B→D*π崩壊を用いたCP対称性の破れの測定

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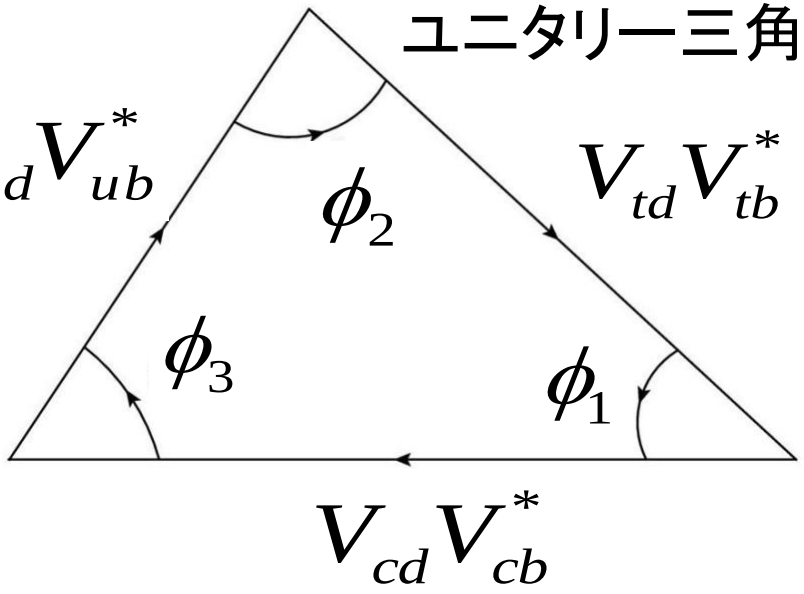
内容

- 導入
- 再構成
  - Signal MC, Generic MC
- Generic MC を使用した Signal fraction の見積もり
- Generic MC のΔt fit
- まとめ と 計画

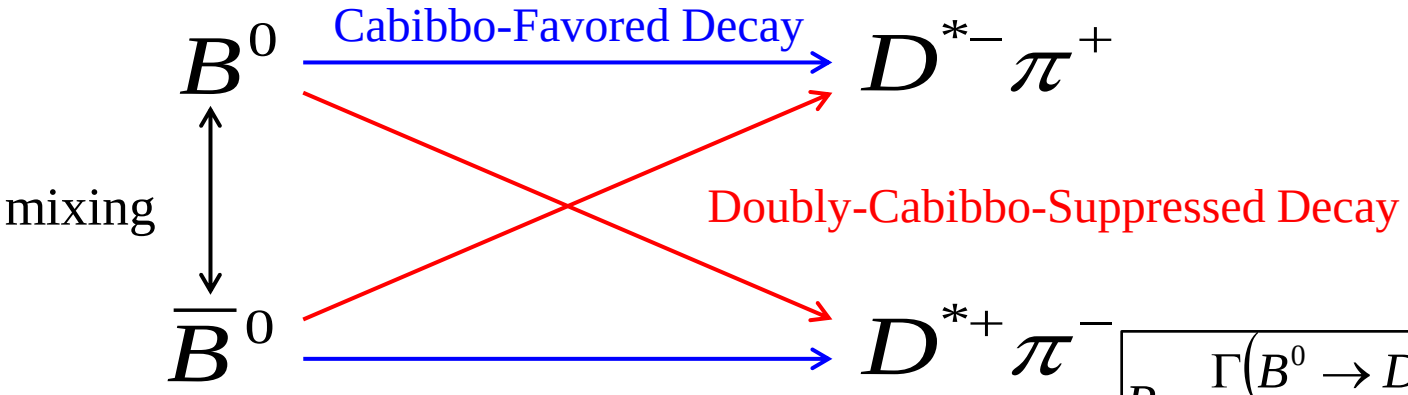
導入

- **動機**：ϕ_3 の精密測定

ユニタリー三角形



- $B^0 \to D^*\pi$ 崩壊

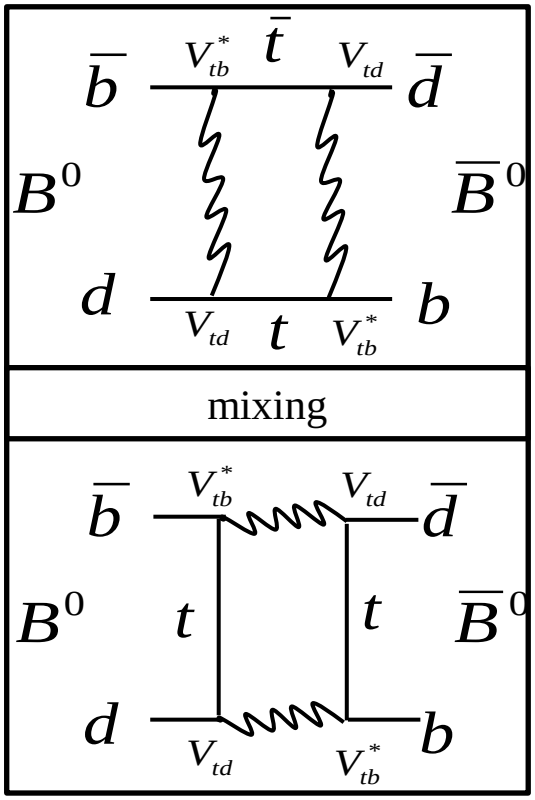


$$R = \frac{\Gamma\left(B^0 \to D^{*+}\pi^-\right)}{\Gamma\left(B^0 \to D^{*-}\pi^+\right)} \sim \frac{V_{cd}V_{ub}^*}{V_{cb}V_{ud}^*} \sim \mathrm{O}\left(\lambda^2\right)$$

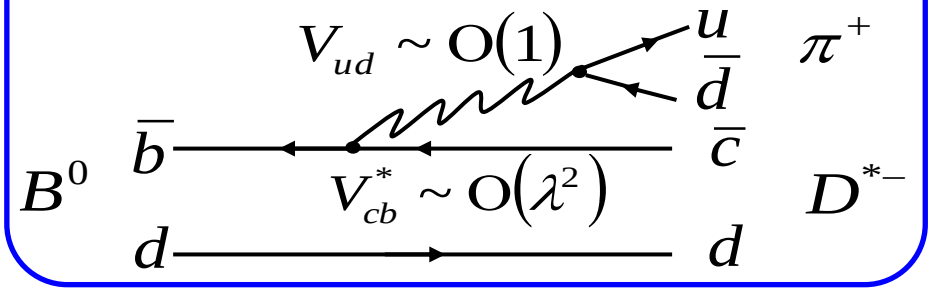
$$\lambda \cong 0.23$$

二つの崩壊経路：干渉 → CP対称性の破れ

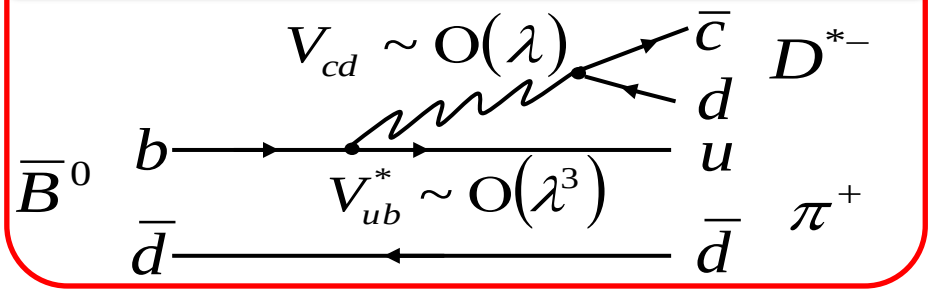
導入：$B^0 \to D^{*}\pi$ 崩壊



Cabibbo-Favored Decay



Doubly-Cabibbo-Suppressed Decay



干渉項の位相

$$\arg\left(-\frac{V_{td}^{*}V_{tb}}{V_{td}V_{tb}^{*}}\frac{V_{ub}V_{cd}^{*}}{V_{cb}^{*}V_{ud}}\right)=\arg\left(\frac{V_{cd}V_{cb}^{*}}{-V_{td}V_{tb}^{*}}\frac{V_{cd}V_{cb}^{*}}{-V_{td}V_{tb}^{*}}\frac{V_{ud}V_{ub}^{*}}{-V_{cd}V_{cb}^{*}}\right)=2\phi_1+\boxed{\phi_3}$$

導入：$B^0 \to D^* \pi$ 崩壊

$B^0 \to D^* \pi$ の崩壊率

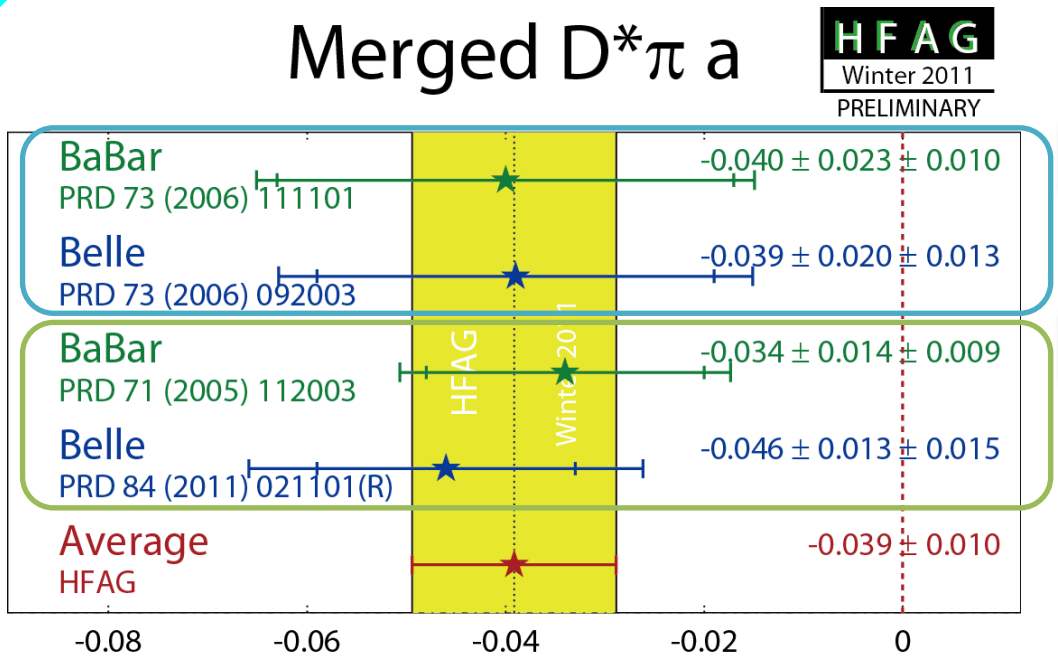
$$P\left(B^0 \to D^{*\mp}\pi^{\pm}\right) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{8\tau_{B^0}}\left[1 \pm C\cos\left(\Delta m \Delta t\right) - S^{\mp}\sin\left(\Delta m \Delta t\right)\right]$$

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

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

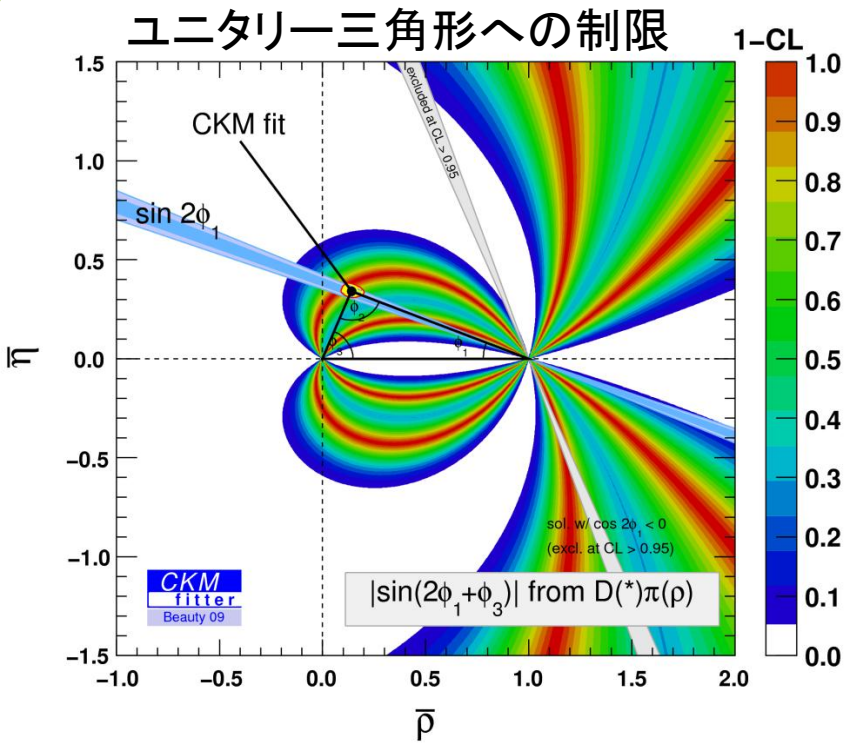
$B^0 \to D^* \pi$ の崩壊時間分布を測定する

導入:今までの結果



Full reconstruction

Partial reconstruction



導入

partial reconstruction と full reconstruction

$$B^0 \to D^* \pi_{fast}$$

$$D^* \to D^0 \pi_{slow}$$

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

B^0 崩壊　D^* 崩壊 で生成される荷電π が特徴的

- 再構成方法
  - Partial reconstruction

    荷電π のみ観測 ー 運動量、電荷、方向
    - D の下位崩壊によらないため、検出効率が良い
  - Full reconstruction

    D を再構成
    - 信号事象/背景事象 の比が良い

導入 : my analysis

- Belle 全データを使用した full reconstruction

- 使用する下位崩壊

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

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

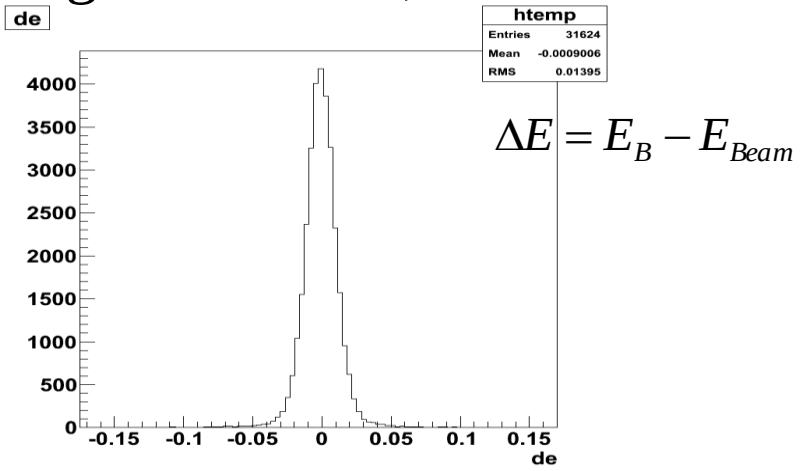
$D^* \to D\pi^0$

$D \to K\pi\pi$

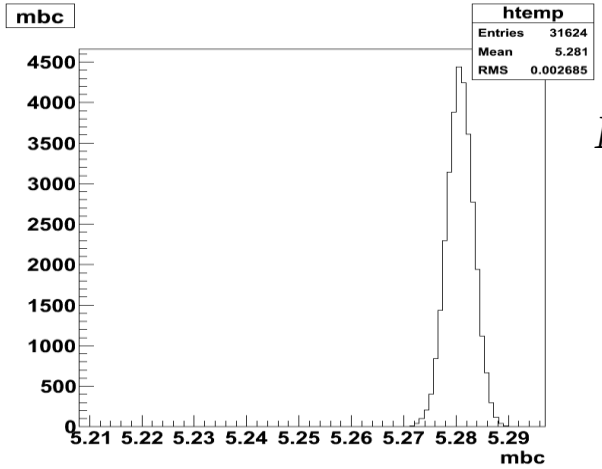
$D^* \to D^0\pi$, $D^0 \to K\pi$ の進行状況についての talk

再構成

- Signal MC 100,000 events を生成、再構成



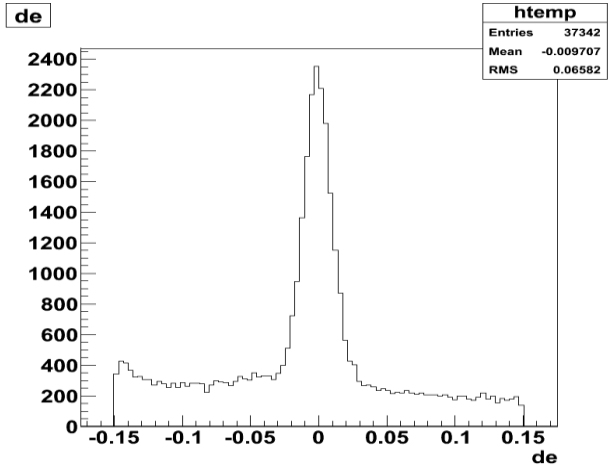
$$\Delta E = E_B - E_{Beam}$$

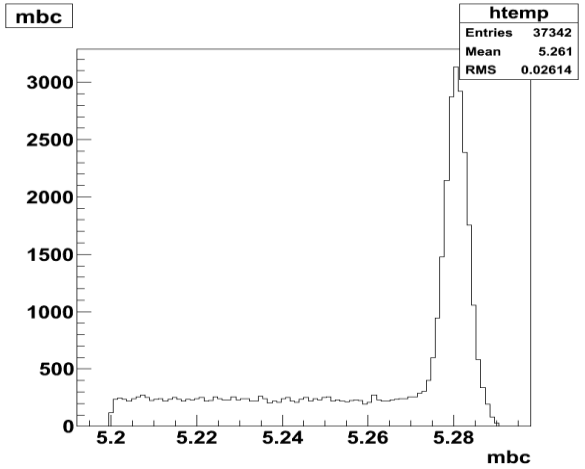


$$M_{bc} = \sqrt{E_{Beam}^2 - P_B^2}$$

再構成数: 31,624 ~ 32%

- Generic MC の再構成

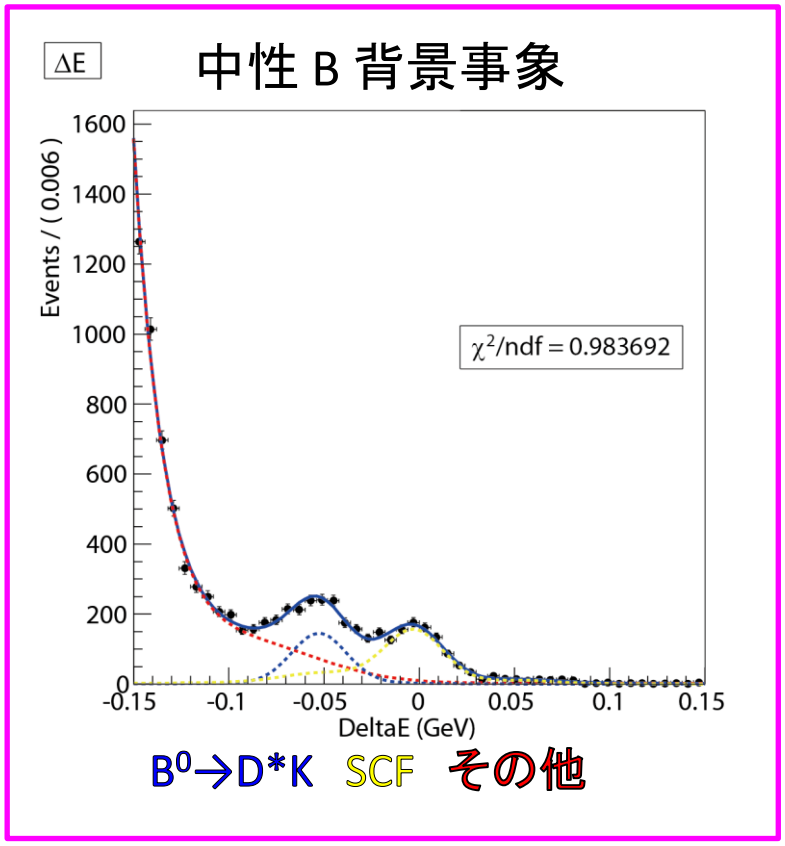


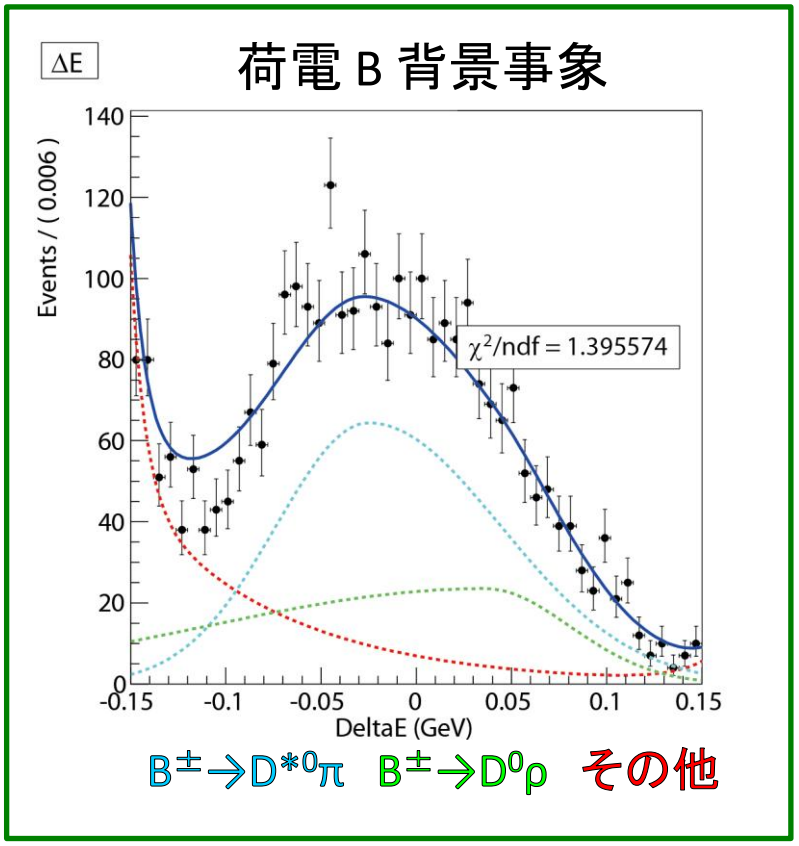


  - よく再構成できている

ΔE PDF

- Signal fraction を計算するため、**ΔE PDF を見積もった**
  実験データの 5倍の統計量を使用
  範囲 : 5.27 GeV < M_{bc} < 5.29 GeV　-0.15 GeV < ΔE < 0.15 GeV
- 得られた 中性/荷電 B 背景事象のΔE PDF

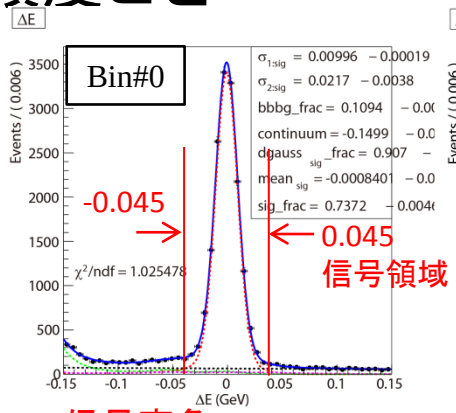




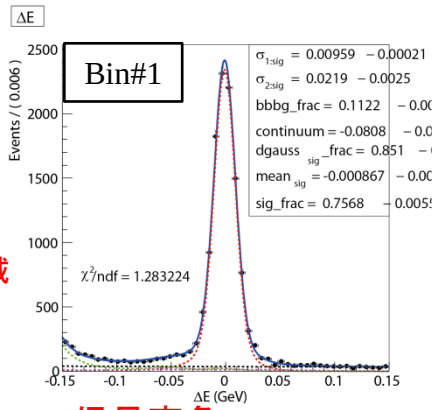
ΔE PDF

- ΔE をfit し、 signal fraction を求めた
  - flavor tag の信頼度ごと

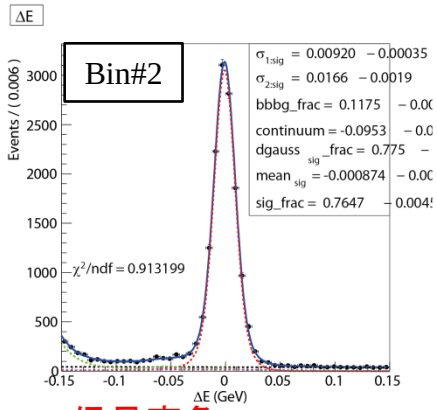
Bin#0 → Bin#6 信頼度高
変数
信号事象：ダブルガウシアン B以外の背景事象：直線 Signal fraction
B 背景事象：固定



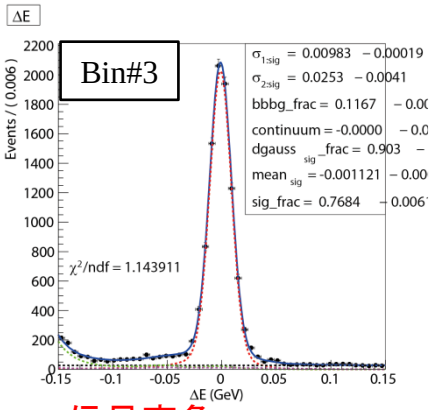
信号事象 ~ 90%
B^0 BG ~ 2%, $B^{\pm}$ BG ~ 2%
B 以外 ~ 6%



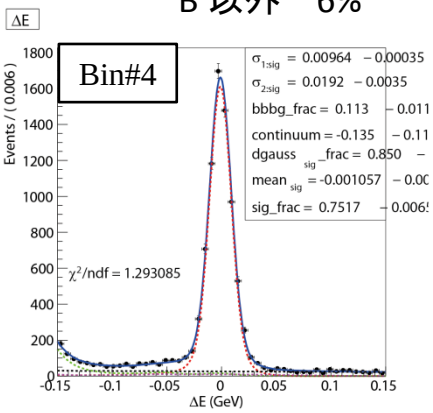
信号事象 ~ 91%
B^0 BG ~ 2%, $B^{\pm}$ BG ~ 2%
B 以外 ~ 5%



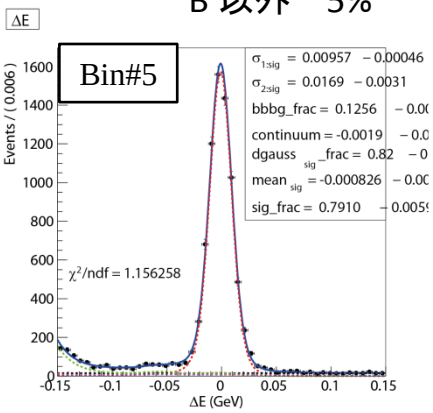
信号事象 ~ 92%
B^0 BG ~ 2%, $B^{\pm}$ BG ~ 2%
B 以外 ~ 4%



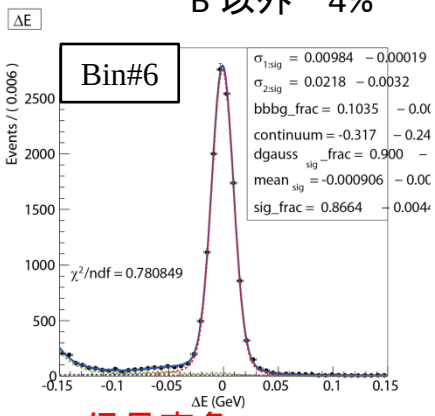
信号事象 ~ 92%
B^0 BG ~ 2%, $B^{\pm}$ BG ~ 2%
B 以外 ~ 4%



信号事象 ~ 91%
B^0 BG ~ 2%, $B^{\pm}$ BG ~ 2%
B 以外 ~ 5%



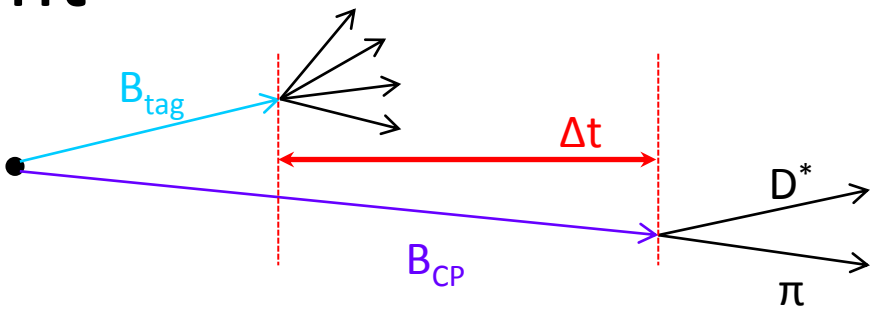
信号事象 ~ 93%
B^0 BG ~ 2%, $B^{\pm}$ BG ~ 2%
B 以外 ~ 3%



信号事象 ~ 96%
B^0 BG ~ 2%, $B^{\pm}$ BG ~ 1%
B 以外 ~ 1%

Δt fit

- Δt : B_{tag} とB_{CP} の崩壊時間差



- PDF

$$P(\Delta t) = (1 - f_{ol})\left[f_{sig} P_{sig} + (1 - f_{sig})\left\{f_{B^0\bar{B}^0} P_{B^0\bar{B}^0} + f_{B^+B^-} P_{B^+B^-} + (1 - f_{B^0\bar{B}^0} - f_{B^+B^-}) P_{con}\right\}\right] + f_{ol} P_{ol}$$

P_{sig} : ϕ_3を含む信号事象項

$P_{B^0B^0}$: 中性B中間子背景事象項

$P_{B^+B^-}$: 荷電B中間子背景事象項

P_{con} : B中間子以外の背景事象項

P_{ol} : 検出器のresolution の補正項

- Generic MC のΔt fit
  - Fitter program の挙動確認
  - B 背景事象項の決定

信号事象のΔt fit

- τ , Δm を fit

$$P_{sig}(\Delta t, q_{tag}, q_{cp}) = \frac{1}{8\tau} e^{-|\Delta t|/\tau} \left\{1 - q_{tag}\Delta w_{rbin}^{official} - q_{tag}q_{cp}(1 - 2w_{rbin}^{official})\cos(\Delta m \Delta t)\right\}$$

$B_{tag} = \bar{B}^0, f_{CP} = D^{*-}\pi^+$ と $B_{tag} = B^0, f_{CP} = D^{*+}\pi^-$

$B_{tag} = \bar{B}^0, f_{CP} = D^{*+}\pi^-$ と $B_{tag} = B^0, f_{CP} = D^{*-}\pi^+$

を $\delta = 0$ として 統合 → sin 項を無視

w, Δw : flavor tagの間違いを補正

$$w = \frac{w_{B^0} + w_{\bar{B}^0}}{2}, \Delta w = w_{B^0} - w_{\bar{B}^0}$$

Official wrong tag fraction を使用

R bin #	official wrong tag fraction	
Bin#0	w = 0.5	Δw=0.
Bin#1	w = 0.412222	Δw=0.0569661
Bin#2	w = 0.307838	Δw=0.0126192
Bin#3	w = 0.212765	Δw=0.0147724
Bin#4	w = 0.149933	Δw=0.000550289
Bin#5	w = 0.0913264	Δw=0.00887704
Bin#6	w = 0.0218754	Δw=0.00465683

信号事象のΔt fit

- Fit 結果

MC 入力値

Name	Value
τ_{B0}	1.534
Δm	0.507

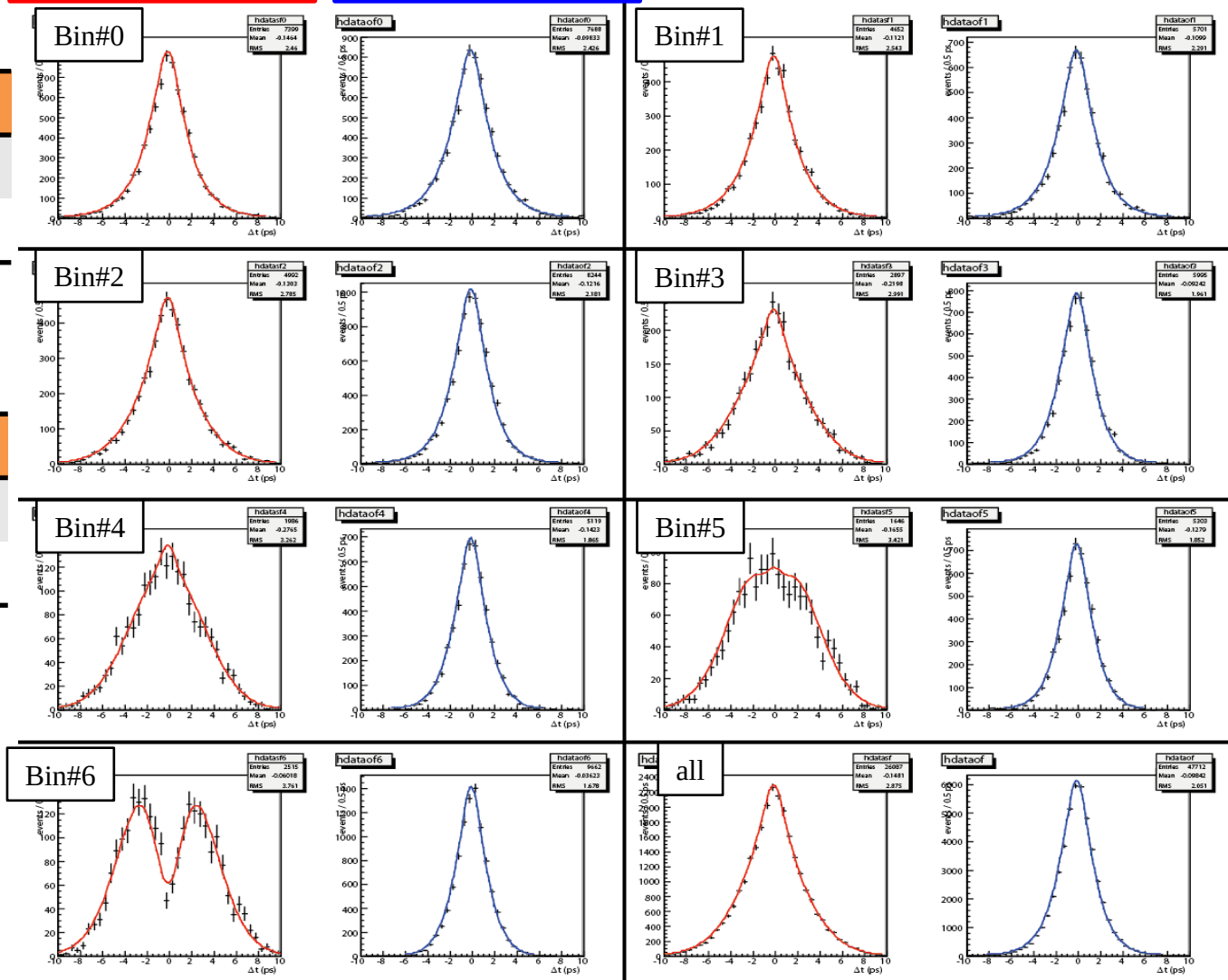
Fit 結果

Name	Value
τ_{B0}	1.533 ± 0.006 (ps)
Δm	0.505 ± 0.004

- Fit 結果は入力値と consistent

$B_{tag} = \bar{B}^0,\ f_{CP} = D^{*+}\pi^-$
$B_{tag} = B^0,\ f_{CP} = D^{*-}\pi^+$

$B_{tag} = \bar{B}^0,\ f_{CP} = D^{*-}\pi^+$
$B_{tag} = B^0,\ f_{CP} = D^{*+}\pi^-$



背景事象のΔt fit

- 背景事象のPDFを得るため、各々を fit
- Fit 範囲 : -0.15 GeV < ΔE < 0.15 GeV, 5.2 GeV < M_{bc} < 5.3 GeV

中性B中間子背景事象 PDF

$$P_{B^0BG}(\Delta t, q_{tag}, q_{cp}) = \frac{1}{8\tau_{B^0BG}} e^{-|\Delta t|/\tau_{B^0BG}} \left\{1 - q_{tag} q_{cp} (1 - 2w_{rbin}) \cos(\Delta m \Delta t)\right\}$$

荷電B中間子背景事象 PDF

$$P_{chg}(\Delta t, q_{tag}, q_{cp}) = \frac{1}{8\tau_{chgB}} e^{-|\Delta t|/\tau_{chgB}} \left\{1 - q_{tag} q_{cp} (1 - 2w_{rbin})\right\}$$

B中間子以外からの背景事象 PDF

$$P_{con}(\Delta t) = \int P_{con}(\Delta t') \cdot R_{bkg}(\Delta t - \Delta t') \cdot d\Delta t'$$

$$P_{con}(\Delta t) = f_\delta \cdot \delta(\Delta t - \mu_\delta) + (1 - f_\delta) \cdot \exp\left(-\frac{|\Delta t - \mu_\tau|}{\tau_{con}}\right)$$

$$R_{con}(\Delta t) = (1 - f_{con}^{tail}) \cdot G(\Delta t; s_{con}^{main} \cdot \sigma_{vtx}) + f_{con}^{tail} \cdot G(\Delta t; s_{con}^{tail} \cdot \sigma_{vtx})$$

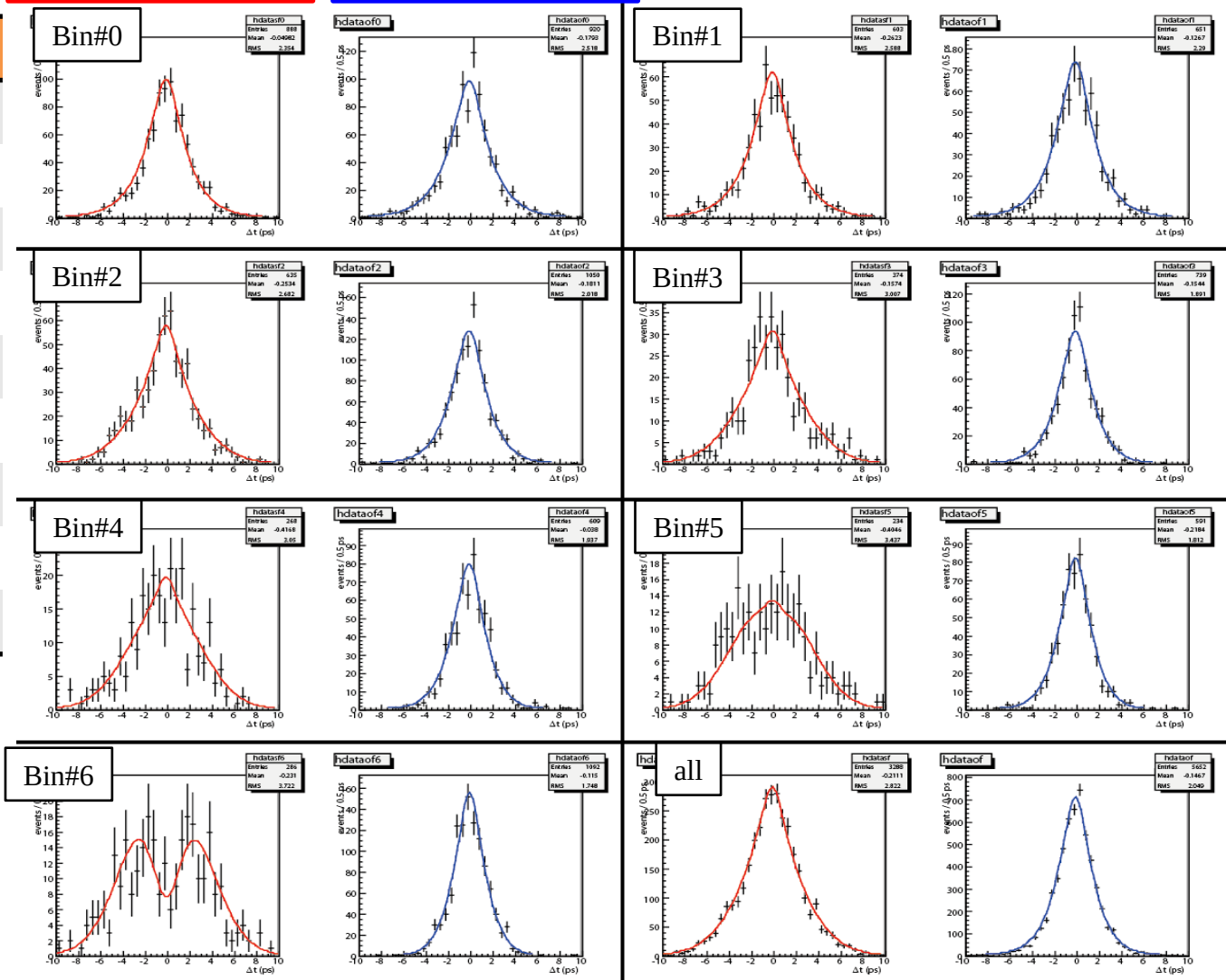
中性B中間子背景事象のΔt fit

- Fit 結果

Name	Value
τ_{B0BG}	1.525±0.019 (ps)
Δm	0.516±0.013
w_0	0.50 (fixed)
w_1	0.45±0.02
w_2	0.29±0.02
w_3	0.23±0.02
w_4	0.18±0.02
w_5	0.12±0.02
w_6	0.03±0.01

$B_{tag} = \bar{B}^0,\ f_{CP} = D^{*+}\pi^-$
$B_{tag} = B^0,\ f_{CP} = D^{*-}\pi^+$

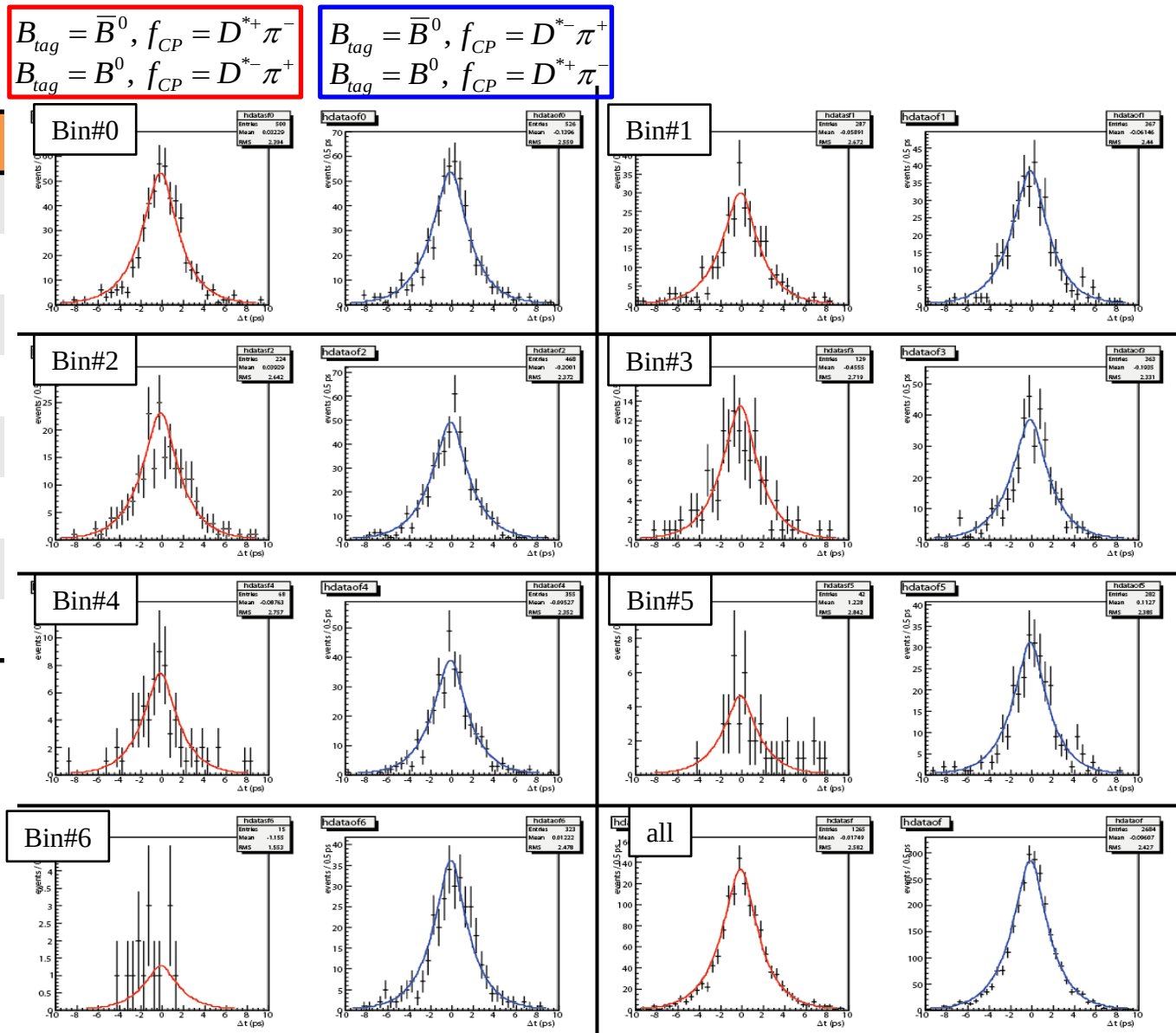
$B_{tag} = \bar{B}^0,\ f_{CP} = D^{*-}\pi^+$
$B_{tag} = B^0,\ f_{CP} = D^{*+}\pi^-$



荷電B中間子背景事象のΔt fit

- Fit 結果

Name	Value
τ_{chgB}	1.599±0.029 (ps)
w_0	0.50 (fixed)
w_1	0.44±0.02
w_2	0.32±0.02
w_3	0.26±0.02
w_4	0.16±0.02
w_5	0.13±0.02
w_6	0.04±0.01



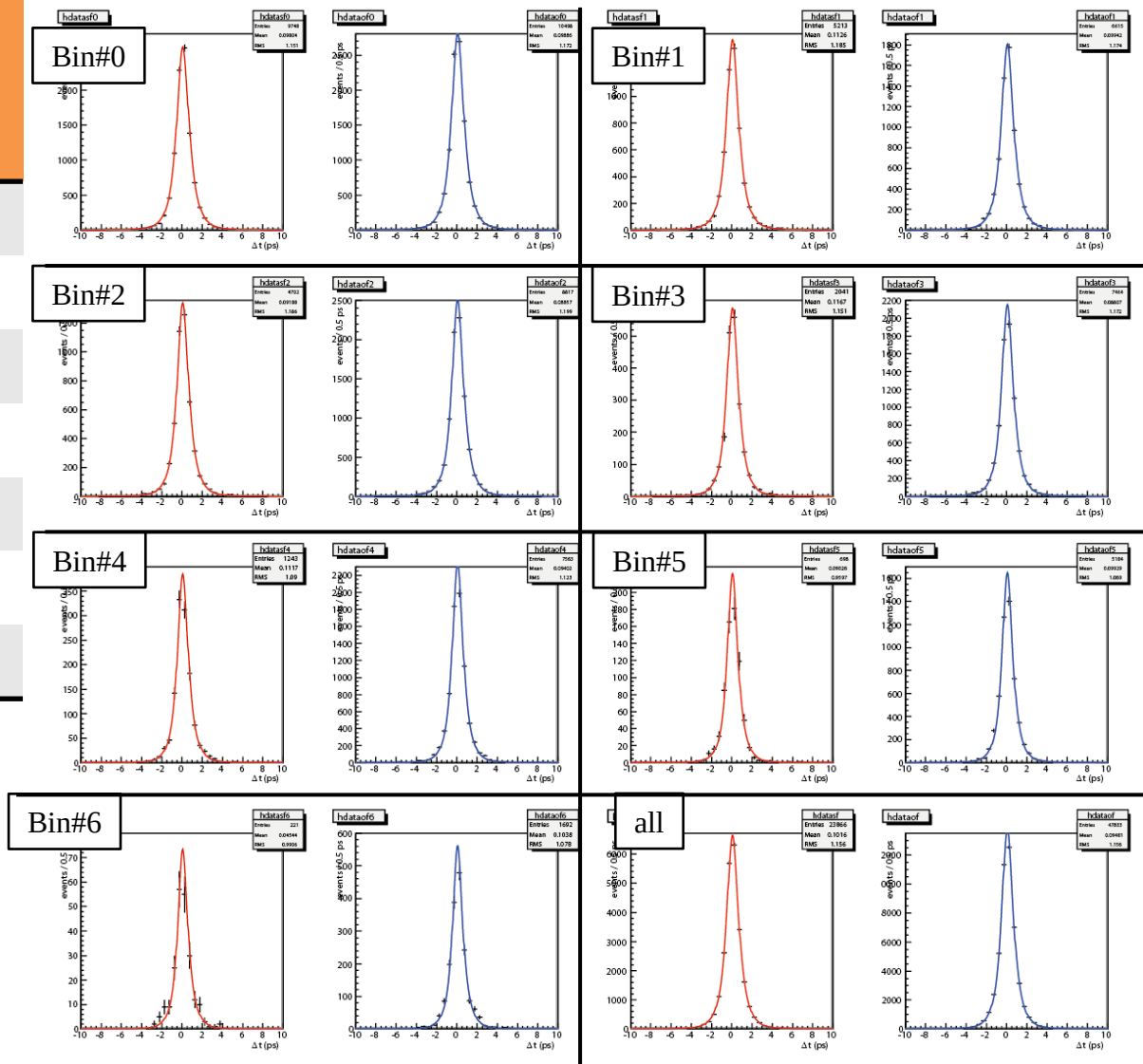
B以外の背景事象のΔt fit

- Fit 結果

	Single-track vertex Either CP or tag B	Multi-track vertex Both CP and tag B
f_d	0.26±0.04	0.39±0.02
m_d	0.046±0.007	
m_τ	0.14±0.01	
τ_{con}	0.58±0.02	
s_{bkg}^{main}	1.07±0.03	1.34±0.02
s_{bkg}^{tail}	5.40±0.42	4.87±0.26
f_{bkg}^{tail}	0.088±0.010	0.047±0.007

$B_{tag} = \overline{B}^0,\ f_{CP} = D^{*+}\pi^-$
$B_{tag} = B^0,\ f_{CP} = D^{*-}\pi^+$

$B_{tag} = \overline{B}^0,\ f_{CP} = D^{*-}\pi^+$
$B_{tag} = B^0,\ f_{CP} = D^{*+}\pi^-$



信号事象＋背景事象

- signal fraction に従って背景事象を加え、信号事象の τ , Δm をfit

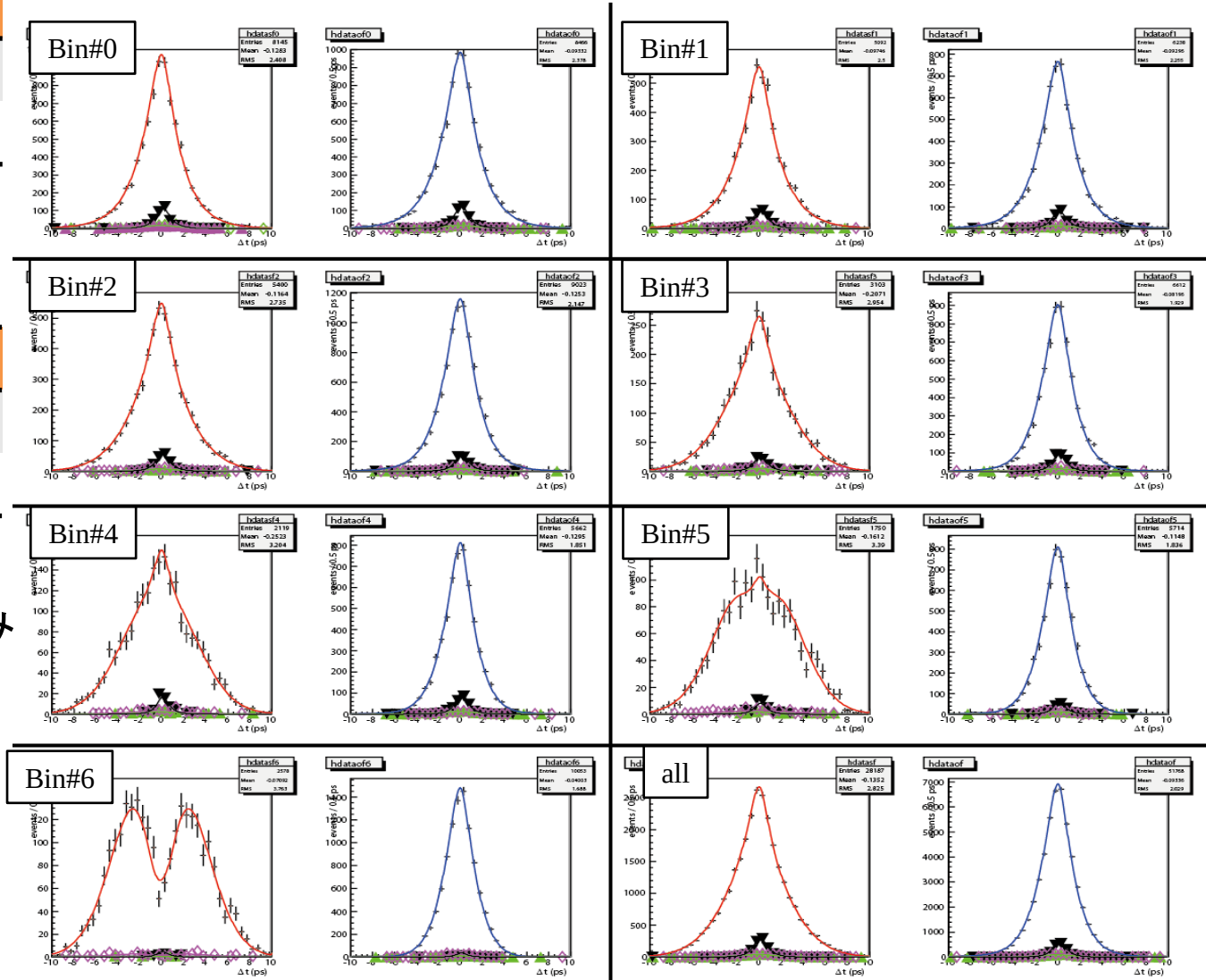
Name	Value 信号事象のみ
τ_{B0}	1.533±0.006 (ps)
Δm	0.505±0.004

⇩ + 背景事象

Name	Value
τ_{B0}	1.534±0.006 (ps)
Δm	0.506±0.004

Fit 結果は信号事象のみと consistent.

背景事象 PDF が得られた



まとめ

- $B \to D^{*}\pi$ 解析を進行中.

  ϕ_3 の測定

  - $D^{*} \to D^{0}\pi$, $D^{0} \to K\pi$ を解析中
    - BG PDFs が MC から得られた

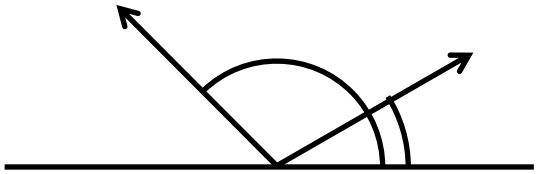
計画

- $S^{\pm}$ fit for MC
- 他の下位崩壊を加えてのΔt fit

Buck up

Signal event selection

- 正確なvertex の決定のための Fast pion への要求
- Impact parameter
  - radial : $dr < 0.1\,cm$
  - longitudinal : $|dz| < 2.0\,cm$
  - SVDにヒットをもつ
  - Polar angle in the laboratory frame : $30° < \theta_{lab} < 135°$



- The vertex positions are obtained by fits of the candidate tracks with the IP.
- Lepton, kaon hypothesis と一致しない
  - Based on information from the CDC, TOF and ACC.
- Fast pion cms momentum : $1.83\,{}^{GeV}\!/_{c} < p_{\pi_f} < 2.43\,{}^{GeV}\!/_{c}$

Signal event selection

- Slow pion cms momentum : $0.05\ {}^{GeV}\!/_{c} < p_{\pi_s} < 0.30\ {}^{GeV}\!/_{c}$
- Particle identification のとき、slow pion には何の条件も課さない
- Vertexing に使用しない
- IP から生じることのみ要求する

- fast pion とslow pion は逆の電荷をもつ

再構成

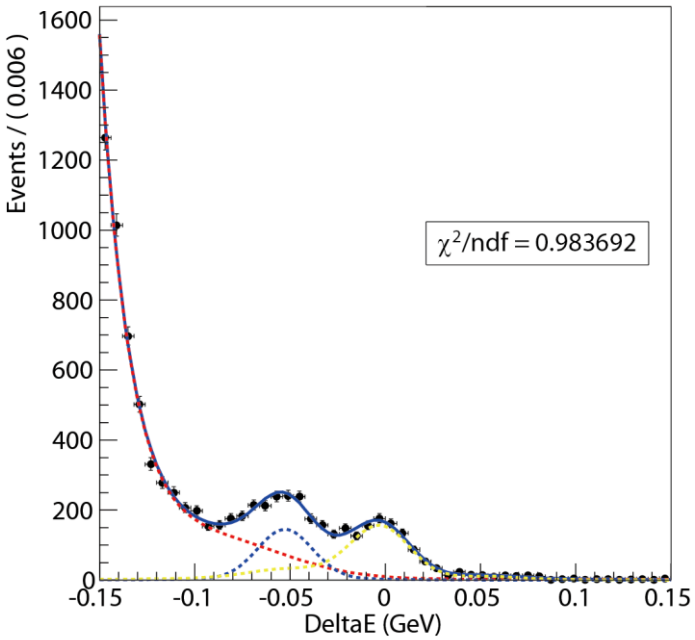
- $D^* \rightarrow D^0\pi$, $D^0 \rightarrow K\pi$ 信号選択

Slow π 以外の π SVD hit in r-ϕ ≧1, z ≧2 Pid(K/ π) ≦ 0.7	D^0 1.82 GeV < $\lvert M_{K\pi}\rvert$ < 1.92 GeV
K SVD hit : π と同じ Pid(K/ π) ≧ 0.3	D^* 0.143 GeV < $M_{D^*} - M_{D^0}$ < 0.148 GeV
Slow π 要求なし	B 5.2 GeV < M_{bc} < 5.3 GeV -0.15 GeV < ΔE < 0.15 GeV 最良候補選択（M_{bc}, $M_{D^*} - M_{D^0}$）

Neutral B BG ΔE PDF

ΔE

B^0 background



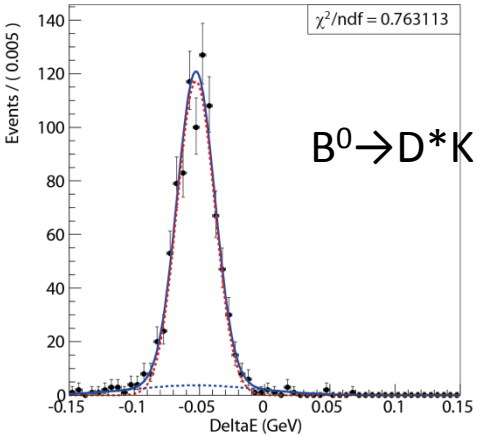
$B^0 \rightarrow D^*K$

SCF

Others

ΔE

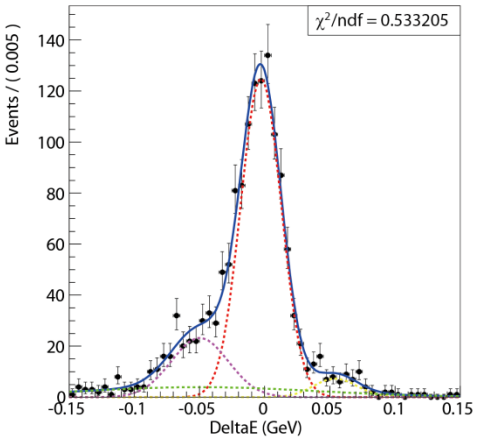
$B^0 \rightarrow D^*K$



Double gaussian

ΔE

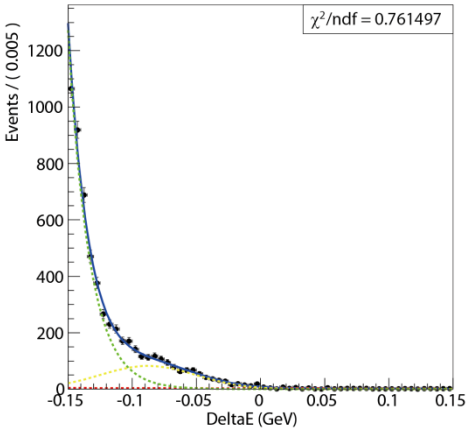
SCF



Gaussian x4

ΔE

Others



Exponential

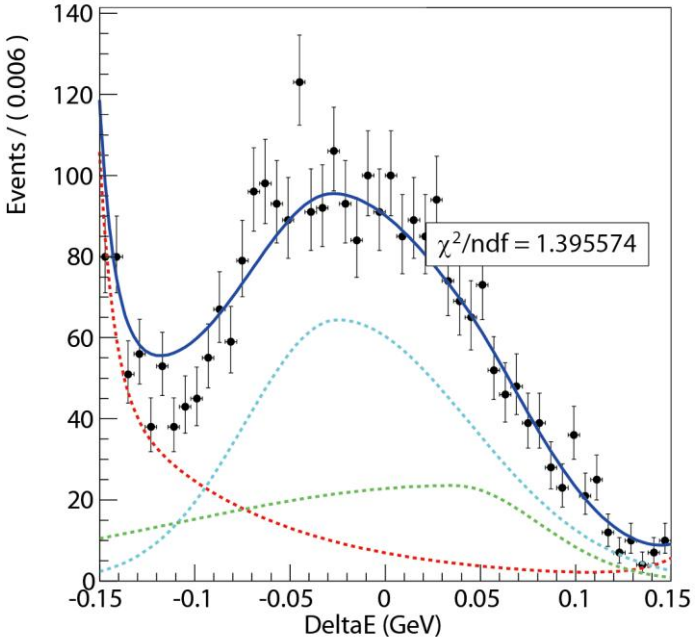
Line

gaussian

Charged B BG ΔE PDF

ΔE

$B^{\pm}$ background



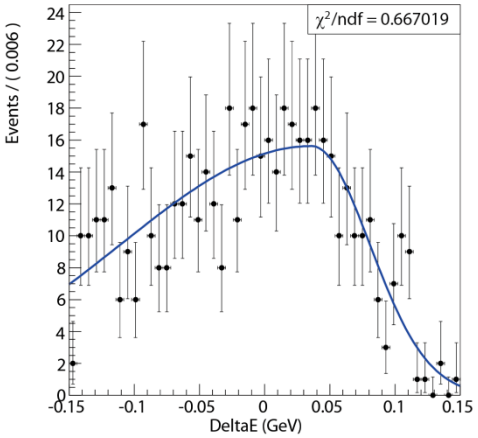
$B^{\pm} \to D^{0*}\pi$

$B^{\pm} \to D^{0}\rho$

Others

ΔE

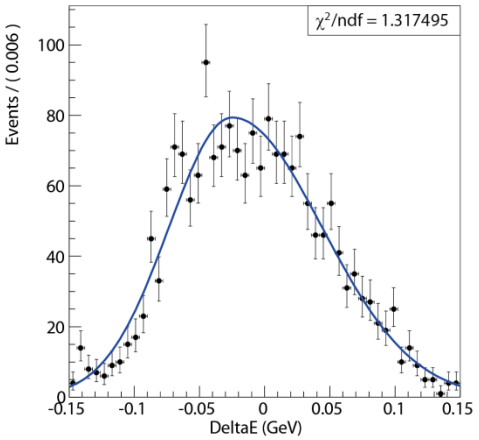
$B^{\pm} \to D^{0}\rho$



Bifurcated gaussian

ΔE

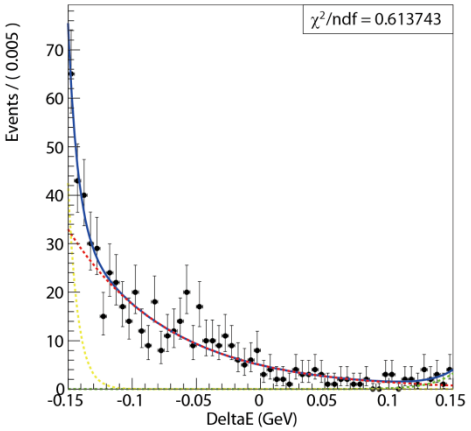
$B^{\pm} \to D^{*0}\pi$



Bifurcated gaussian

ΔE

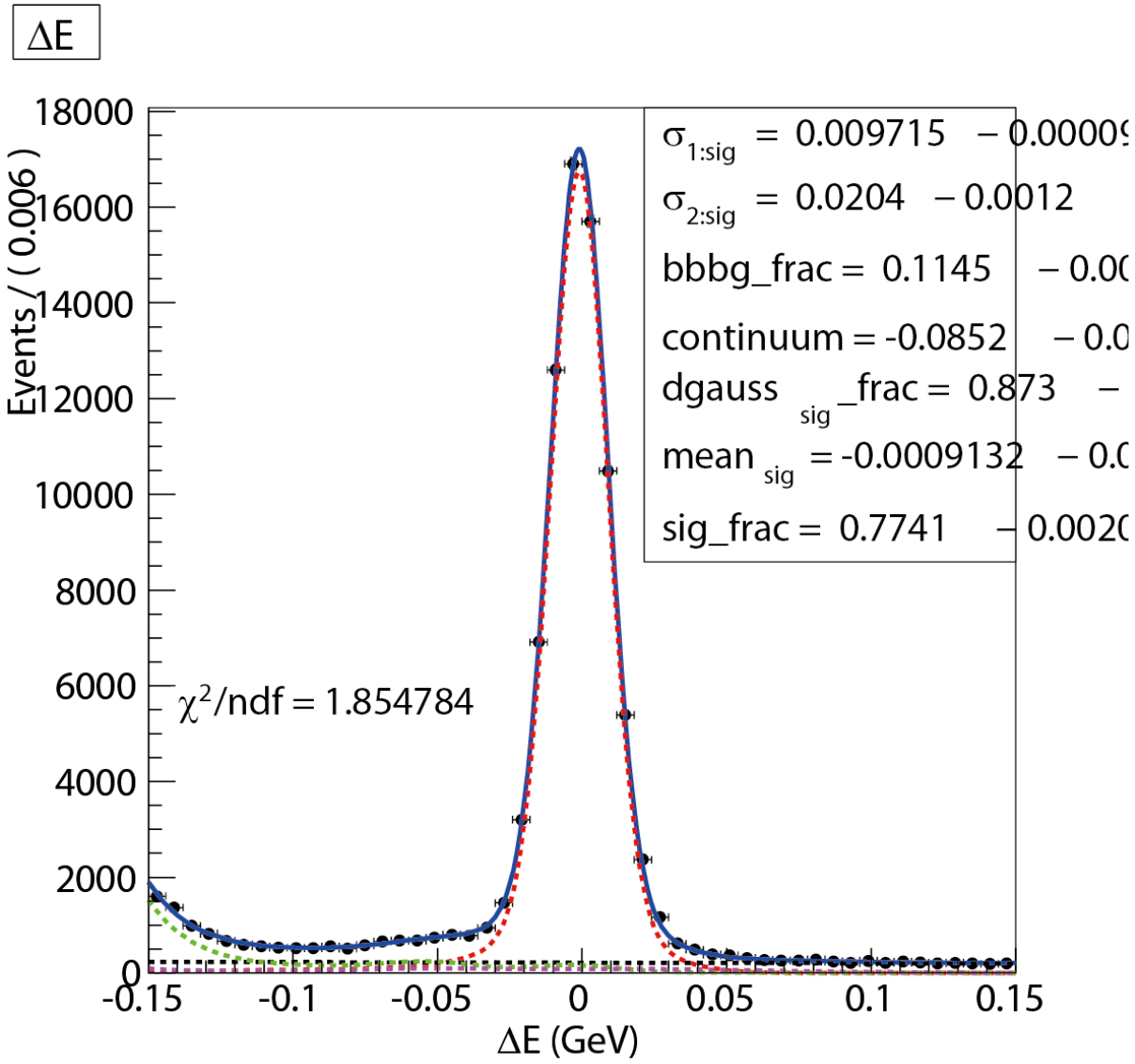
Others



Exponential x3

B reconstruction

- Generic MC were reconstructed.
  - Case B
  - 5 streams



r bin

- r bin : bin definition of the flavor tagging category

R bin #		**wrong tag fraction for SVD2 MC**	
Bin#0	0 <= |r| <= 0.1	w = 0.5	Δw = 0.
Bin#1	0.1 < |r| <= 0.25	w = 0.412222	Δw = 0.0569661
Bin#2	0.25 < |r| <= 0.5	w = 0.307838	Δw = 0.0126192
Bin#3	0.5 < |r| <= 0.625	w = 0.212765	Δw = 0.0147724
Bin#4	0.625 < |r| <= 0.75	w = 0.149933	Δw = 0.000550289
Bin#5	0.75 < |r| <= 0.875	w = 0.0913264	Δw = 0.00887704
Bin#6	0.875 < |r| <= 1.0	w = 0.0218754	Δw = 0.00465683

Signal + $B^0\overline{B^0}$ Background

- To check the correctness of BG PDF, Signal + $B^0\overline{B^0}$ BG was fitted.

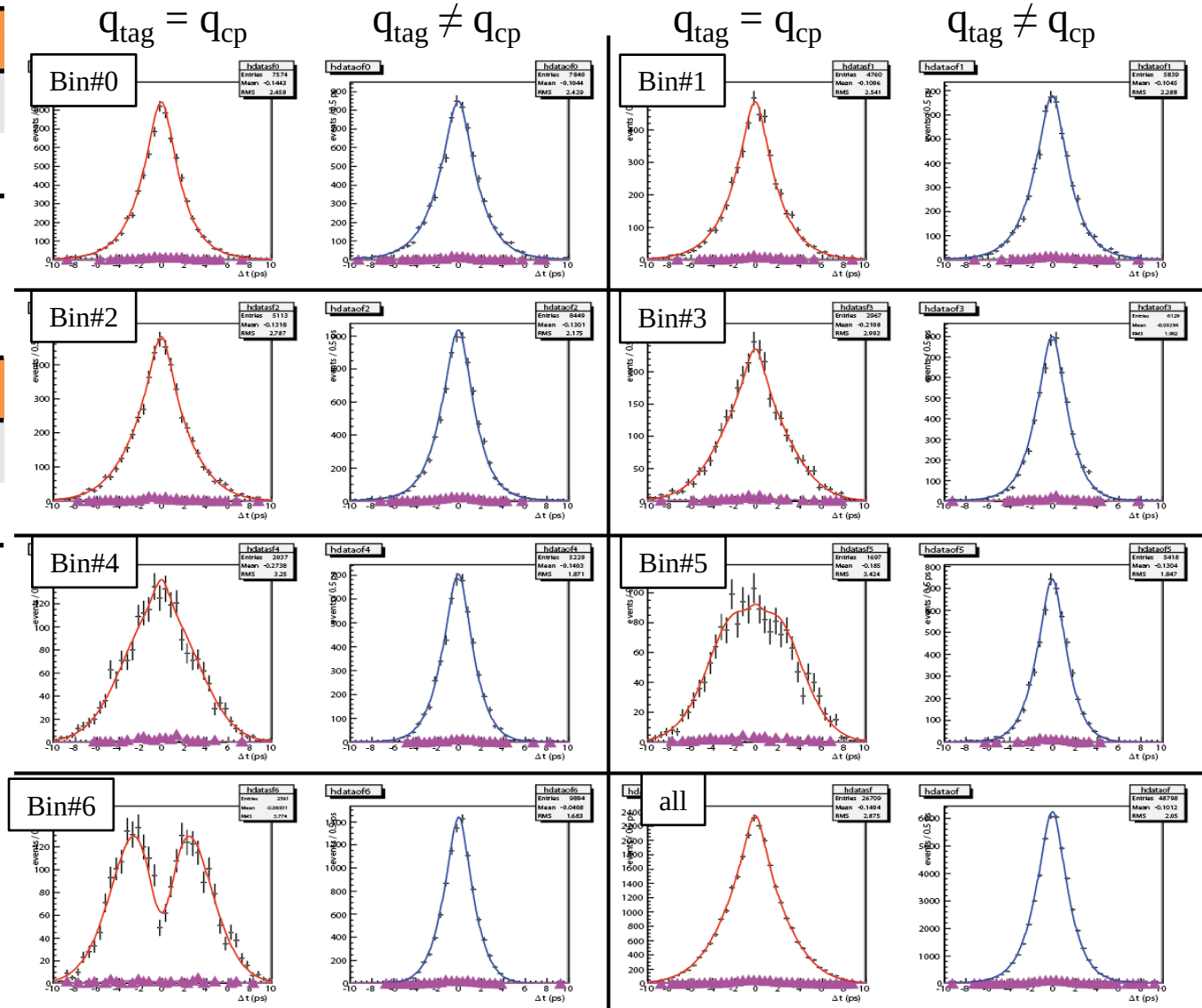
Name	Value	Signal Only
τ_{B0}	1.533±0.006 (ps)	
Δm	0.505±0.004	

⇩ + $B^0\overline{B^0}$ BG

Name	Value
τ_{B0}	1.535±0.006 (ps)
Δm	0.505±0.004

- Fit results for signal and signal + $B^0\overline{B^0}$ BG are consistent.

→ $B^0\overline{B^0}$ BG PDF were obtained.



Signal + B^+B^- Background

- To check the correctness of BG PDF, Signal + B^+B^- BG was fitted.

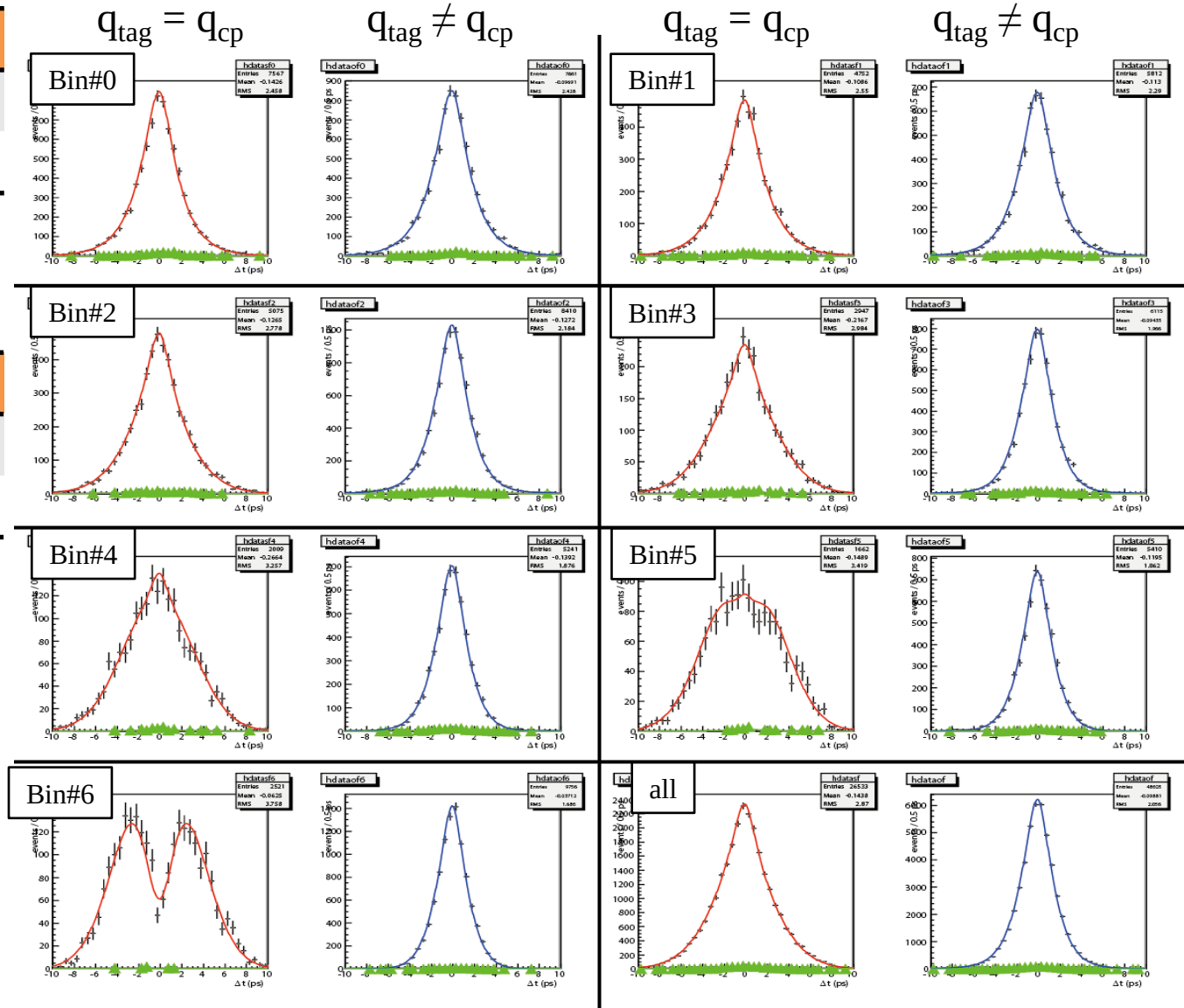
Name	Value	Signal Only
τ_{B0}	1.533 ± 0.006 (ps)	
Δm	0.505 ± 0.004	

⇩ + B^+B^- BG

Name	Value
τ_{B0}	1.535 ± 0.006 (ps)
Δm	0.506 ± 0.004

- Fit results for signal and signal + B^+B^- BG are consistent.

→ B^+B^- BG PDF were obtained.



Signal + continuum Background

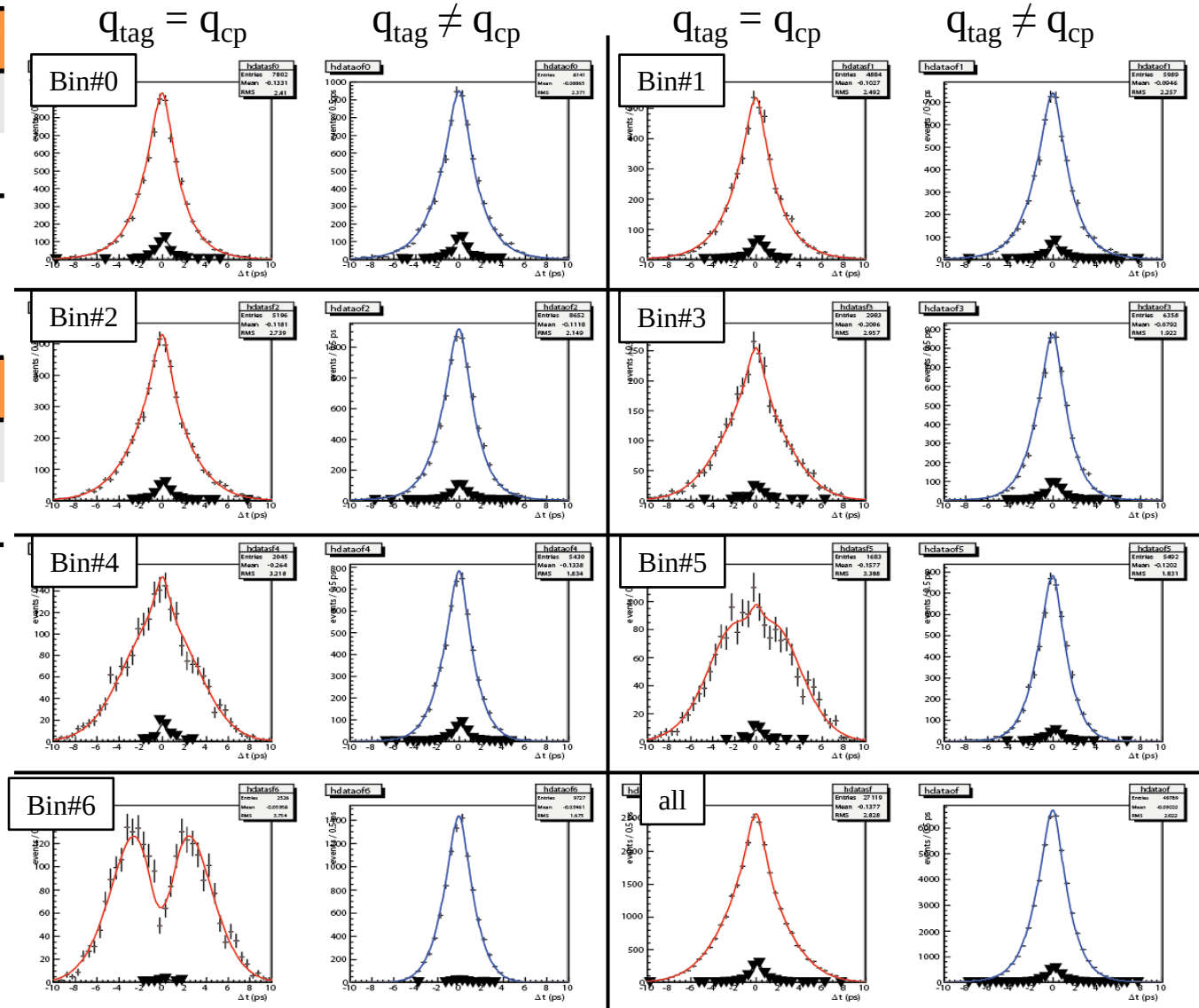
- To check the correctness of BG PDF, Signal + continuum BG was fitted.

Name	Value	Signal Only
τ_{B0}	1.533 ± 0.006 (ps)	
Δm	0.505 ± 0.004	

⇩ + continuum BG

Name	Value
τ_{B0}	1.534 ± 0.006 (ps)
Δm	0.505 ± 0.004

- Fit results for signal and signal + continuum BG are consistent.
→ continuum BG PDF were obtained.



D*π 数

- **771.581 x 10^6 x 2.76 x 10^-3 = 2.13 x 10^6**
  - **Kπ : x 67.7 x 10^-2 x 3.89 x 10^-2 = 56000**

- 使用する下位崩壊

  $D^* \rightarrow D^0 \pi$ (67.7%)

  $D^0 \rightarrow K\pi$ (3.89%), $K\pi\pi^0$ (13.9%), $K\pi\pi\pi$ (8.09%), $K_s\pi\pi$ (2.94%)

  $D^* \rightarrow D\pi^0$ (30.7%)

  $D \rightarrow K\pi\pi$ (9.4%)