$B^0 \to D^* \pi$崩壊事象を用いたCP対称性破れの測定

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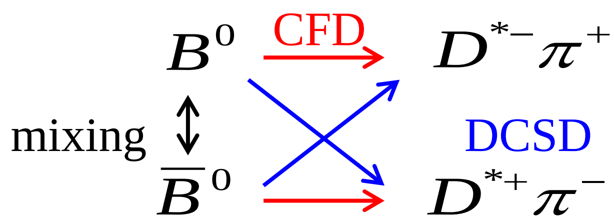
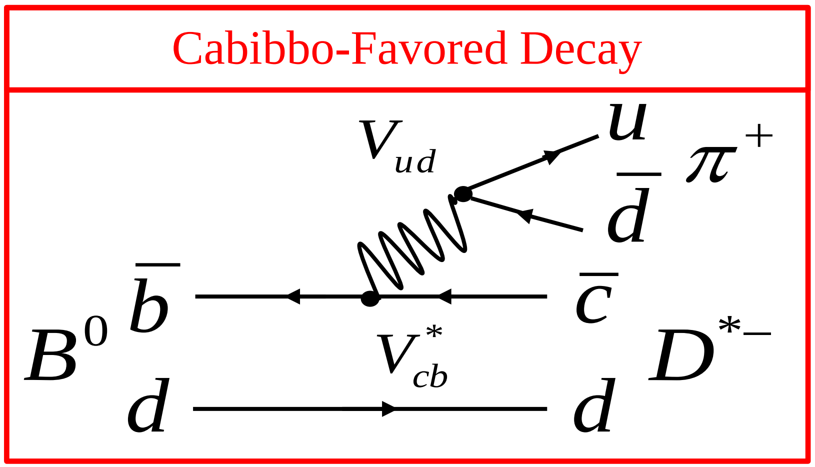
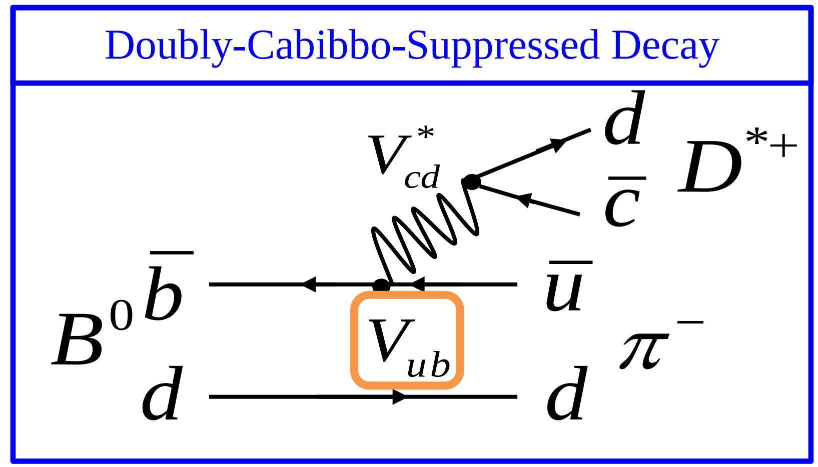
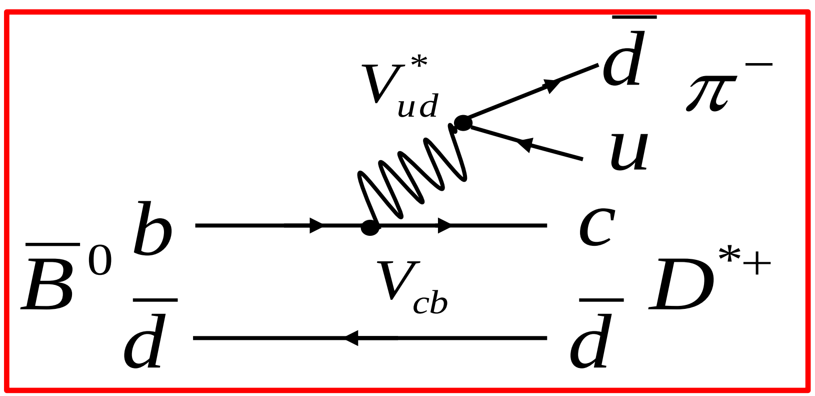
導入

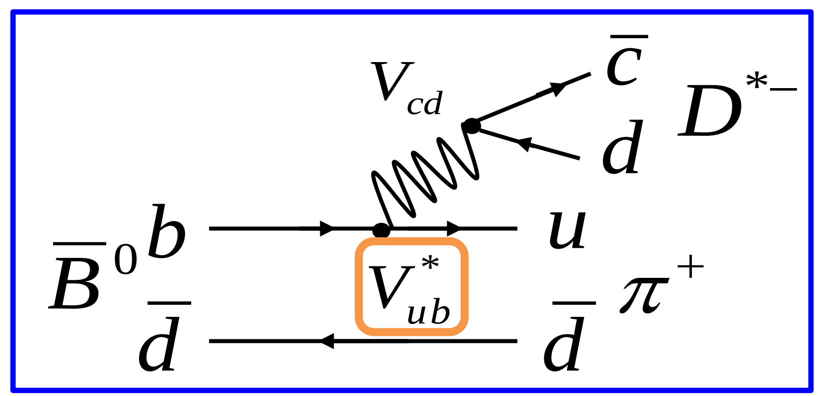
- $B^0 \to D^* \pi$ 崩壊











- $\phi_3 \sim -\arg(V_{ub})$ に感度

導入

$$\Gamma\left(B^0 \to D^{*-}\pi^+\right) \propto 1 + C\cos(\Delta m \Delta t) - S^- \sin(\Delta m \Delta t)$$

$$\Gamma\left(B^0 \to D^{*+}\pi^-\right) \propto 1 - C\cos(\Delta m \Delta t) - S^+ \sin(\Delta m \Delta t)$$

$$\Gamma\left(\overline{B}^0 \to D^{*+}\pi^-\right) \propto 1 + C\cos(\Delta m \Delta t) + S^+ \sin(\Delta m \Delta t)$$

$$\Gamma\left(\overline{B}^0 \to D^{*-}\pi^+\right) \propto 1 - C\cos(\Delta m \Delta t) + S^- \sin(\Delta m \Delta t)$$

CPの破れのパラメータ

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

$$C = \frac{1-R^2}{1+R^2}$$

$$R = \frac{|A(DCSD)|}{|A(CFD)|} = \frac{\left|A\left(B^0 \to D^{*+}\pi^-\right)\right|}{\left|A\left(B^0 \to D^{*-}\pi^+\right)\right|} \sim 0.02$$

DCSDが起こりづらく、
CP の破れも小さい
→ 精密測定が必要

- Belle 実験の全データ(772x10^6 BB)を用いた測定結果を報告する
  - 同じ手法で386 x 10^6 BB を用いた結果 PRD73(2006)092003

$$S^+ = 0.050 \pm 0.029 \pm 0.014, \quad S^- = 0.028 \pm 0.028 \pm 0.014$$

$B^0 \to D^*\pi$ の再構成

- 以下の崩壊を再構成し、信号事象を得た

$$B^0 \to D^{*\mp}\pi^{\pm}$$
$$D^{*+} \to D^0\pi^+$$
$$D^0 \to K^-\pi^+, K^-\pi^+\pi^+\pi^-, K^-\pi^+\pi^0, K_s\pi^+\pi^-$$
$$D^{*+} \to D^+\pi^0$$
$$D^+ \to K^-\pi^+\pi^+$$

荷電共役も同様に再構成

- 事象選別

PID(K,π)	138 MeV < $M_{D*} - M_{D0}$ <143 MeV
0.118 GeV < $M_{\pi 0}$ < 0.150 GeV	143 MeV < $M_{D*} - M_{D+}$ <148 MeV
$\gamma_{\pi 0}$ energy > 0.04 GeV	-0.15 GeV< ΔE <0.5 GeV
π^0 を含むD^0質量 ±30MeV (PDG)	5.2 GeV < M_{bc} <5.3 GeV
π^0 を含まないD^0質量 ±20MeV	
$M_{D\pm}$ ±20MeV (PDG)	

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

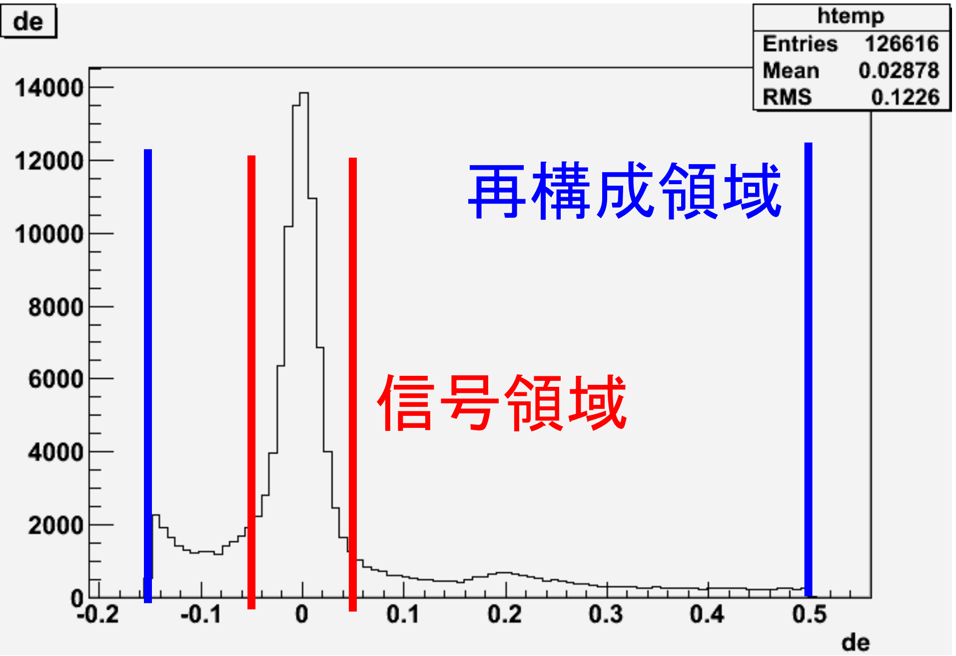
- Belle 全データを再構成した

$B^0 \to D^* \pi$ の再構成

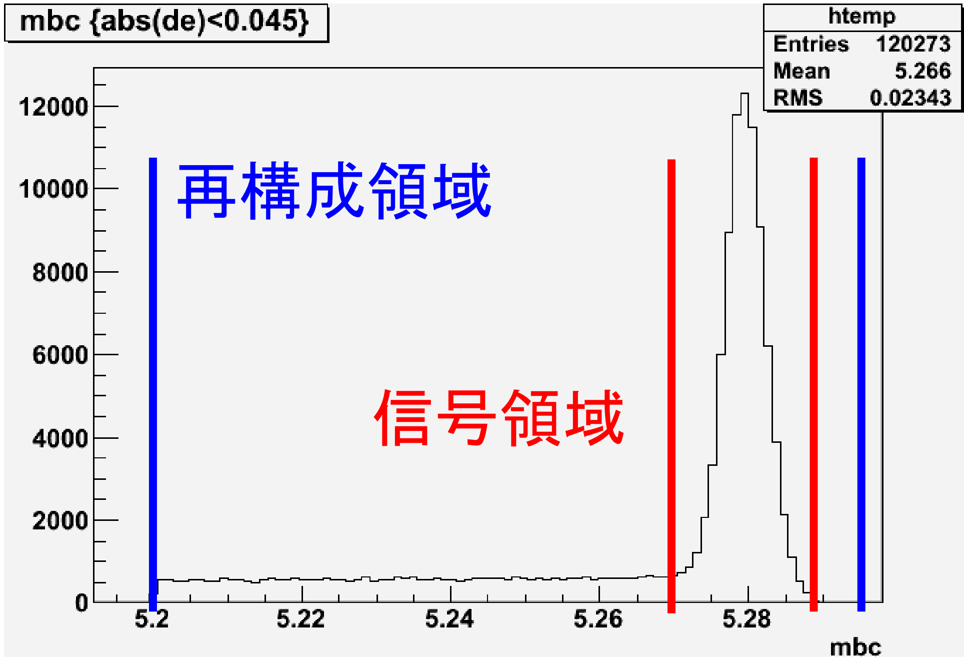
- 信号領域

  -0.045 GeV< ΔE <0.045 GeV, 5.27 GeV < M_{bc} <5.29 GeV

$\Delta E = E_B - E_{Beam}$　　M_{bc} 信号領域



$M_{bc} = \sqrt{E_{Beam}^2 - P_B^2}$　　ΔE 信号領域

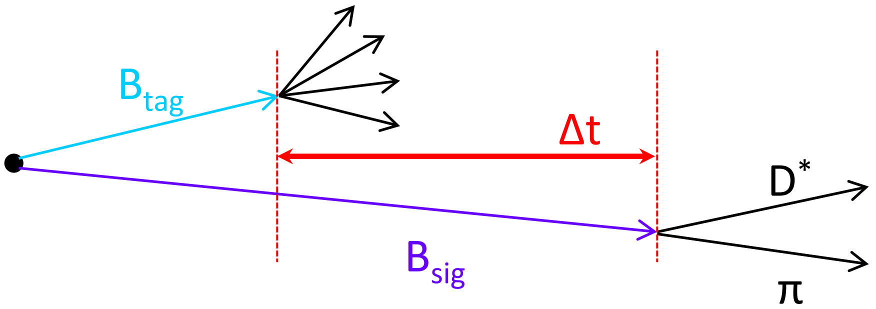


- 信号領域で 78,065 個のB候補を再構成した

Δt

- Δt から $S^{\pm}$(CPの破れパラメータ) を求める
- Δt : B_{tag} と B_{sig} の崩壊時間差
  - B_{sig} : $B^0 \rightarrow D^* \pi$
  - B_{tag} : flavor 同定に使用
    - Belle 標準
  - 崩壊時間 : 崩壊点から求める

$$\Delta t \approx \left(z_{sig} - z_{tag}\right) / \beta\gamma c$$



Δt PDF

- 信号事象のΔt PDF

$$P\left(B_{tag}=\overline{B}^0; B_{sig}\to D^{*\mp}\pi^{\pm}\right)=\left(1-w_{\overline{B}^0}\right)\times P\left(B^0\to D^{*\mp}\pi^{\pm}\right)+w_{B^0}\times P\left(\overline{B}^0\to D^{*\mp}\pi^{\pm}\right)$$

$$P\left(B_{tag}=B^0; B_{sig}\to D^{*\pm}\pi^{\mp}\right)=\left(1-w_{B^0}\right)\times P\left(\overline{B}^0\to D^{*\pm}\pi^{\mp}\right)+w_{\overline{B}^0}\times P\left(B^0\to D^{*\pm}\pi^{\mp}\right)$$

w : flavor tag 精度

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

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

- $S^{\pm}$をfloatしてΔt分布をfitする

Δt PDF

- Δt PDF

信号 中性B 荷電B B以外

$$P(\Delta t) = \boxed{f_{sig} P_{sig}} + (1 - f_{sig})\left\{\boxed{f_{B^0\overline{B}^0} P_{B^0\overline{B}^0}} + \boxed{f_{B^+B^-} P_{B^+B^-}} + \boxed{(1 - f_{B^0\overline{B}^0} - f_{B^+B^-}) P_{con}}\right\}$$

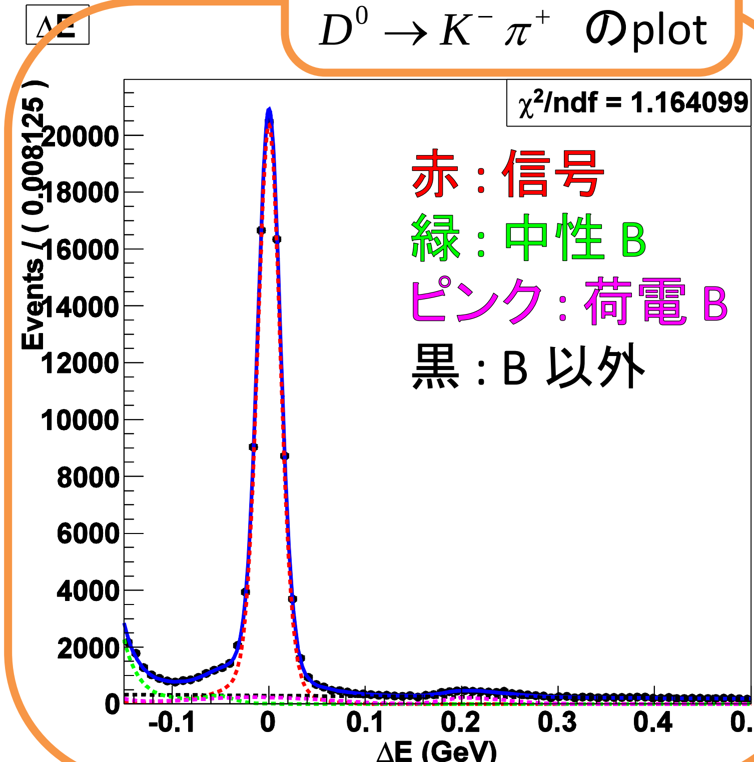
- $P_{B^0\overline{B}^0}, P_{B^+B^-}$: MCをfitして決定
- P_{con} : 実データ の信号領域の外をfitして決定

- f : 実データのΔEをfitして決定
  - – 下位崩壊、flavor tag の精度 ごと

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

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

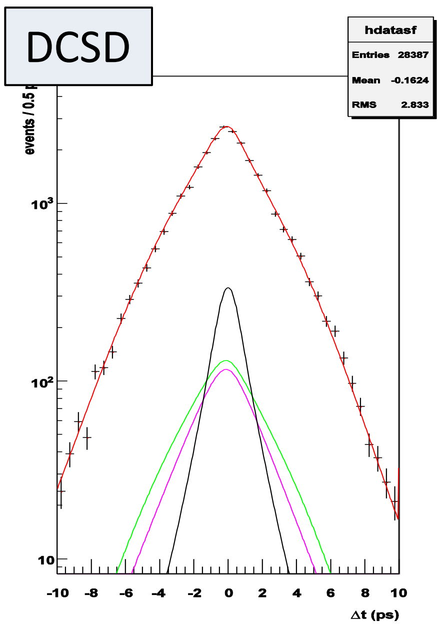
$D^0 \to K^- \pi^+$ のplot

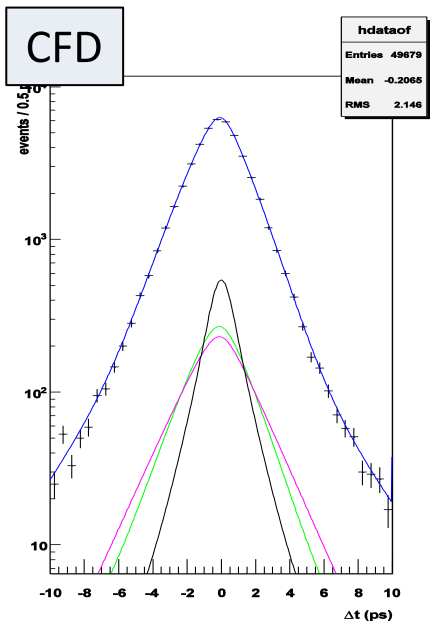


寿命、mixing parameter のfit

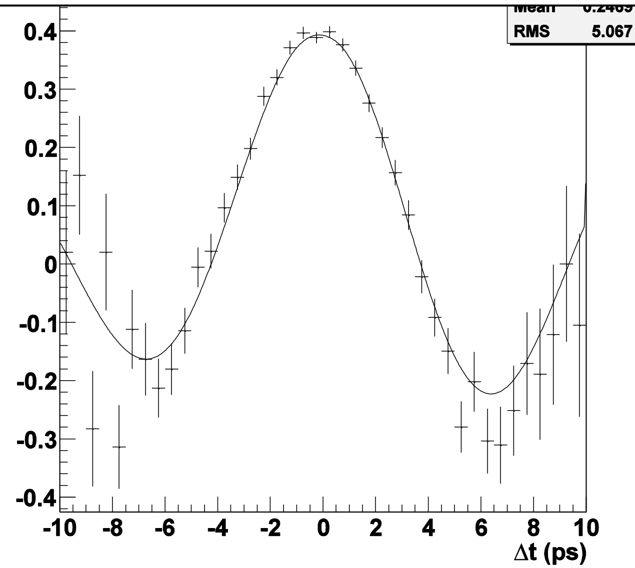
- B^0の寿命、B^0-B^0bar 混合のパラメータをfit した
  - B^0 と B^0bar を足し合わせ
  - $S^{\pm}$ を相殺

$$PDF_{sig} = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left(1 \pm C(1 - w_{B^0} - w_{\overline{B}^0})\cos(\Delta m \Delta t)\right)$$





$$Mixing\ asymmetry = \frac{CFD - DCSD}{CFD + DCSD} \propto \cos(\Delta m \Delta t)$$



Fit 結果

Name	Value
τ_{B0}	1.532±0.007 (ps)
Δm	0.505±0.005 (ps^{-1})

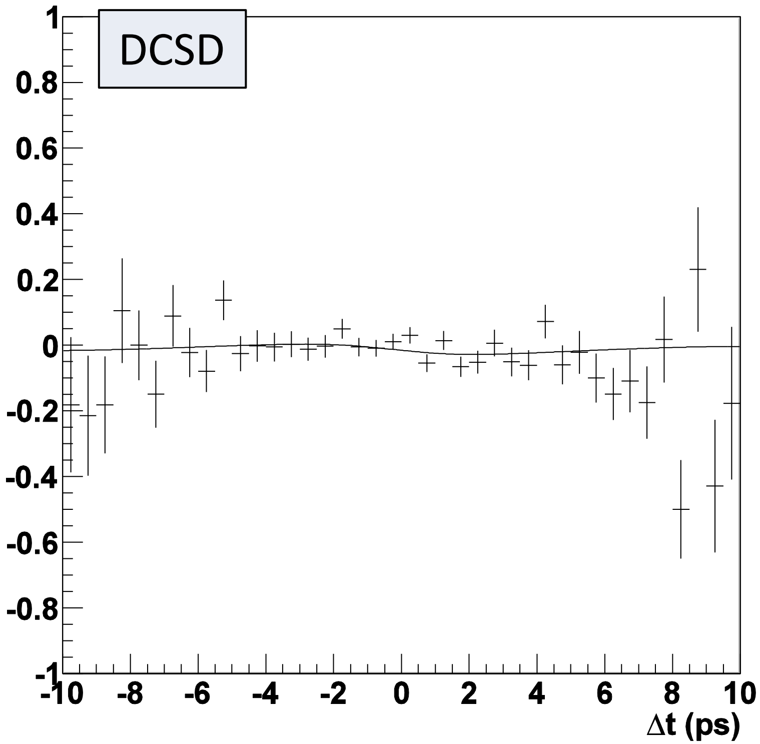
世界平均

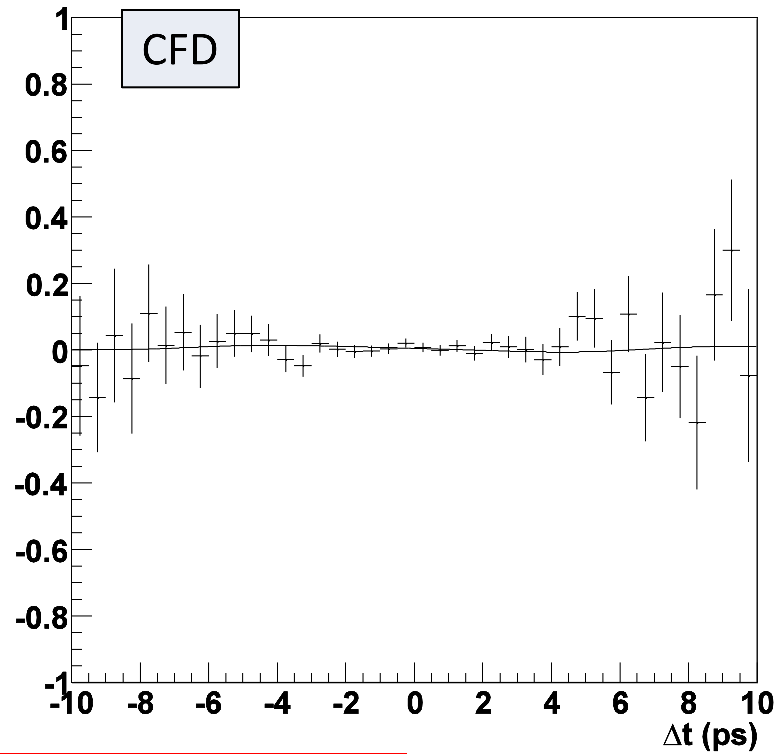
Name	Value
τ_{B0}	1.519 ± 0.007
Δm	0.507 ± 0.004

➢ Fit 結果は世界平均と無矛盾

S± のfit 結果

- S± をfit $\dfrac{tag\overline{B}^0 - tagB^0}{tag\overline{B}^0 + tagB^0} \propto -\left(S^+ + S^-\right)\left(1 - w_{B^0} - w_{\overline{B}^0}\right)\sin(\Delta m \Delta t)$





$$S^+ = 0.000 \pm 0.017(\text{統計})$$

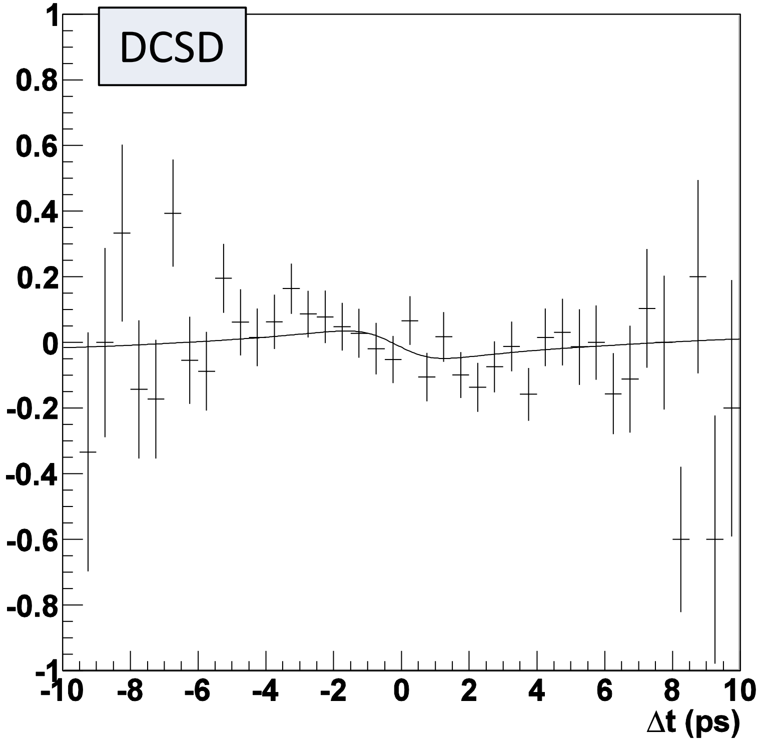
$$S^- = 0.057 \pm 0.017(\text{統計})$$

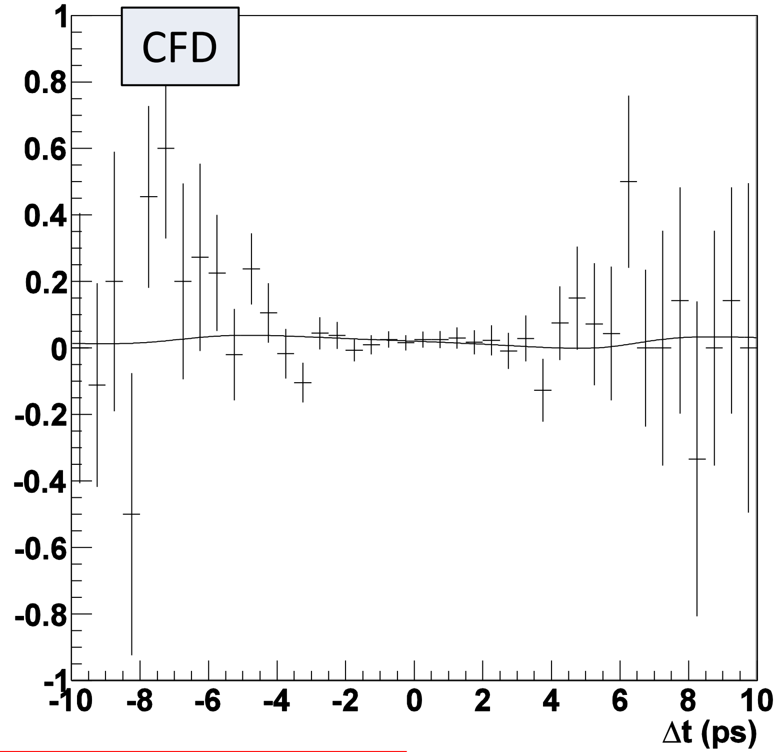
S± のfit 結果

- S± をfit

$$\frac{tag\bar{B}^0 - tagB^0}{tag\bar{B}^0 + tagB^0} \propto -(S^+ + S^-)(1 - w_{B^0} - w_{\bar{B}^0})\sin(\Delta m \Delta t)$$

Flavor tag の精度が良いイベントのみの plot





$$S^+ = 0.000 \pm 0.017(統計)$$

$$S^- = 0.057 \pm 0.017(統計)$$

Systematic error

- 各項目について、その値を変えて$S^{\pm}$をfit し、標準のfit 結果との差をsystematic error としている

source	Previous ($\Delta S^{+}=\Delta S^{-}$)	ΔS^{+}	ΔS^{-}
Δt resolution	0.005	+0.010 -0.010	+0.0010 -0.010
background Δt shape	0.0001	+0.0001 -0.0001	+0.0001 -0.0001
Signal fraction	0.002	+0.0010 -0.0005	+0.0007 -0.0007
wrong tag fraction	0.002	+0.0006 -0.0005	+0.0005 -0.0004
physics parameters (τ , Δm)	0.001	+0.0001 -0.0001	+0.0007 -0.0005
tag-side interference	0.005	+0.005 -0.005	+0.005 -0.006
Fit bias	0.010		
Vertexing	0.004	+0.0008 -0.0001	+0.0004 -0.0005
combined	0.014	+0.011 -0.011	+0.011-0.011

- 前回の結果で最も大きかったfit bias はtag-side interference の誤差に含まれることが分かったため、統合した

まとめ

- Belle 実験で得られた全データを用いて、$B^0 \to D^* \pi$崩壊事象に現れるCP対称性破れを測定した

$$S^+ = 0.000 \pm 0.017(stat) \pm 0.011(sys)$$

$$S^- = 0.057 \pm 0.017(stat) \pm 0.011(sys)$$

- この結果を ϕ_3 の制限に使うことができる

以前の結果との比較

- 前回の結果と今回の結果を比較した.

前回の結果 $S^{+} = 0.050 \pm 0.029 \pm 0.014$

$S^{-} = 0.028 \pm 0.028 \pm 0.014$

$S^{+} = 0.000 \pm 0.017(stat)$

$S^{-} = 0.057 \pm 0.017(stat)$

– 前回と同じ統計量での結果(386 x 10⁶ BB)

$S^{+} = 0.033 \pm 0.026$

$S^{-} = 0.044 \pm 0.026$

– 前回の測定以後のデータ

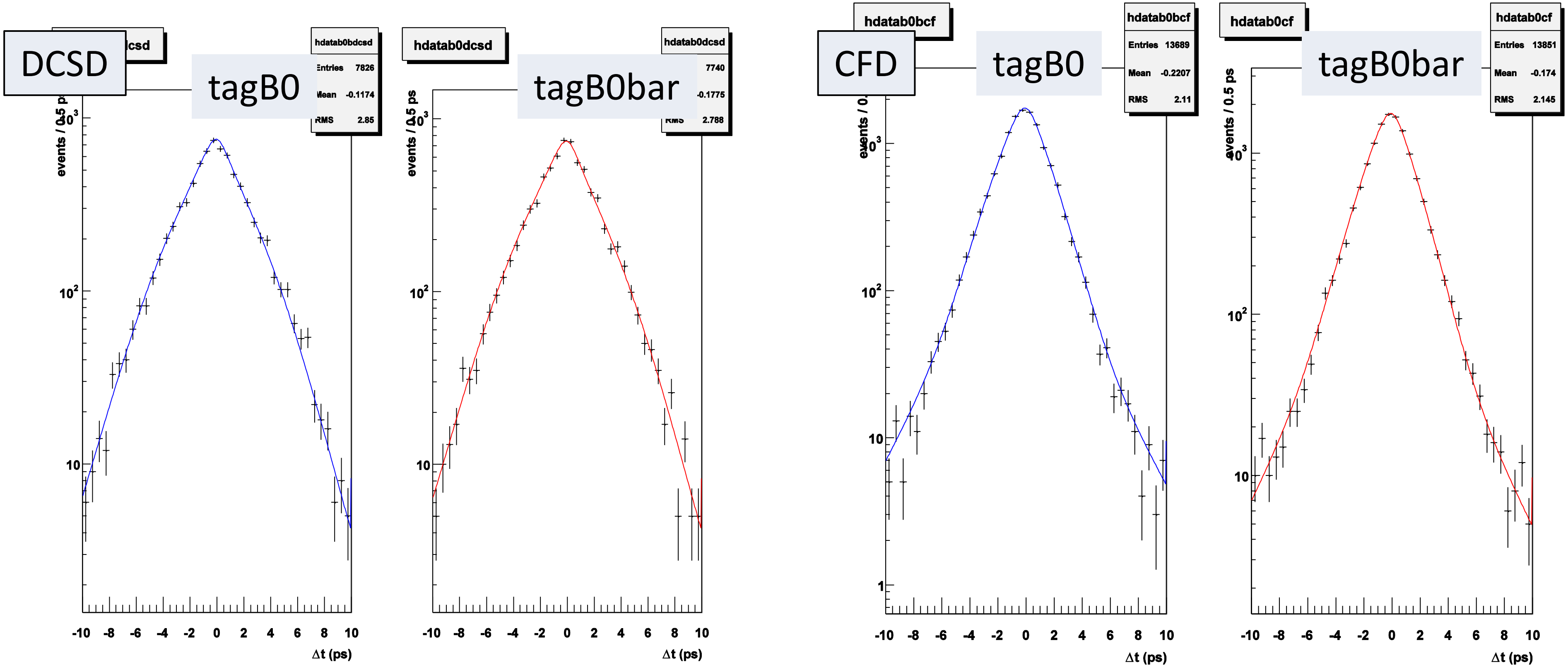
$S^{+} = -0.027 \pm 0.024$

$S^{-} = 0.067 \pm 0.023$

- 前回の測定以後のデータがS^{+}を小さくしている
- 無矛盾

S± のfit 結果

- S± をfit

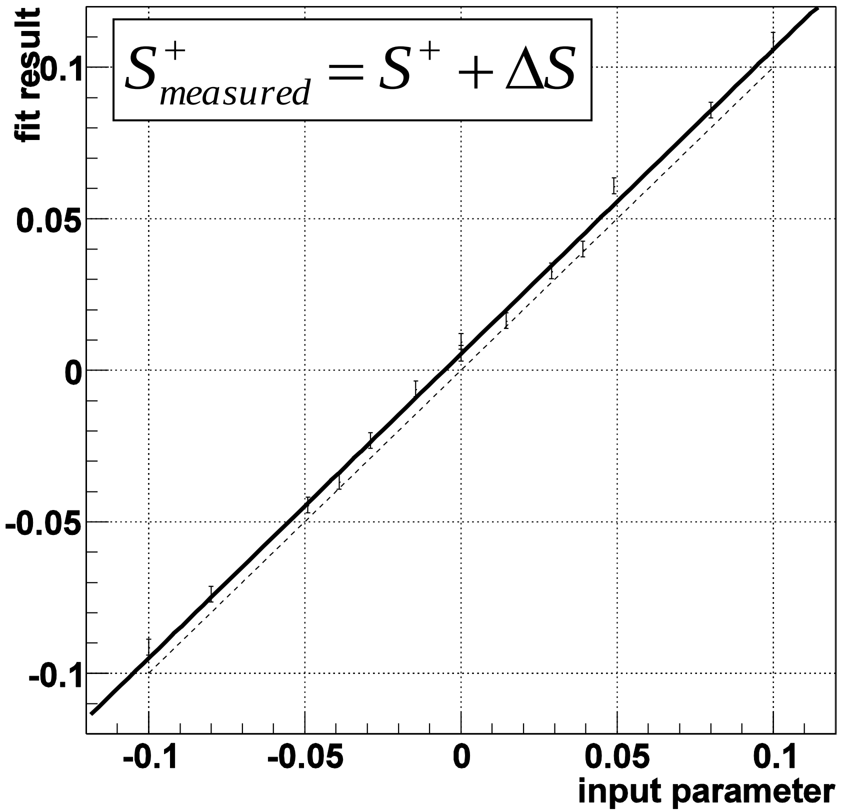


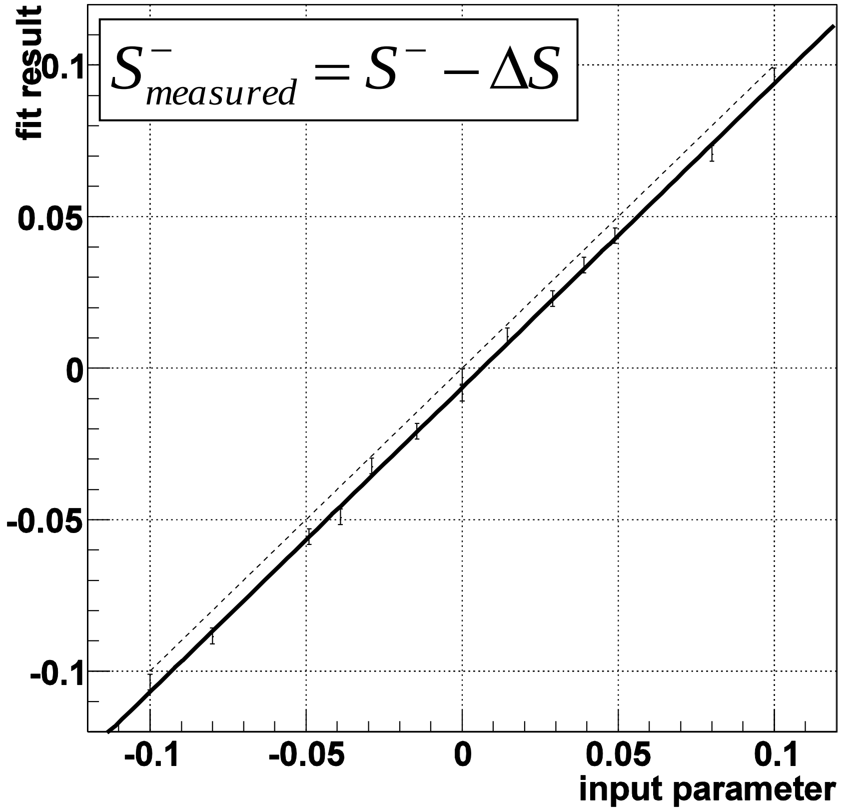
$$S^{+} = 0.000 \pm 0.017(\text{統計})$$

$$S^{-} = 0.057 \pm 0.017(\text{統計})$$

Linearity check of CP fit

- 32 stream signal MC (evtgen, gsim) were used for fit.
- S^+ gradient : 1.00 ± 0.01, y-intercept : 0.0060 ± 0.0007 (8.6 σ)
- S^- gradient : 1.00 ± 0.01, y-intercept : -0.0058 ± 0.0007 (8.3 σ)
- There are some bias.(ΔS)

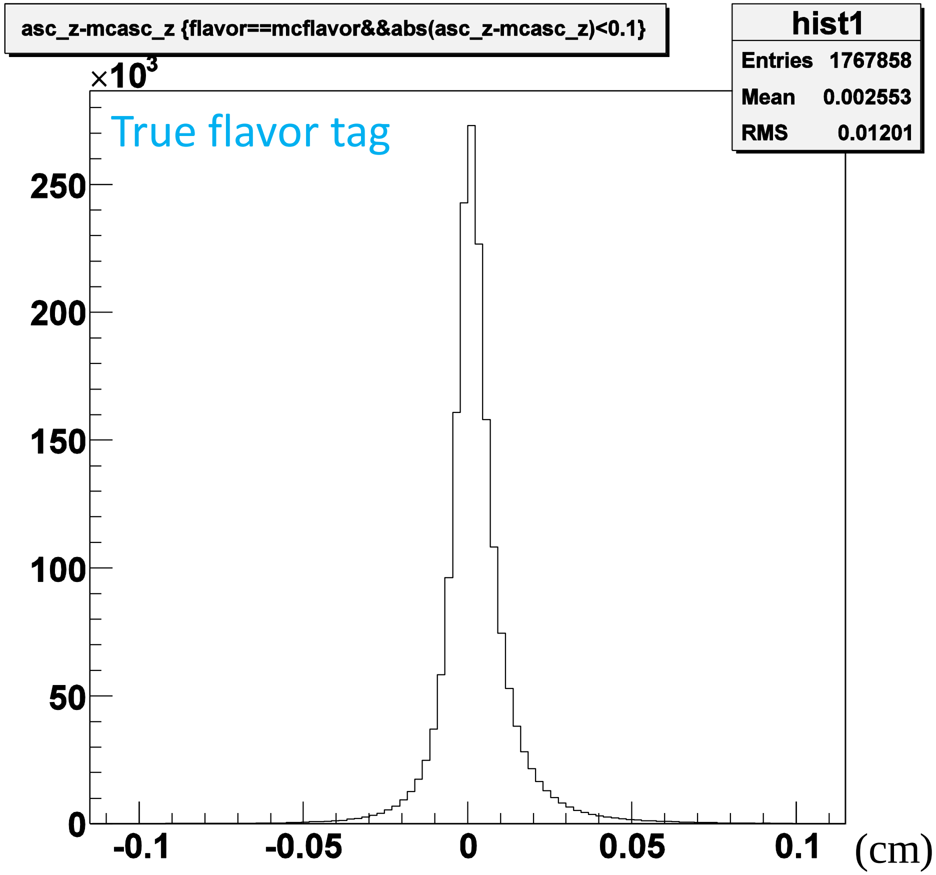


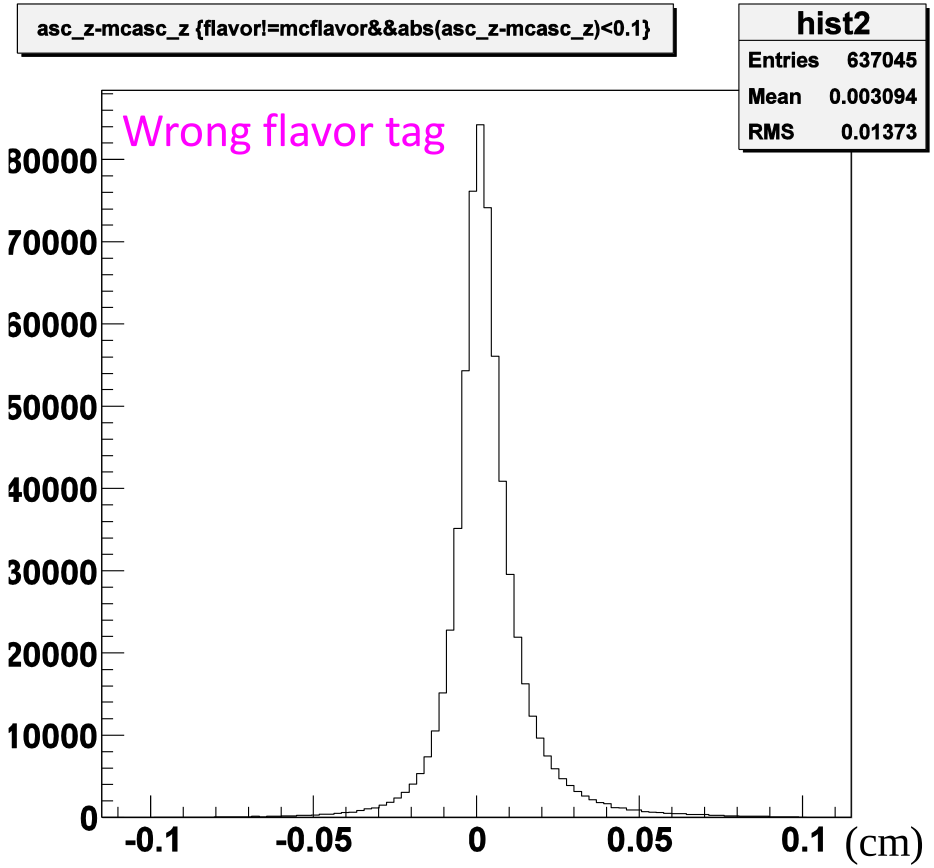


- We find that it comes from the position of tag-side vertex.

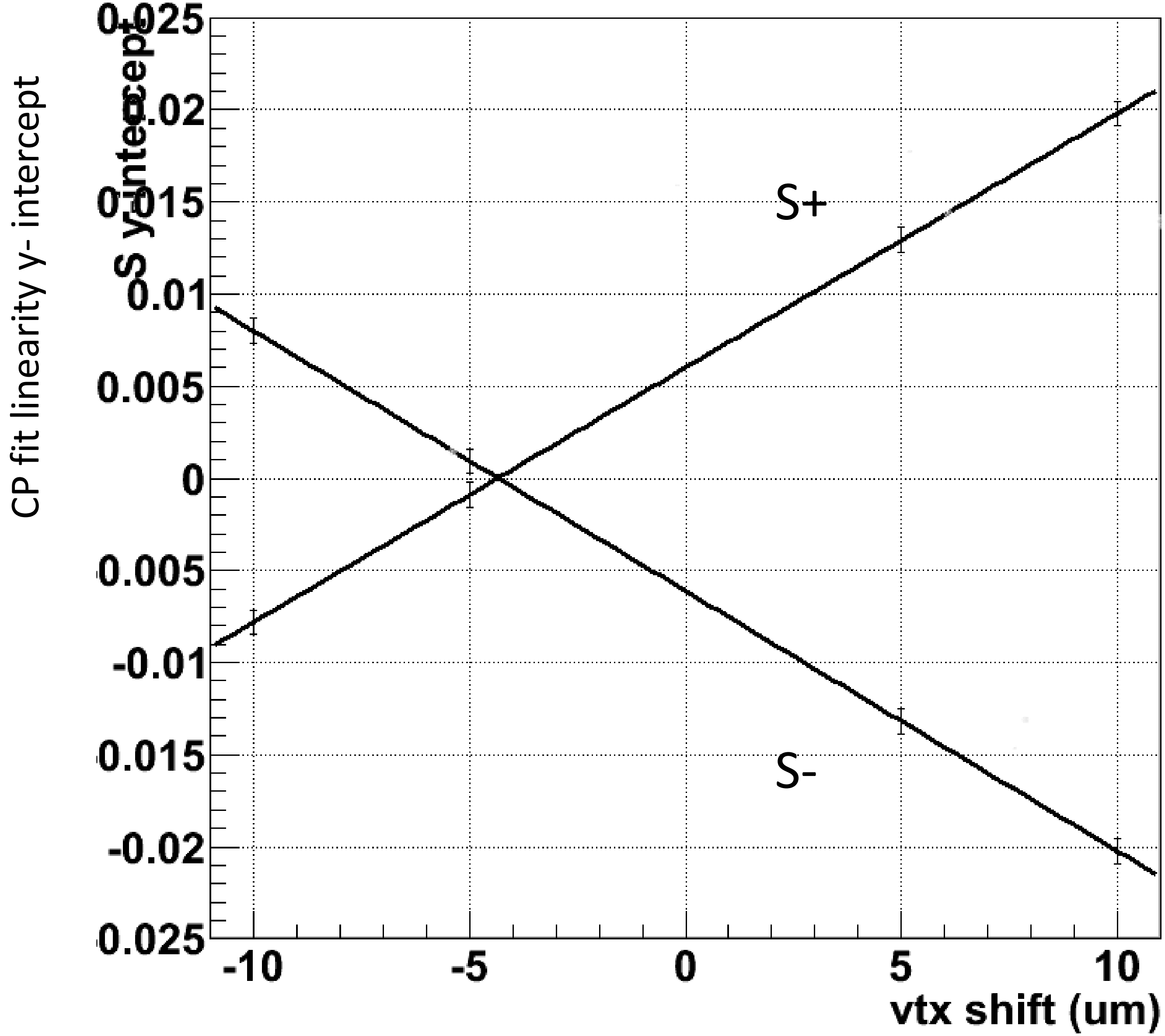
The difference arising from the result of flavor tag

- Difference between generated tag-side vertex and reconstructed tag-side vertex are not same between wrong flavor tag events and true flavor tag events.
- Their mean differ.



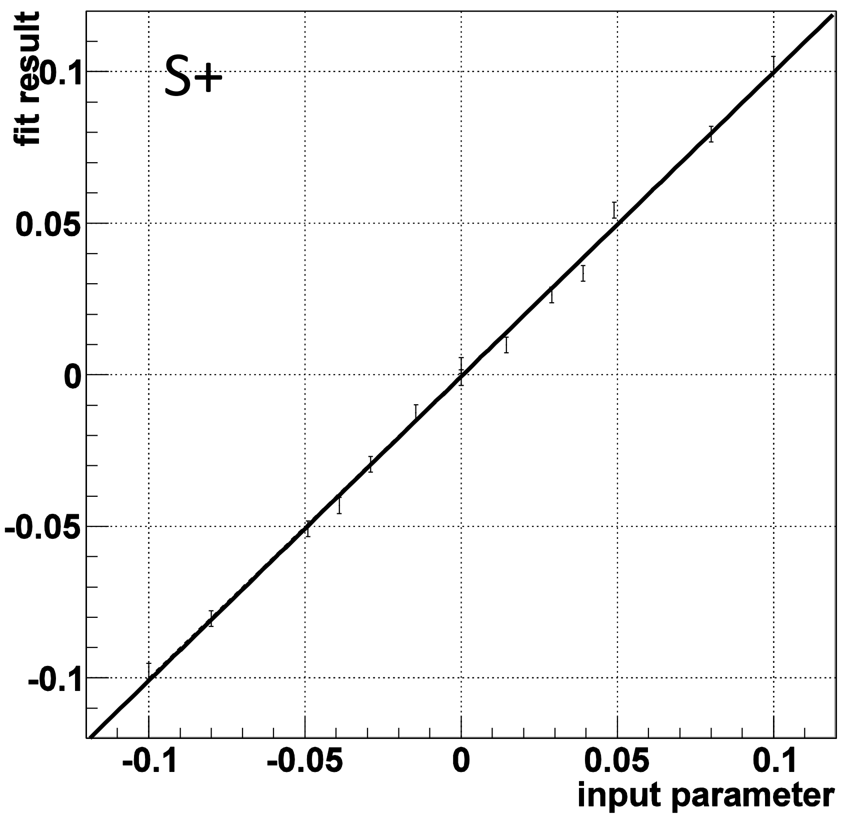


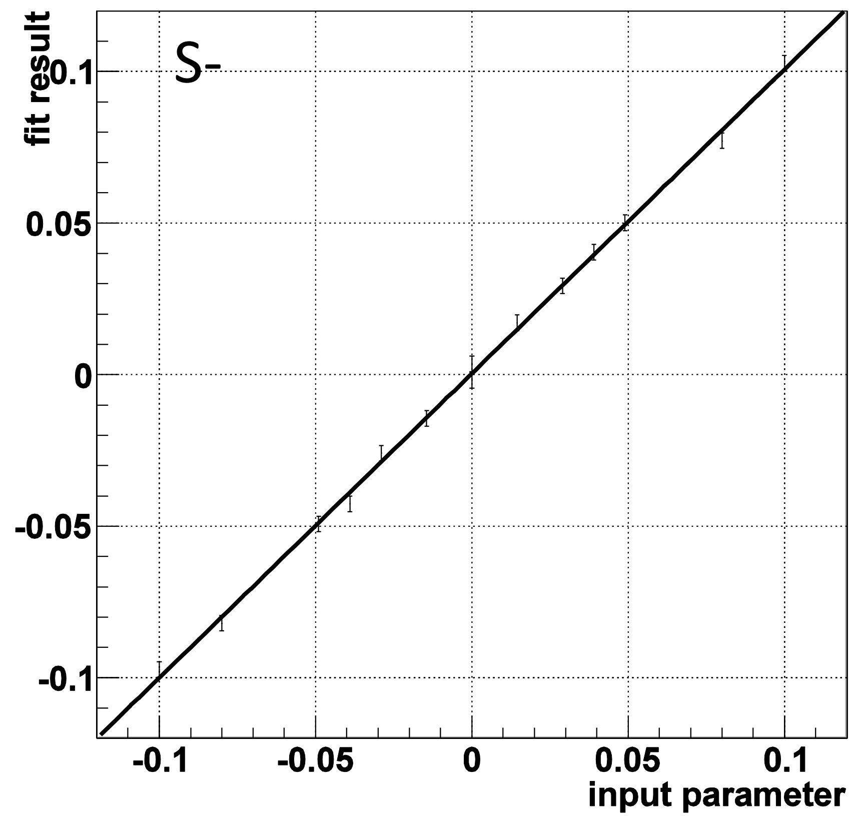
Shift of tag-side vertex of wrong tag events



Linearity check of CP fit

- Tag side vertex in wrong tag part were shifted -4.35 μm.
- S^+ gradient : 1.00 ± 0.01, y-intercept : -0.0004 ± 0.0007 (0.6 σ)
- S^- gradient : 1.00 ± 0.01, y-intercept : 0.0005 ± 0.0007 (0.7 σ)
- There are no bias.
- The cause of bias is the shift of the tag-side vertex of wrong tag events.





Tag side interference

- Measured $S^{\pm}$ include the interference in the tag side decay.

$$S^{+}_{measured,\,favored} = S^{+} + S^{-}_{tag}$$

$$S^{+}_{measured,\,suppressed} = S^{+} - S^{+}_{tag}$$

$$S^{-}_{measured,\,favored} = S^{-} + S^{+}_{tag}$$

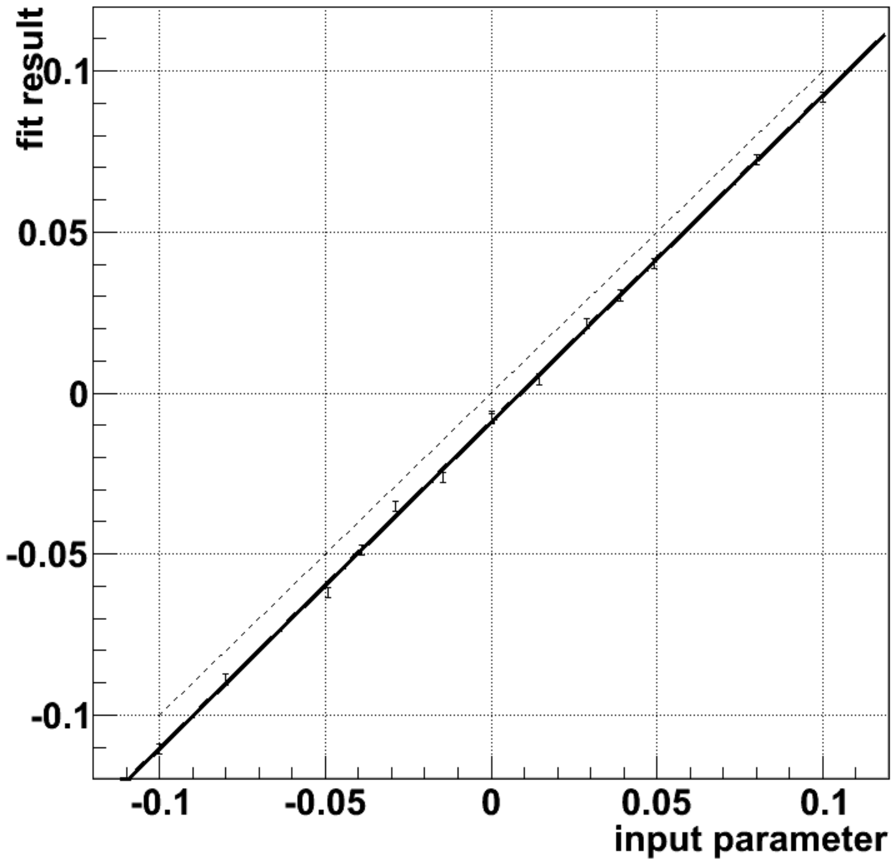
$$S^{-}_{measured,\,suppressed} = S^{-} - S^{-}_{tag}$$

S_{tag} linearity

Stag+

gradient = 1.014 ± 0.008

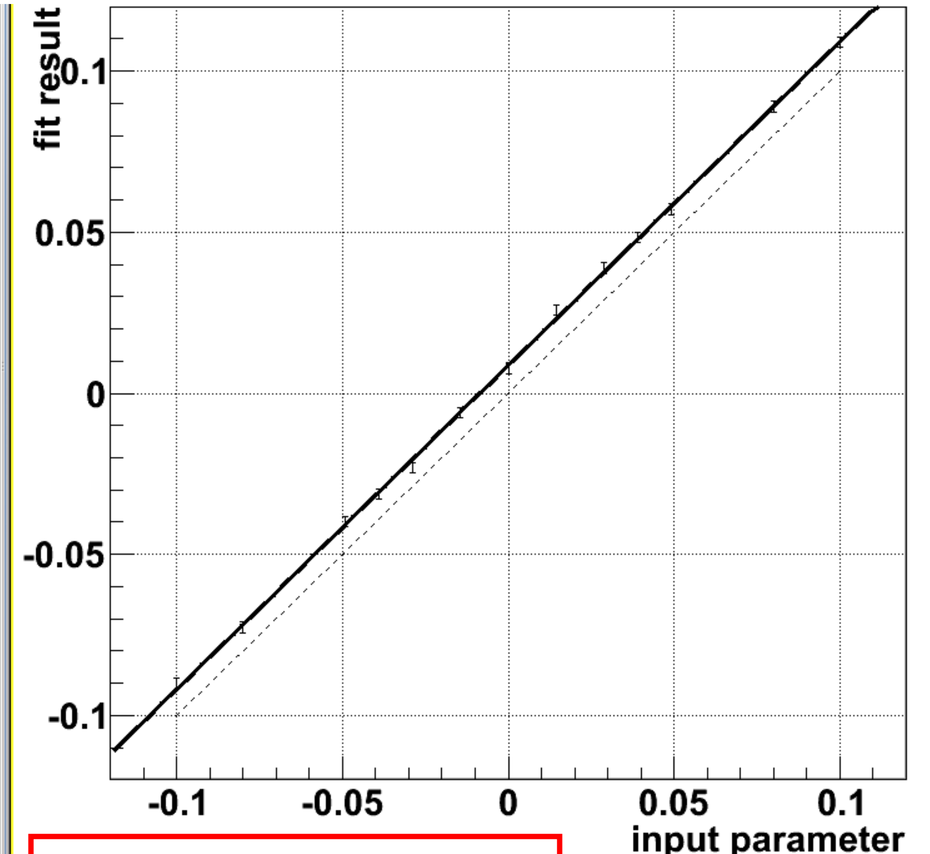
Y intercept = -0.0090 ± 0.0004



Stag-

gradient = 1.005 ± 0.008

Y intercept = 0.0086 ± 0.0004



- S_{tag} has shift bias (ΔS = shift bias).

$$S^{+}_{tag,measure} = S^{+}_{tag} - \Delta S$$

$$S^{-}_{tag,measure} = S^{-}_{tag} + \Delta S$$

Cancel of ΔS

$$S^{+}_{measured,\,favored} = S^{+} + S^{-}_{tag} + \Delta S$$

$$S^{-}_{tag,measured} = S^{-}_{tag} + \Delta S$$

then $$S^{+}_{measured,\,favored} = S^{+} + S^{-}_{tag} + \Delta S = S^{+} + S^{-}_{tag,measured}$$

also

$$S^{+}_{measure,\sup} = S^{+} - S^{+}_{tag} + \Delta S = S^{+} + S^{+}_{tag,measure}$$

$$S^{-}_{measure,\,fav} = S^{-} + S^{+}_{tag} - \Delta S = S^{-} + S^{+}_{tag,measure}$$

$$S^{-}_{measure,\sup} = S^{-} - S^{-}_{tag} - \Delta S = S^{-} - S^{-}_{tag,measure}$$

$S_{tag,\ measured}$ includes ΔS and cancels ΔS in $S_{measured}$

Dominant error in previous analysis is fit bias.

In this analysis, it can be combined with TSI error and decreased.

Systematic error

- Fit condition is changed and take difference from the main result as a systematic error
- Source of systematic error
  - Δt resolution, background Δt shape, Signal fraction, wrong tag fraction, physics parameters (τ , Δm), tag-side interference, Vertexing
- Vertexing
  - Vertex fit quality: $h < 50 \rightarrow$ 20, 100
  - Precise vertex positioning: σ_z<200μm for multi-track vertex and σ_z<500μm for single-track vertex. → no cut
  - Realistic lifetime: $|\Delta t| < 70$ ps → 40 ps, 100 ps
  - Scale error
- Other
  - Vary $\pm 1\ \sigma$

Signal/background fraction

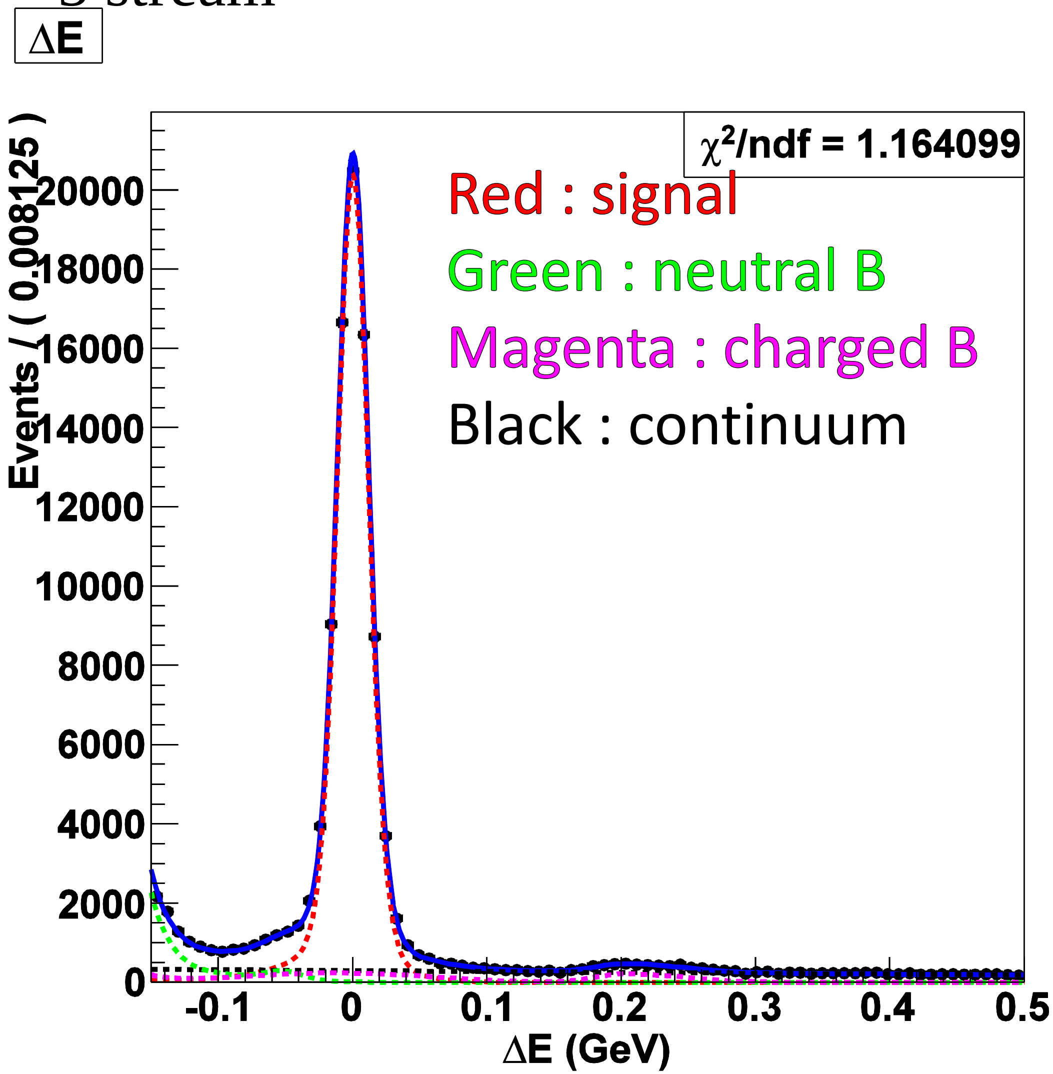
- Signal/background fraction were obtained from ΔE fit.
  - each sub-decay, rbin, SVD
  - Fit region : $-0.15 < \Delta E < 0.5$, $5.27\ \mathrm{GeV} < M_{bc} < 5.29\ \mathrm{GeV}$
- Fitting procedure

1. Function shape without signal and continuum BG were fixed.
   - by fitting each background taken from generic MC
2. Signal shape were fixed each sub-decay.
   - by fitting all events which are not divided for every rbin
     - Float : signal shape, continuum BG shape, signal fraction, continuum fraction
3. Obtain signal/background fraction
   - by fitting each rbin events.
     - Float : continuum BG shape, signal fraction, continuum fraction

ΔE fit of generic MC : $D^0 \to K\pi$

SVD2

- ΔE fit result of Kπ (generic MC, SVD2)
- 5 stream



Every rbin events

Float

Signal fraction

Signal shape

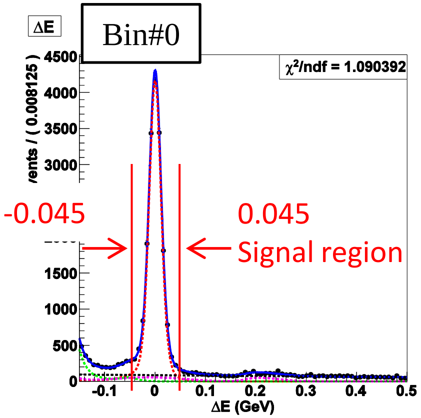
Continuum BG fraction

Continuum shape

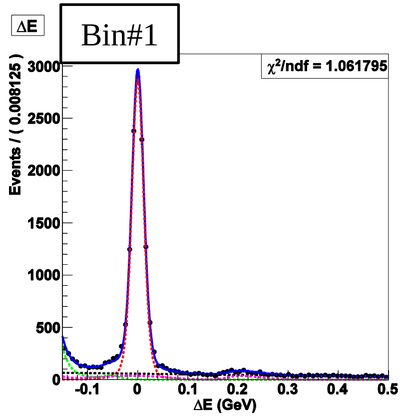
ΔE fit of generic MC : $D^0 \to K\pi$

SVD2

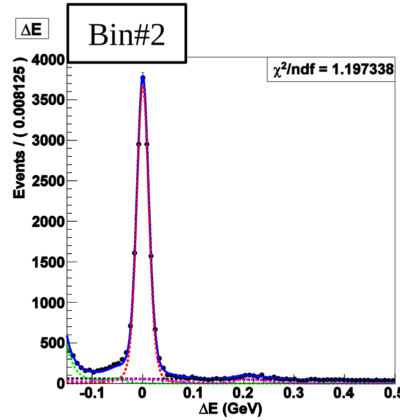
- Each rbin events were fitted.



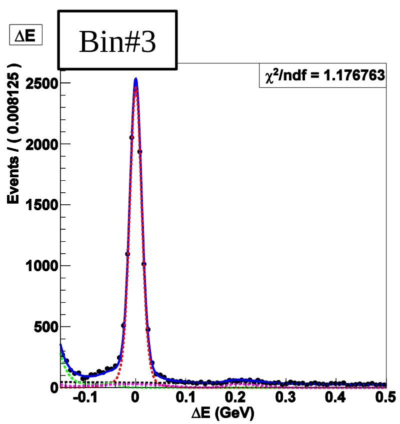
Signal 90.7%
B^0 BG 0.6%, $B^\pm$ BG 3.3%
Continuum 5.4%



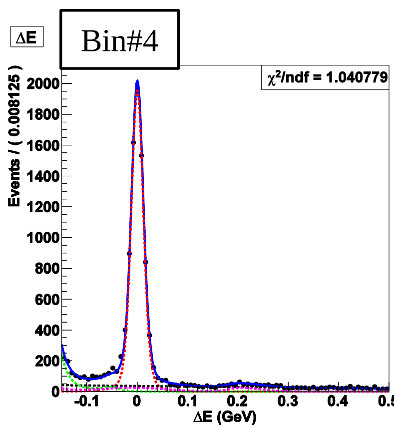
Signal 90.9%
B^0 BG 0.6%, $B^\pm$ BG 3.2%
Continuum 5.3%



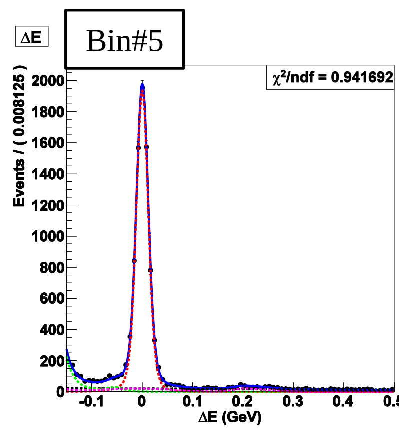
Signal 91.7%
B^0 BG 0.8%, $B^\pm$ BG 3.4%
Continuum 4.1%



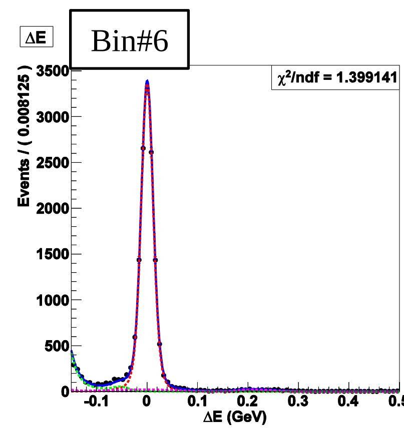
Signal 91.8%
B^0 BG 0.7%, $B^\pm$ BG 3.0%
Continuum 4.5%



Signal 91.2%
B^0 BG 0.7%, $B^\pm$ BG 3.2%
Continuum 4.9%



Signal 93.4%
B^0 BG 0.7%, $B^\pm$ BG 2.8%
Continuum 3.1%

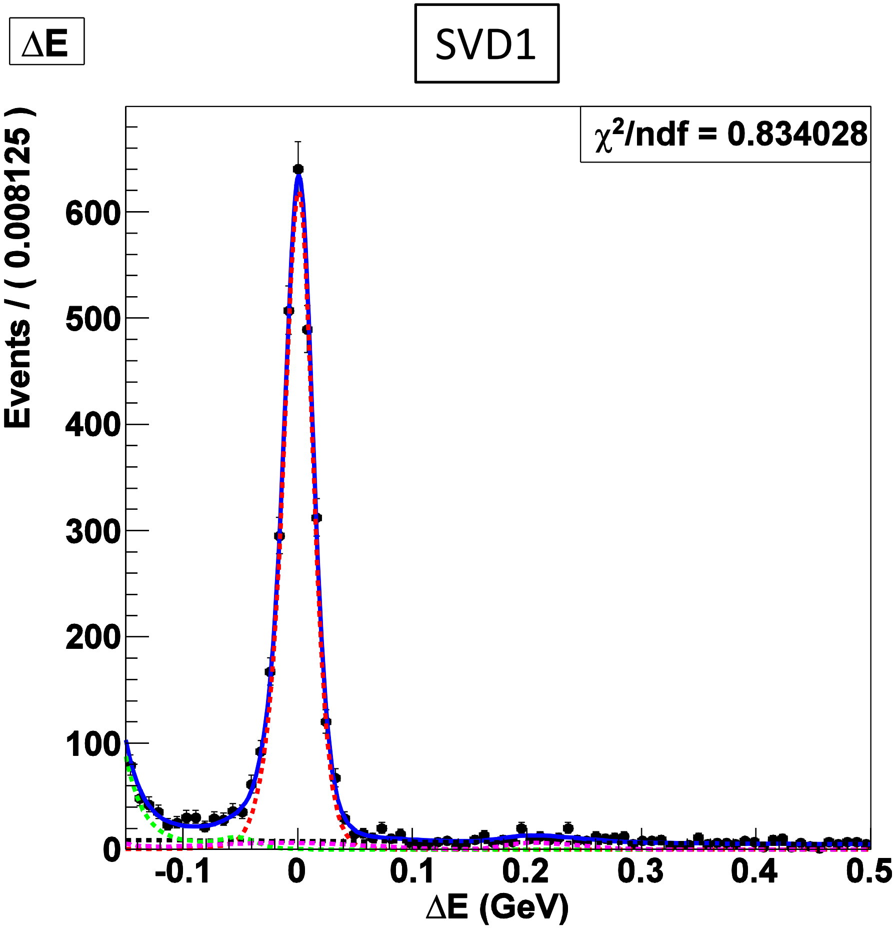


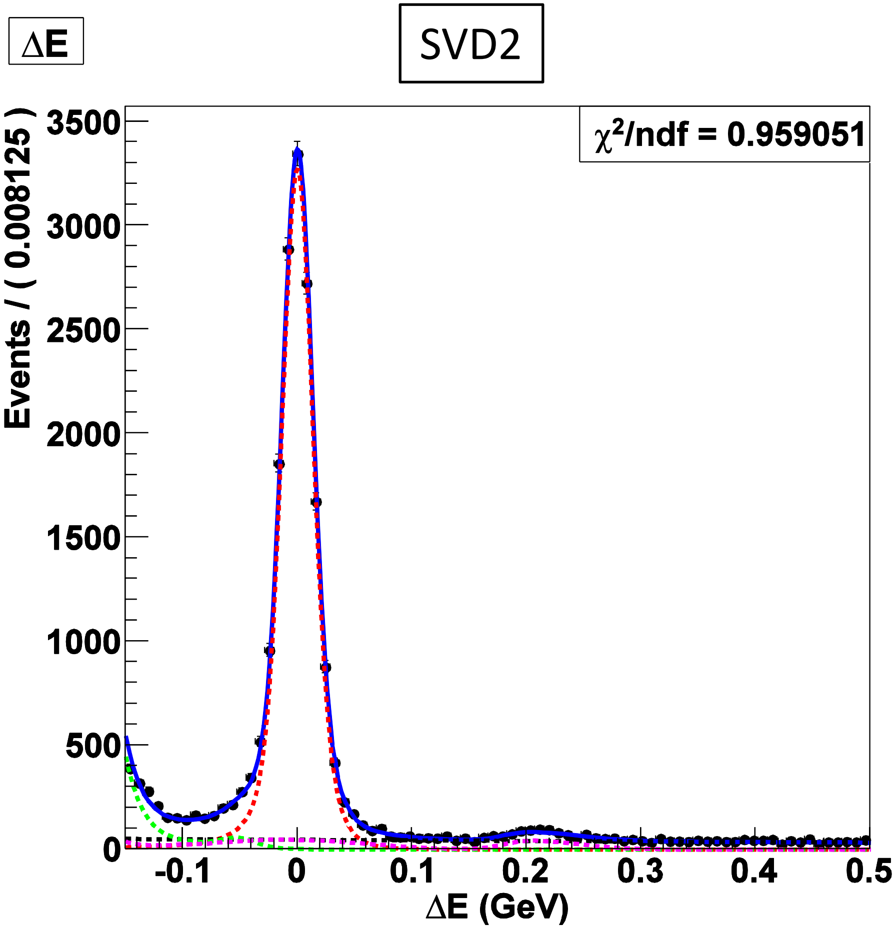
Signal 96.8%
B^0 BG 0.8%, $B^\pm$ BG 1.8%
Continuum 0.6%

- Signal fraction in signal region for each rbin were obtained.

ΔE fit : Kπ real data

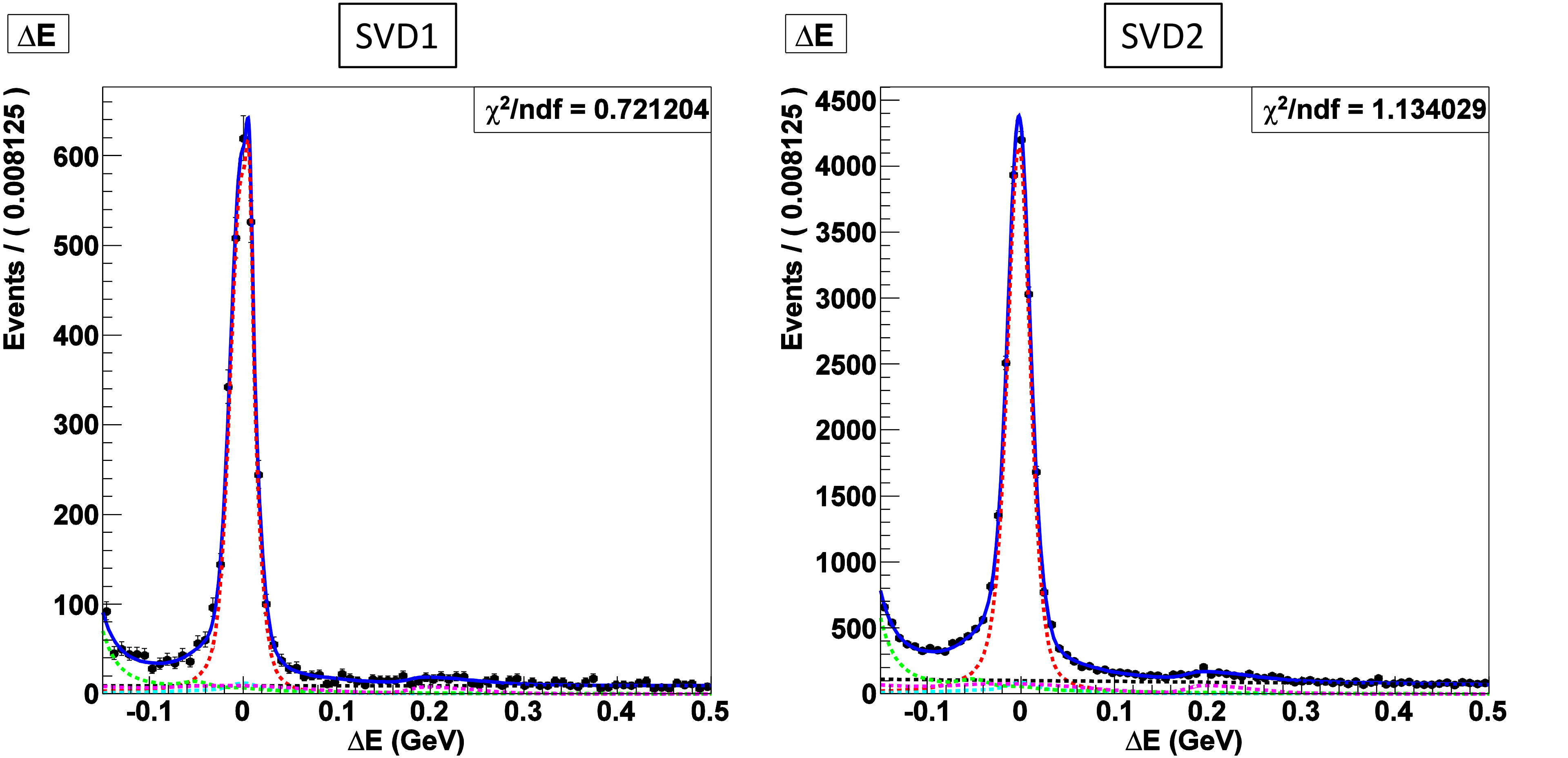
- -0.15 GeV< ΔE < 0.5 GeV, 5.27 GeV< Mbc < 5.29 GeV





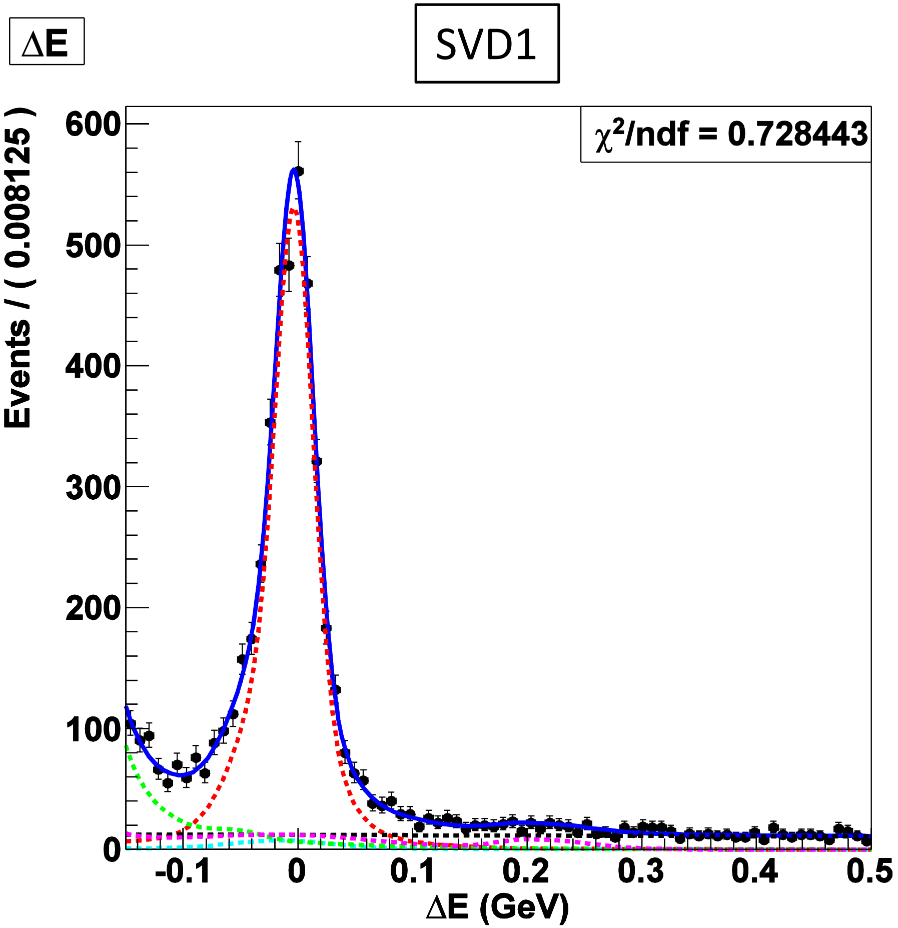
ΔE fit : Kπππ real data

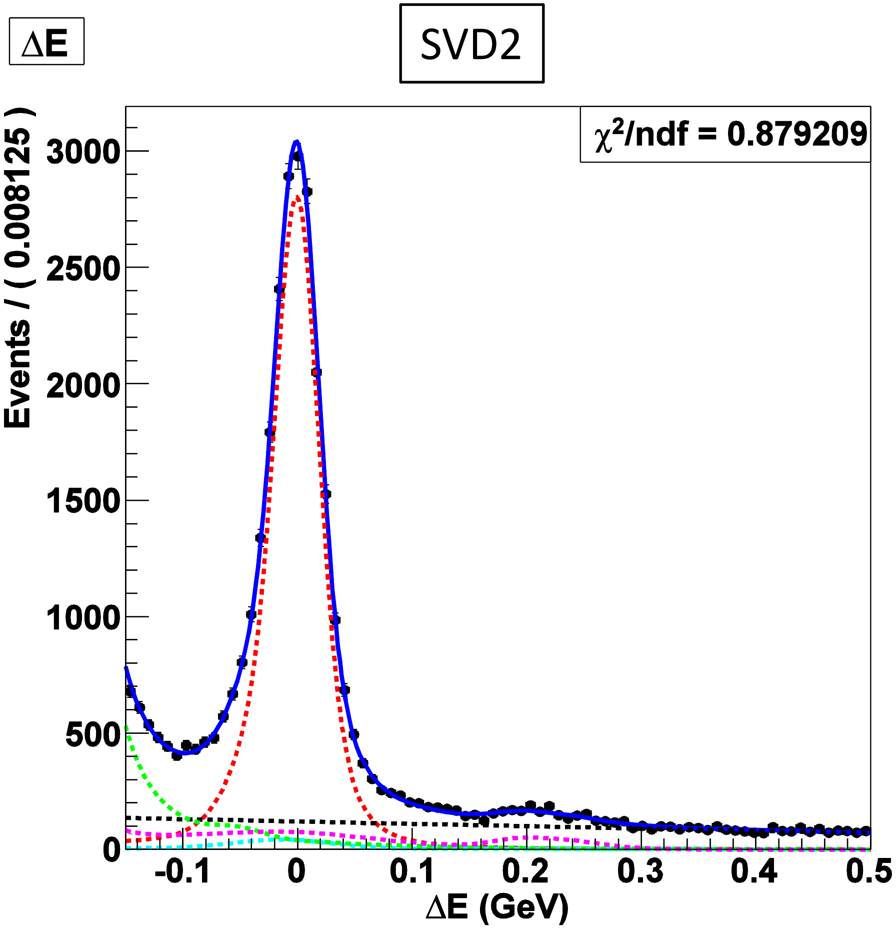
- -0.15 GeV< ΔE < 0.5 GeV, 5.27 GeV< Mbc < 5.29 GeV



ΔE fit : Kππ0 real data

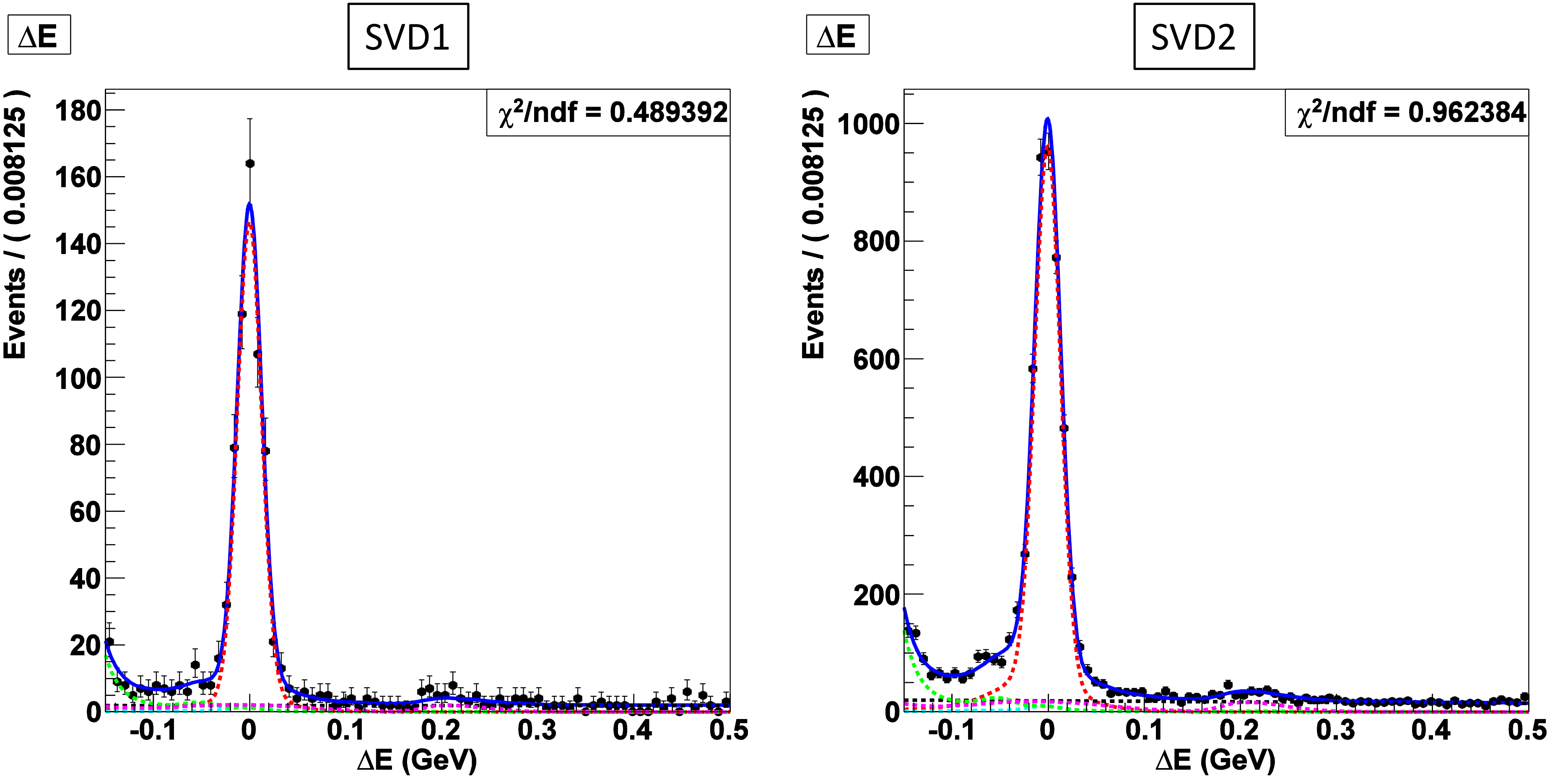
- -0.15 GeV< ΔE < 0.5 GeV, 5.27 GeV< Mbc < 5.29 GeV





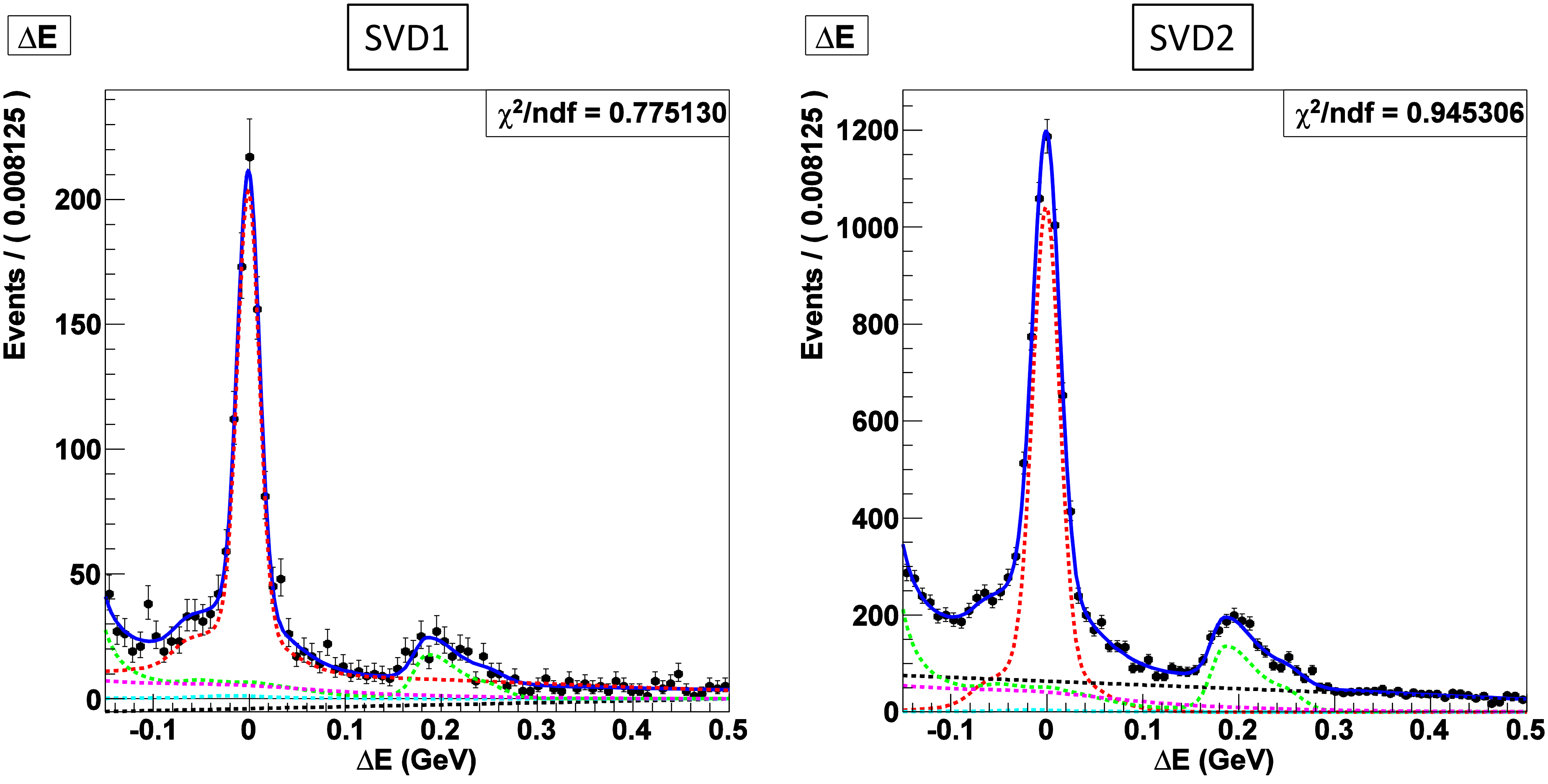
ΔE fit : Ksππ real data

- -0.15 GeV< ΔE < 0.5 GeV, 5.27 GeV< Mbc < 5.29 GeV



ΔE fit : Kππ real data

- -0.15 GeV< ΔE < 0.5 GeV, 5.27 GeV< Mbc < 5.29 GeV



Δt fit for Background

- To get BG shape, Δt PDF for each BG was fitted.

Neutral B BG PDF

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

Charged B BG PDF

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

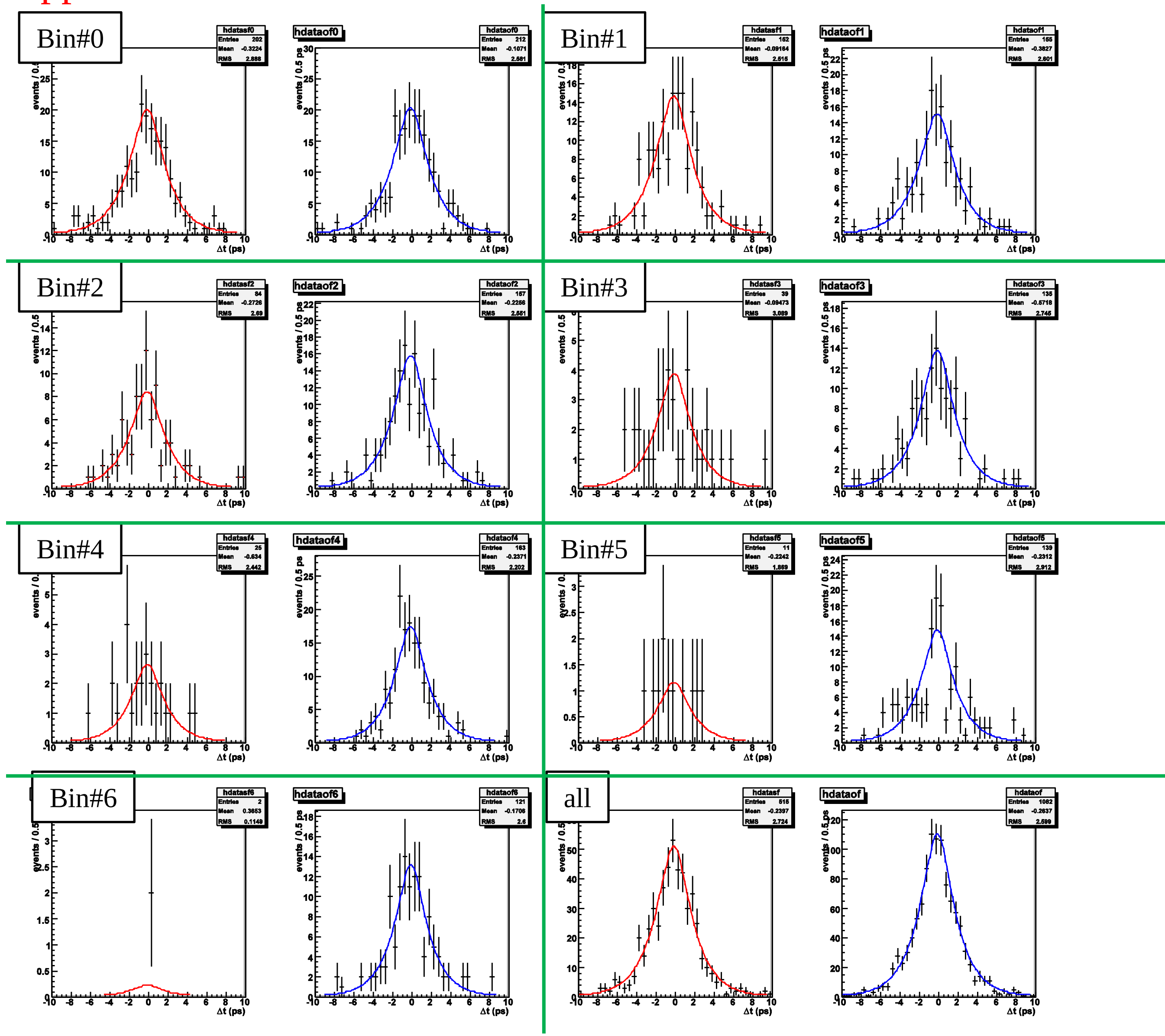
Continuum BG PDF

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

Charged B background SVD1

- Fit results

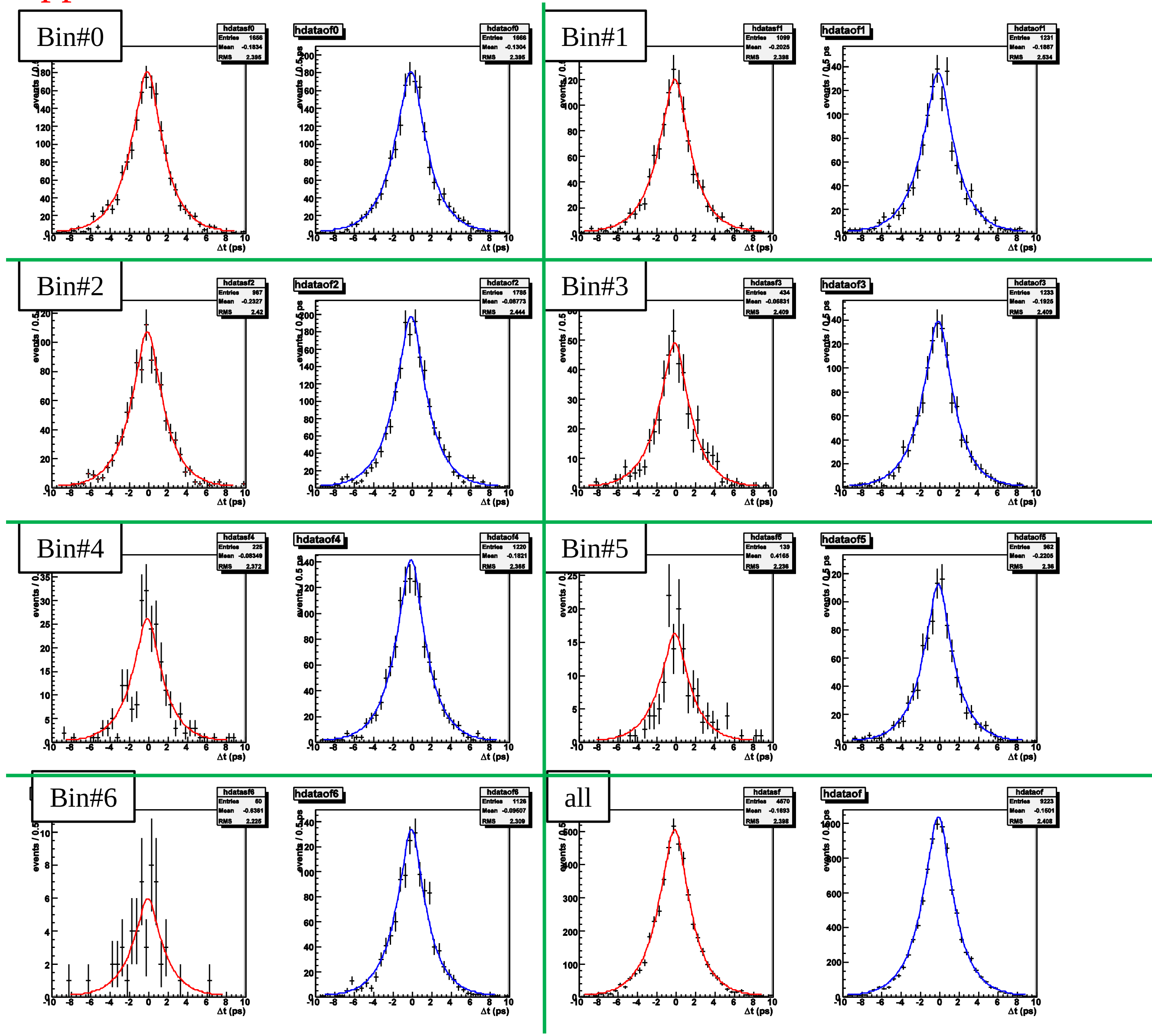
Suppressed mode Favored mode



Charged B background SVD2

- Fit results

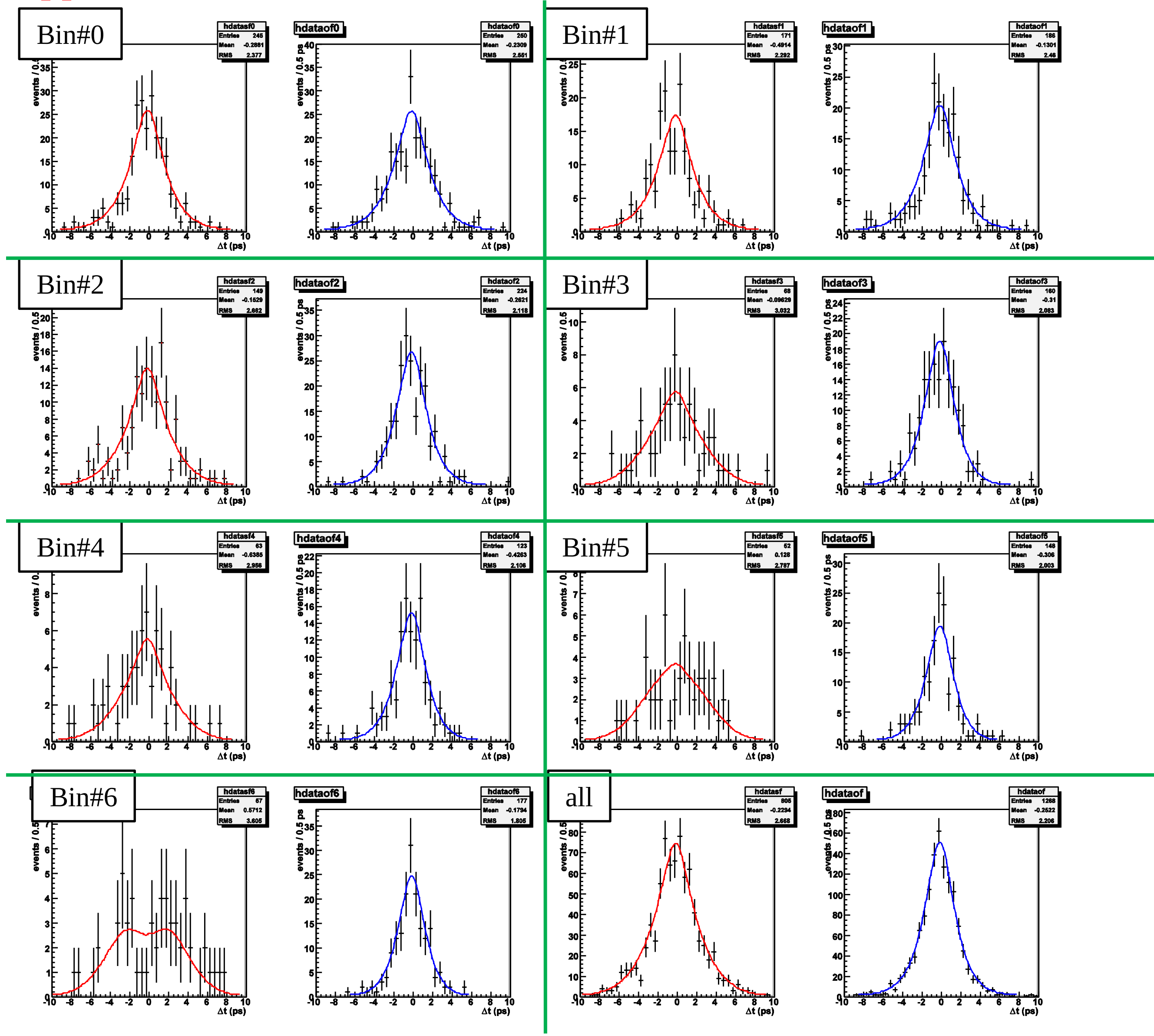
Suppressed mode Favored mode



neutral B background SVD1

- Fit results

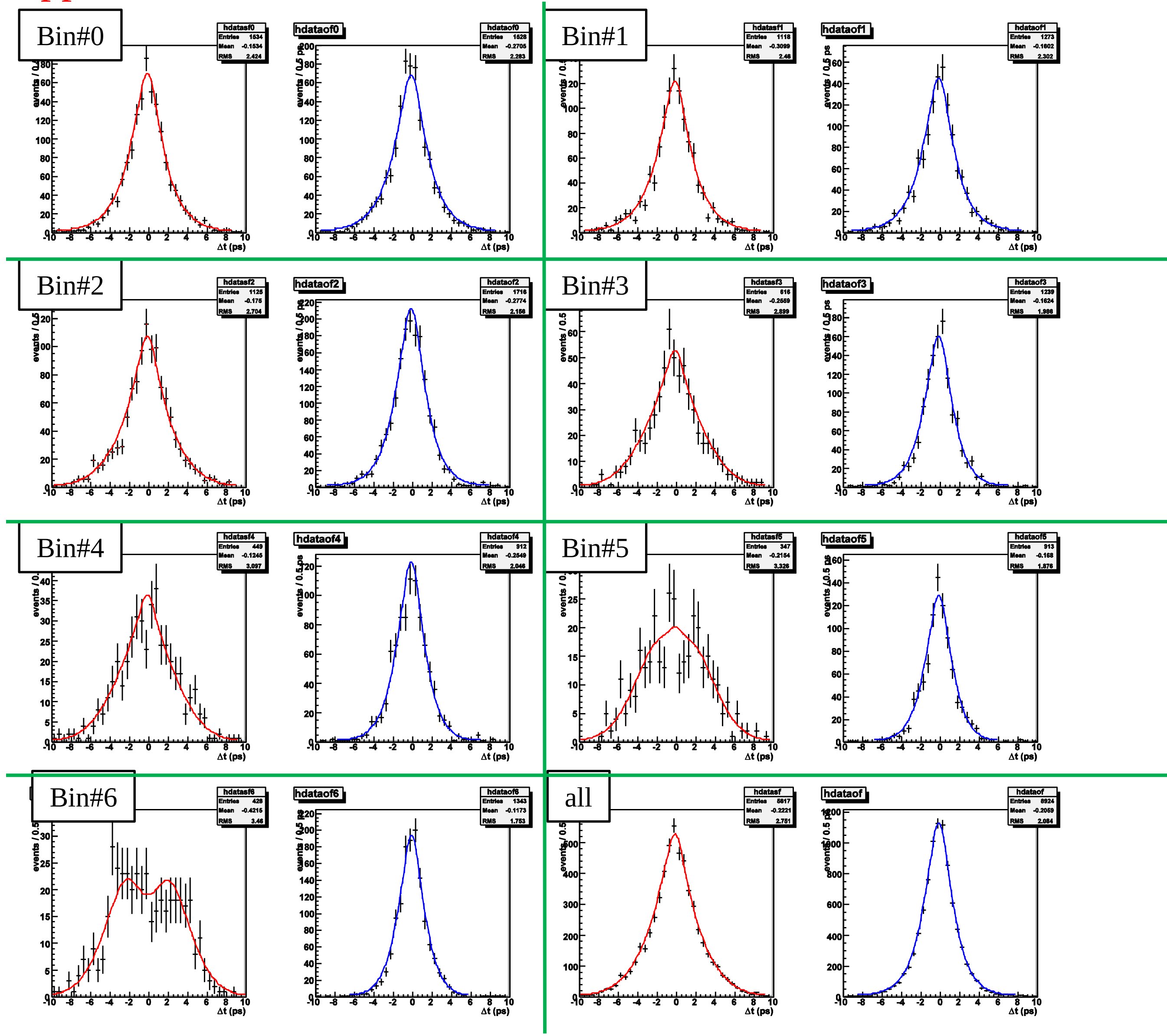
Suppressed mode Favored mode



neutral B background SVD2

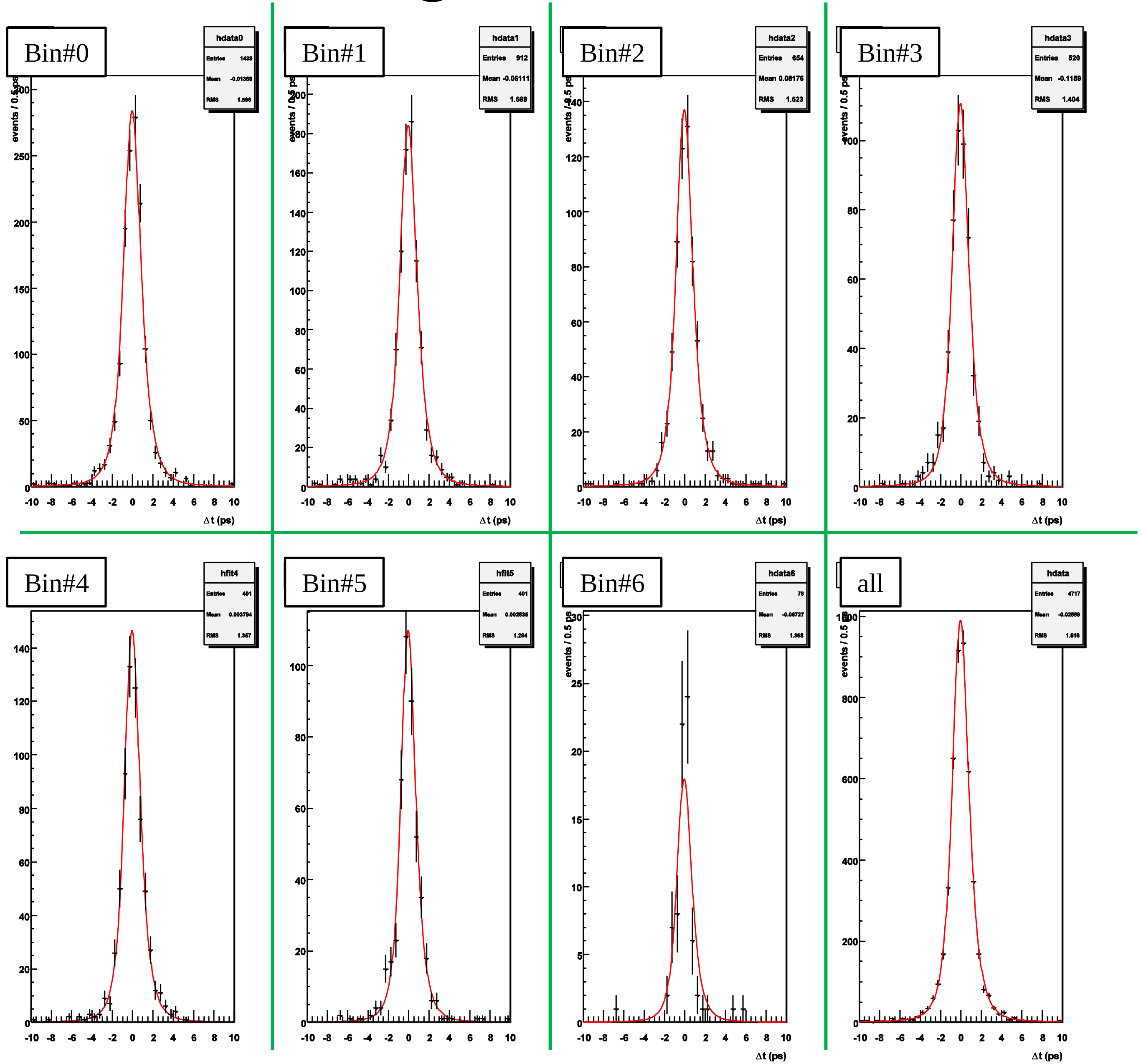
- Fit results

Suppressed mode Favored mode



Continuum background SVD1

- Fit results



Continuum background SVD2

- Fit results