}\pi^0$
- $\hookrightarrow D^0\pi_s^+$
  - $\hookrightarrow K^-\pi^+$
  - $\hookrightarrow K^-\pi^+\pi^0$
  - $\hookrightarrow K^-\pi^+\pi^-\pi^+$
  - $\hookrightarrow K_S\pi^+\pi^-$

- 4 sub-decay modes are combined in reconstruction.

$B^+ \to D^{*+}\pi^0$ reconstruction

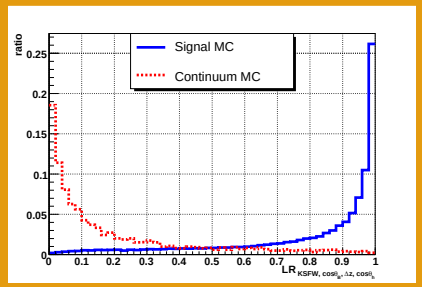
$B^+ \to D^{*+}\pi^0$
$\hookrightarrow D^0\pi_s^+$
$\hookrightarrow K^-\pi^+$
$\hookrightarrow K^-\pi^+\pi^0$
$\hookrightarrow K^-\pi^+\pi^-\pi^+$
$\hookrightarrow K_S\pi^+\pi^-$



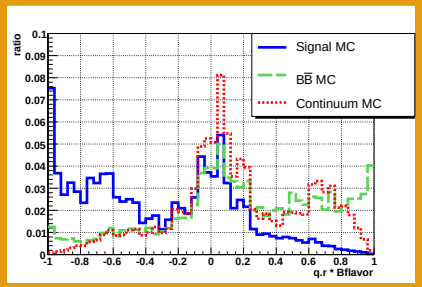
- 4 sub-decay modes are combined in reconstruction.
- Likelihood is calculated through the combination of SFW, $\cos\theta_B$, Δz and $\cos\theta_h$.

$B^+ \to D^{*+}\pi^0$ reconstruction

$B^+ \to D^{*+}\pi^0$
$\hookrightarrow D^0\pi_s^+$
$\hookrightarrow K^-\pi^+$
$\hookrightarrow K^-\pi^+\pi^0$
$\hookrightarrow K^-\pi^+\pi^-\pi^+$
$\hookrightarrow K_S\pi^+\pi^-$



combined likelihood



tagged B-flavor $\times$ quality parameter

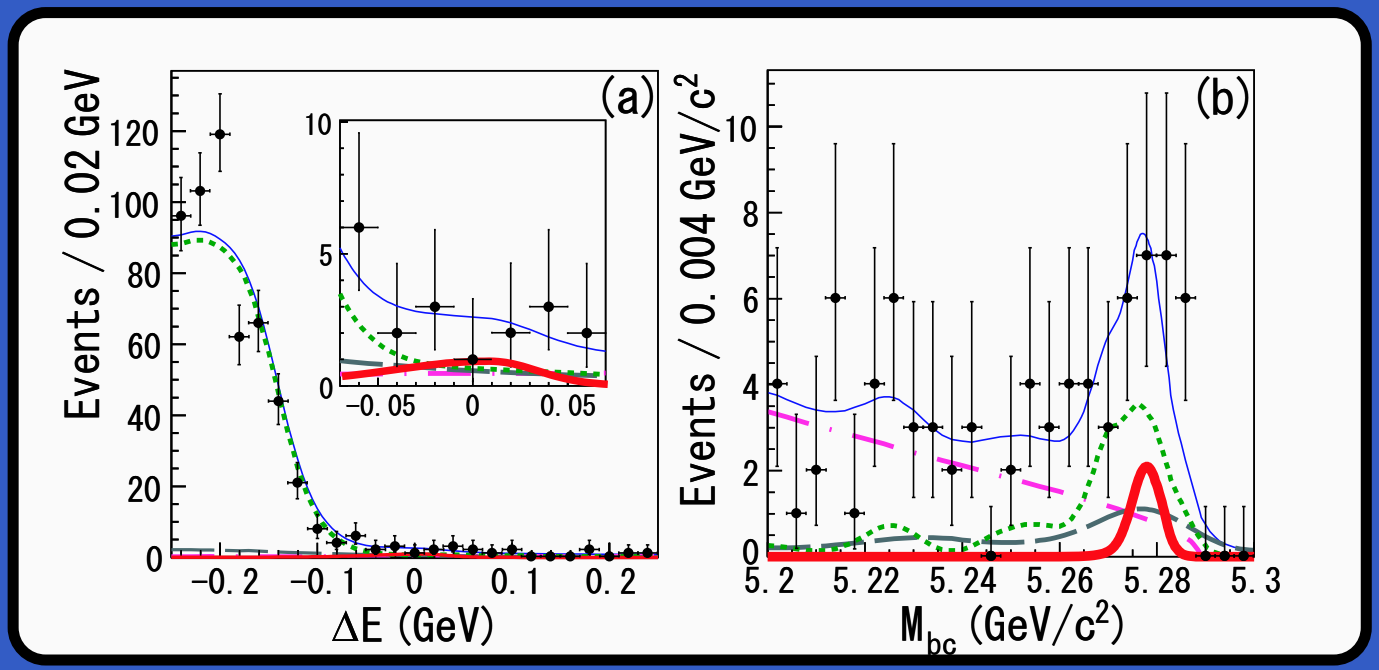
- 4 sub-decay modes are combined in reconstruction.
- Likelihood is calculated through the combination of SFW, $\cos\theta_B$, Δz and $\cos\theta_h$.
- Its requirements are applied with the flavor information, for the maximal point of $S/\sqrt{S+B}$ in the signal region ($|\Delta E| < 0.1\,\mathrm{GeV}$, $5.27\,\mathrm{GeV}/c^2 < M_{\mathrm{bc}} < 5.29\,\mathrm{GeV}/c^2$).

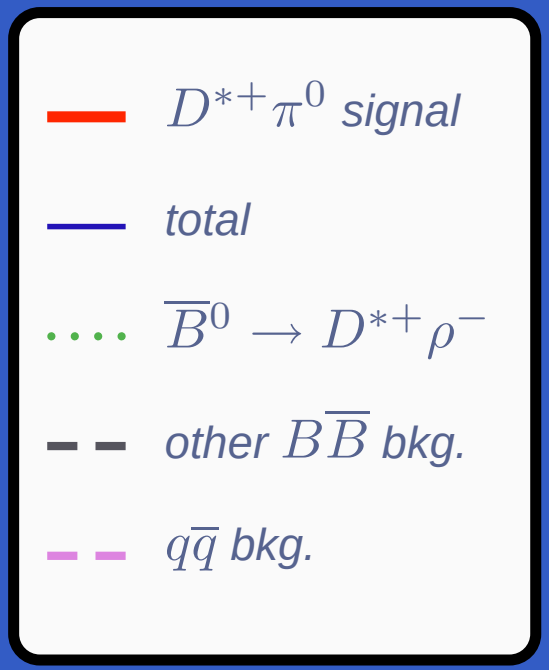
Extraction of $B^+ \to D^{*+}\pi^0$ event and R

- Two-dimensional unbinned extended-ML fi t

Extraction of $B^+ \to D^{*+}\pi^0$ event and R

- Two-dimensional unbinned extended-ML fi t

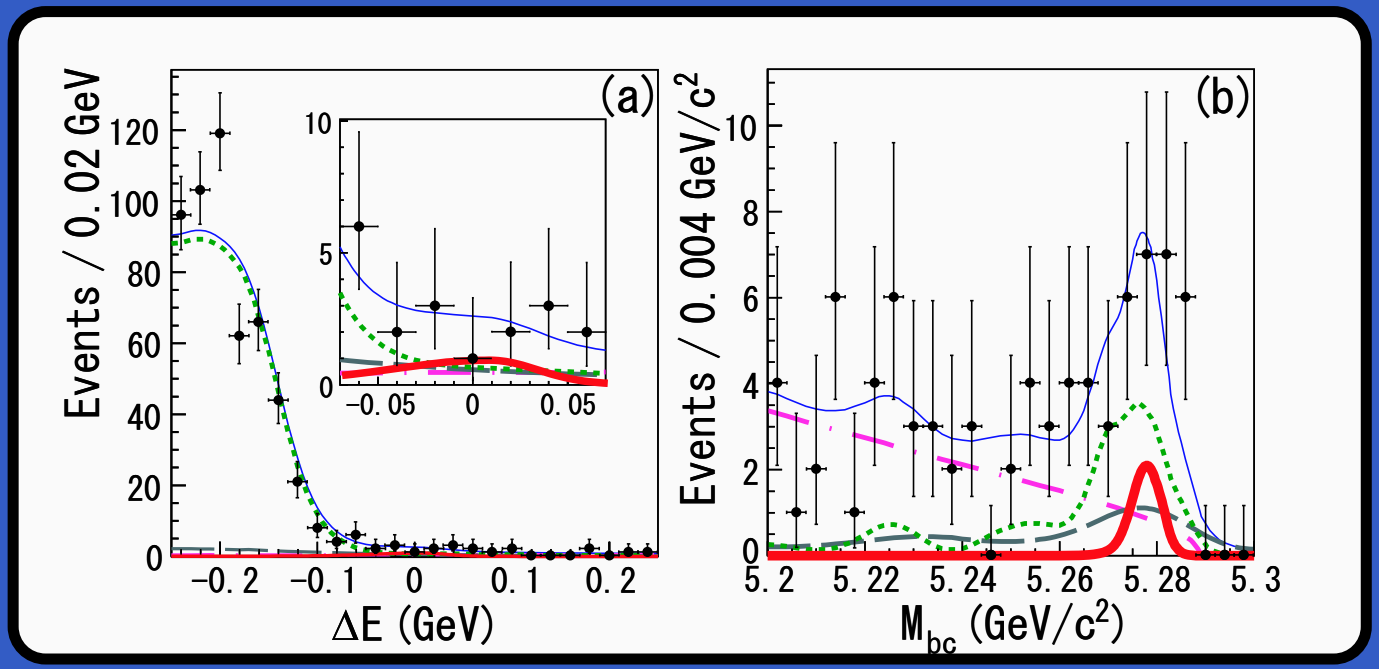


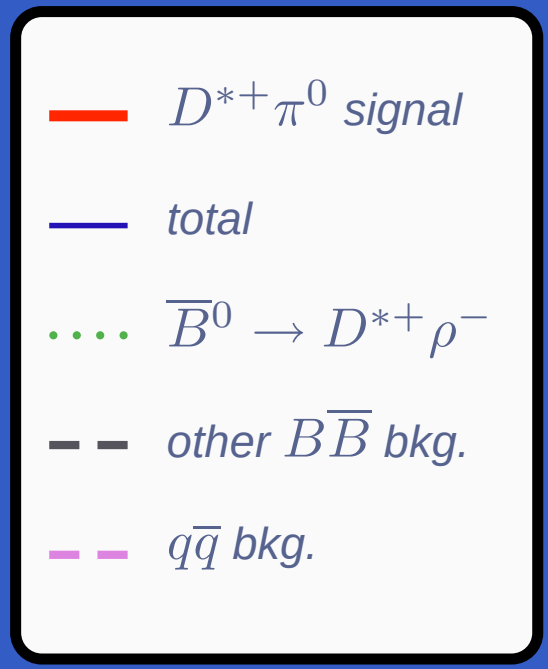


Extraction of $B^+ \to D^{*+}\pi^0$ event and R

published in PRL 101, 041601 (2008)

- Two-dimensional unbinned extended-ML fi t





- Signal event is extracted as $4.5^{+4.1}_{-3.4}$ in the signal region from 657 M $B\overline{B}$ pairs ($\varepsilon = 0.56\%$ from MC).

$$\mathcal{B}(B^+ \to D^{*+}\pi^0) = [1.2^{+1.1}_{-0.9}(\mathrm{stat})^{+0.3}_{-0.9}(\mathrm{syst})] \times 10^{-6}$$

($< 3.6 \times 10^{-6}$ at 90% C.L.) $\quad \to R < 0.051$ (90% C.L.)

Main systemtaic uncertainties for $\mathcal{B}(B^+ \to D^{*+}\pi^0)$

Source	Systematic error (number of events)	
	$+\sigma$	$-\sigma$
$\|H_0\|$ of $\overline{B}^0 \to D^{*+}\rho^-$	0.7	-1.9
ΔE shift of $\overline{B}^0 \to D^{*+}\rho^-$	0.0	-0.6
Fraction of backgrounds	0.8	-0.4
Gaussian width of background PDF	0.5	-2.0
2D correlation for $q\overline{q}$ and $B^+ \to D^{*+}\pi^0$	0.0	-1.3
Fit bias	0.0	-0.5
Quadratic sum	1.2	-3.2

Summary

- $a = 0.047 \pm 0.014 \pm 0.012 \quad c = 0.009 \pm 0.014 \pm 0.012$
  CPV in $B \to D^{*-}\pi^+$ is found to be 2.6σ from lepton-tag analysis of 657 M $B\overline{B}$ pairs at Belle.
- $\mathcal{B}(B^+ \to D^{*+}\pi^0) < 3.6 \times 10^{-6} \quad R < 0.051 \quad$ at 90% C.L.
  from isospin relation. Estimate of R is still much better in SU(3)-related measurement. (Much data will be needed for using isospin, $\sim \times 10$ or more ..)
- Weak phase $2\phi_1 + \phi_3$ can be extracted using $S^{\pm}$. Additional kaon-tag analysis will be achieved in near future. SU(3) symmetry will be used to obtain $2\phi_1 + \phi_3$, at that time.

Backup slides

Other systemtaic uncertainties for $\mathcal{B}(B^+ \to D^{*+}\pi^0)$

Source	Systematic error (%) $\pm\sigma$
$\mathcal{L}$ requirement	3.0
ΔM requirement	3.3
Secondary branching fractions	3.3
Track fi nding effi ciency	5.1
Particle identifi cation	4.4
π^0 reconstruction	4.1
K^0_S reconstruction	0.3
MC statistics	0.5
Number of $B\overline{B}$ pairs	1.4
Quadratic sum	9.8

Experimental and theoretical estimate for R

$$R = \tan\theta_c \frac{f_{D^*}}{f_{D_s^*}} \sqrt{\frac{\mathcal{B}(B^0 \to D_s^{*+}\pi^-)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)}}$$

- Belle PRD 73, 092003 (2006)

  $R(\%) = 2.0 \pm 0.7$ (stat and syst) ± 0.6 (SU(3)-breaking)

- Babar PRD 78, 032005 (2008) (for $R_{(D^*\pi)}$)

  $R(\%) = 1.81^{+0.16}_{-0.15}$ (stat) ± 0.09 (syst) ± 0.10 (f_D)

  $\pm$ SU(3)-breaking ($10 - 15\%$ on R)

  $-$ still $15 - 20\%$ error on R

  $\hookrightarrow \quad \mathcal{B}(B^0 \to D_s^{*+}\pi^-) = [2.6^{+0.5}_{-0.4} \pm 0.2] \times 10^{-5}$

  $\mathcal{B}(B^0 \to D^{*-}\pi^+) = [2.76 \pm 0.13] \times 10^{-3}$

  $f_{D^*}/f_{D_s^*} = 1.24 \pm 0.07$ (lattice QCD)

W-exchange contribution (only seen in $B^0 \to D^{*\pm}\pi^{\mp}$) is included ($\sim 5\%$) in SU(3)-breaking.