

Global Fit for Branching Fractions and Form Factor Slope of $B \rightarrow D^{(*)} \ell \bar{\nu}$ Decays

D^{**} FF re-weighting

Fit Validation

D^* isospin symmetry problem

Fitting Method (Review)

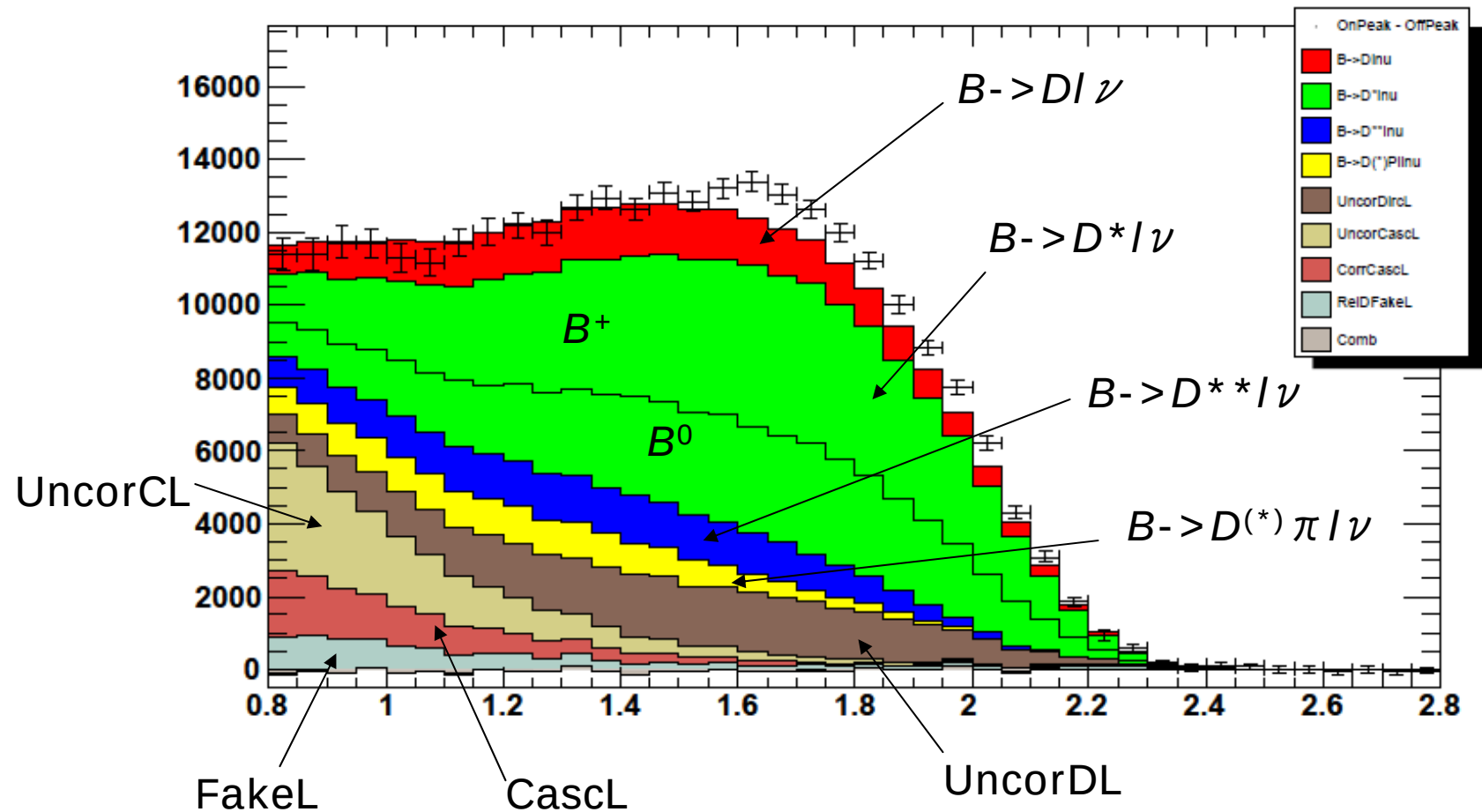
- Binned chi-square fitting

$$\chi^2 = \sum_{i=bin}^{D^0} \frac{\left(N_i^{\text{OnPeak data}} - N_i^{\text{OffPeak data}} - \sum C N_i^{B\bar{B}MC} \right)^2}{\left(\sigma_i^{\text{OnPeak data}} \right)^2 + \left(\sigma_i^{\text{OffPeak data}} \right)^2 + \sum \left(C \sigma_i^{B\bar{B}MC} \right)^2} + \sum_{i=bin}^{D^+} \frac{\left(N_i^{\text{OnPeak data}} - N_i^{\text{OffPeak data}} - \sum C N_i^{B\bar{B}MC} \right)^2}{\left(\sigma_i^{\text{OnPeak data}} \right)^2 + \left(\sigma_i^{\text{OffPeak data}} \right)^2 + \sum \left(C \sigma_i^{B\bar{B}MC} \right)^2}$$

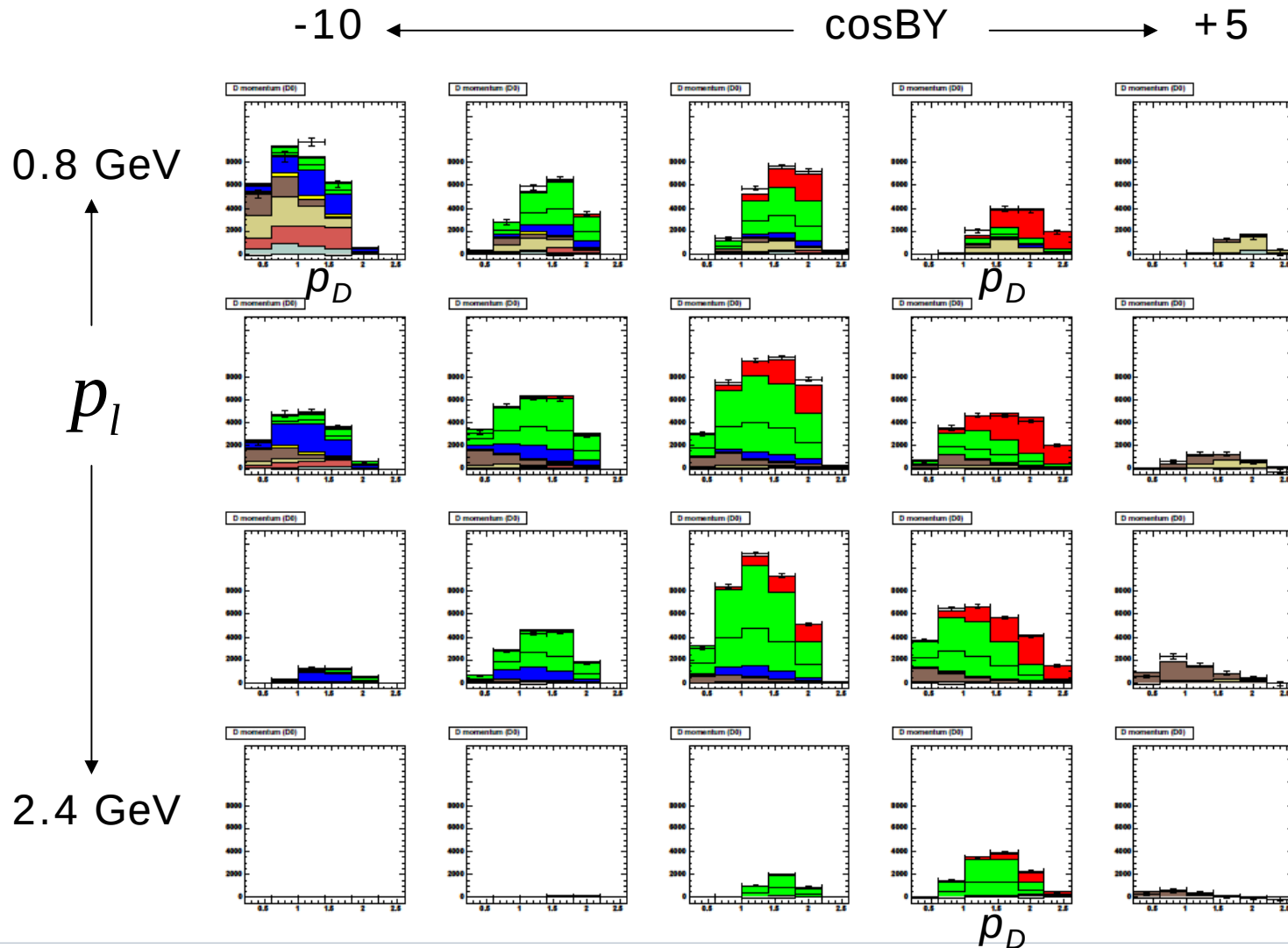
- $N_i^{B\bar{B}MC}$: expected number of candidates from $B\bar{B}$ MC.
- C : consists of **branching fractions** to be determined by the fit.
- BF or FF **re-weighting** is done to produce $N_i^{B\bar{B}MC}$.
- 4 major backgrounds after D mass sideband subtraction.

Lepton Momentum : P_l (Review)

(OnPeak – OffPeak) data vs BB MC

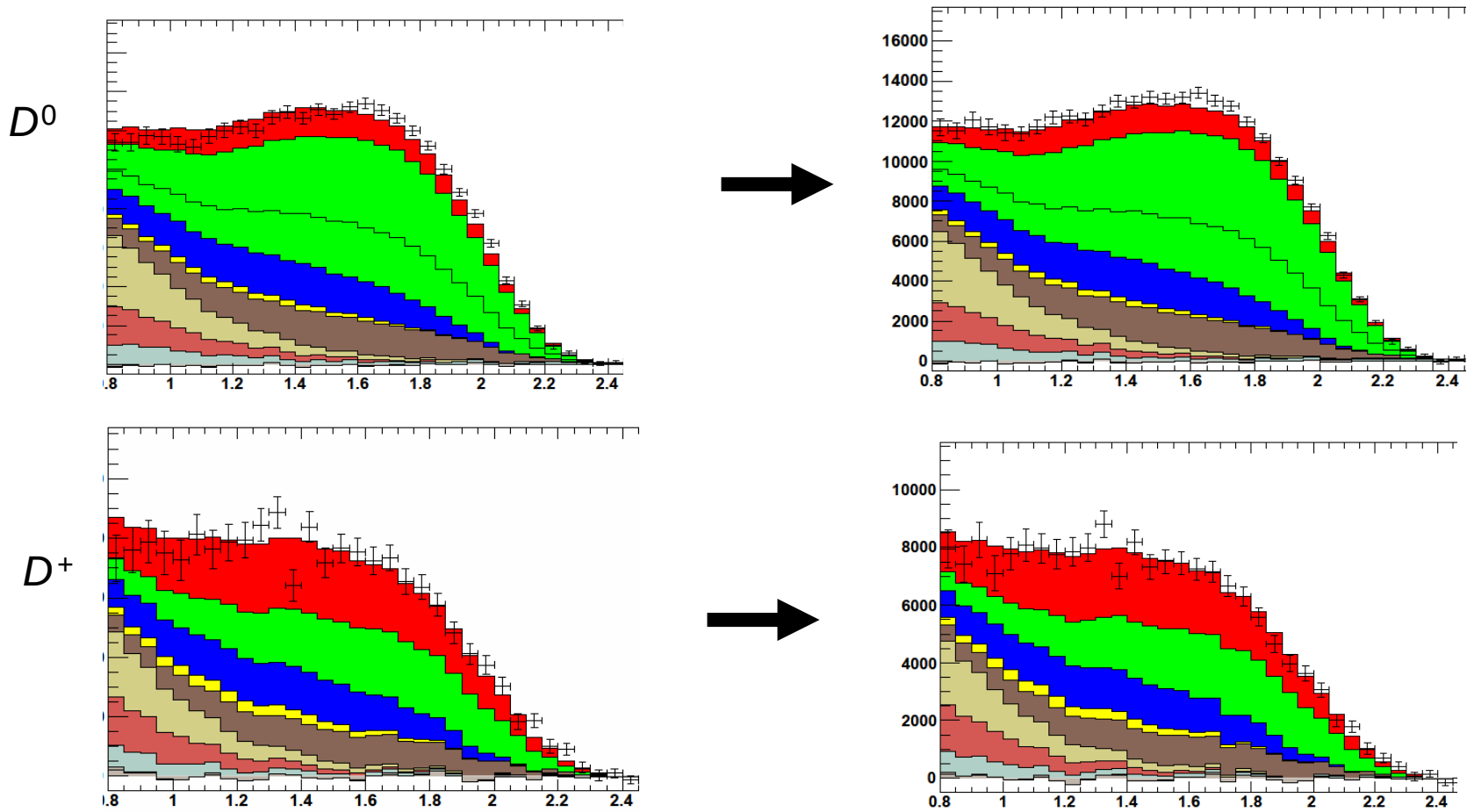


3D Binning : p_l , p_D , cosBY (Review)



$P_l : D^{**}$ FF re-weighting

Dependence on the **Angle between l and D** is included.



Effect is small, but toward a good direction.

Validation Fit

- Split Run2 MC into two halves.
- Make a fake OnPeak data histogram from the first half.
- Fit for the fake data by the second half.
- Fake data can be made with
 - Any BF values.
 - Any FF parameter values.

Validation Fit Result (1)

	Fake OnPeak	Fit Results
$\text{BF}(B^+ \rightarrow D/\nu)$	0.021	0.0217 ± 0.0005
$\text{BF}(B^0 \rightarrow D/\nu)$	Isospin	Isospin
$\text{BF}(B^+ \rightarrow D^*/\nu)$	0.056	0.0560 ± 0.0010
$\text{BF}(B^0 \rightarrow D^*/\nu)$	Isospin	Isospin
$\text{BF}(B^+ \rightarrow D^{**}/D^{(*)}\pi/\nu)$	0.027	0.0264 ± 0.0008
$B \rightarrow D$ FF slope	1.4	1.355 ± 0.058
$B \rightarrow D^*$ FF : slope	1.145	1.252 ± 0.056
R_1	1.396	1.423 ± 0.075
R_2	0.855	0.789 ± 0.065
$\text{BF}(D^{*+} \rightarrow D^0 \pi^+)$	0.677	0.675 ± 0.008
f_{+-}/f_{00}	1.024	1.044 ± 0.018
Chi-square/ndof		227/257

Validation Fit Result (2)

	Fake OnPeak	Fit Results
$\text{BF}(B^+ \rightarrow D/\nu)$	0.021	0.0229 $\pm$ 0.0008
$\text{BF}(B^0 \rightarrow D/\nu)$	0.018	0.0182 $\pm$ 0.0004
$\text{BF}(B^+ \rightarrow D^*/\nu)$	0.056	0.0581 $\pm$ 0.0018
$\text{BF}(B^0 \rightarrow D^*/\nu)$	0.045	0.0477 $\pm$ 0.0015
$\text{BF}(B^+ \rightarrow D^{**}/D^{(*)}\pi/\nu)$	0.027	0.0269 $\pm$ 0.0009
$B \rightarrow D$ FF slope	1.4	1.342 $\pm$ 0.059
$B \rightarrow D^*$ FF : slope	1.145	1.277 $\pm$ 0.056
R_1	1.396	1.450 $\pm$ 0.074
R_2	0.855	0.769 $\pm$ 0.065
$\text{BF}(D^{*+} \rightarrow D^0 \pi^+)$	0.677	0.677 (Fixed)
f_{+-}/f_{00}	1.024	1.019 $\pm$ 0.019
Chi-square/ndof		223/255

Validation Fit Result (3)

	Fake OnPeak	Fit Results
$\text{BF}(B^+ \rightarrow D/\nu)$	0.021	0.0218 $\pm$ 0.0005
$\text{BF}(B^0 \rightarrow D/\nu)$	Isospin	Isospin
$\text{BF}(B^+ \rightarrow D^*/\nu)$	0.056	0.0579 $\pm$ 0.0010
$\text{BF}(B^0 \rightarrow D^*/\nu)$	Isospin	Isospin
$\text{BF}(B^+ \rightarrow D^{**}/D^{(*)}\pi/\nu)$	0.027	0.0264 $\pm$ 0.0008
$B \rightarrow D$ FF slope	1.2	1.150 $\pm$ 0.071
$B \rightarrow D^*$ FF : slope	1.145	1.252 $\pm$ 0.056
R_1	1.396	1.423 $\pm$ 0.074
R_2	0.855	0.788 $\pm$ 0.065
$\text{BF}(D^{*+} \rightarrow D^0\pi^+)$	0.677	0.675 $\pm$ 0.0081
f_{+-}/f_{00}	1.024	1.045 $\pm$ 0.018
Chi-square/ndof		227/256

$B \rightarrow D^* \ell \nu$ isospin symmetry (1)

- Our fit result also show isospin symmetry problem.
 - $\text{BF}(B^+ \rightarrow D^* \ell \nu) = 0.0650 \pm 0.0022$
 - $\text{BF}(B^0 \rightarrow D^* \ell \nu) = 0.0472 \pm 0.0024$
- $\text{BF}(D^{*+} \rightarrow D^+ \pi^0 / \gamma)$ could be too large?
 - What they really measure is
$$\text{BF}(B^0 \rightarrow D^* \ell \nu) * \text{BF}(D^{*+} \rightarrow D^0 \pi^+)$$
If $\text{BF}(D^{*+} \rightarrow D^0 \pi^+)$ becomes smaller,
 $\text{BF}(B^0 \rightarrow D^* \ell \nu)$ becomes larger.
 - $\text{BF}(D^{*+} \rightarrow D \pi)$ measurements use isospin constrain, but isospin symmetry may be broken here.
 - Smaller inclusive $\text{BF}(B \rightarrow D^+)$ (BAD1307 and 1234) imply smaller $\text{BF}(D^{*+} \rightarrow D^+ \pi^0 / \gamma)$.

$B \rightarrow D^* \ell \nu$ isospin symmetry (2)

- Try fit by floating $\text{BF}(D^{*+} \rightarrow D^0 \pi^+)$
 - with constraint :
$$\text{BF}(D^{*+} \rightarrow D^+ \pi^0 / \gamma) + \text{BF}(D^{*+} \rightarrow D^0 \pi^+) = 1$$
 - by requiring $B \rightarrow D^* \ell \nu$ isospin symmetry
 - The result is
$$\text{BF}(D^{*+} \rightarrow D^0 \pi^+) = 0.7065 \pm 0.0103$$
$$(\text{PDG2006} : 0.677 \pm 0.006)$$
- If we fix $\text{BF}(D^{*+} \rightarrow D^0 \pi^+) = 0.7065$, the fit result is
 - $\text{BF}(B^+ \rightarrow D^* \ell \nu) = 0.0586 \pm 0.0023$
 - $\text{BF}(B^0 \rightarrow D^* \ell \nu) = 0.0547 \pm 0.0027$
- Problem is solved!?

Validation Fit Result (4)

	Fake OnPeak	Fit Results
$\text{BF}(B^+ \rightarrow D/\nu)$	0.021	0.0205 ± 0.0005
$\text{BF}(B^0 \rightarrow D/\nu)$	0.018	Isospin
$\text{BF}(B^+ \rightarrow D^*/\nu)$	0.056	0.0536 ± 0.0010
$\text{BF}(B^0 \rightarrow D^*/\nu)$	0.045	Isospin
$\text{BF}(B^+ \rightarrow D^{**}/D^{(*)}\pi/\nu)$	0.027	0.0257 ± 0.0008
$B \rightarrow D$ FF slope	1.4	1.360 ± 0.060
$B \rightarrow D^*$ FF : slope	1.145	1.236 ± 0.059
R_1	1.396	1.396 ± 0.076
R_2	0.855	0.796 ± 0.067
$\text{BF}(D^{*+} \rightarrow D^0 \pi^+)$	0.677	0.699 ± 0.009
f_{+-}/f_{00}	1.024	1.075 ± 0.018
Chi-square/ndof		240/256

Validation Fit Result (5)

	Fake OnPeak	Fit Results
$\text{BF}(B^+ \rightarrow D/\nu)$	0.021	0.0227 $\pm$ 0.0008
$\text{BF}(B^0 \rightarrow D/\nu)$	Isospin	0.0200 $\pm$ 0.0005
$\text{BF}(B^+ \rightarrow D^*/\nu)$	0.056	0.0645 $\pm$ 0.0019
$\text{BF}(B^0 \rightarrow D^*/\nu)$	Isospin	0.0486 $\pm$ 0.0020
$\text{BF}(B^+ \rightarrow D^{**}/D^{(*)}\pi/\nu)$	0.072	0.0271 $\pm$ 0.0009
$B \rightarrow D$ FF slope	1.4	1.348 $\pm$ 0.059
$B \rightarrow D^*$ FF : slope	1.145	1.268 $\pm$ 0.056
R_1	1.396	1.445 $\pm$ 0.077
R_2	0.855	0.776 $\pm$ 0.066
$\text{BF}(D^{*+} \rightarrow D^0\pi^+)$	0.71	0.677 (Fixed)
f_{+-}/f_{00}	1.024	1.018 $\pm$ 0.023
Chi-square/ndof		226/255

Validation Fit Result (6)

	Fake OnPeak	Fit Results
$\text{BF}(B^+ \rightarrow D/\nu)$	0.021	0.0230 $\pm$ 0.0008
$\text{BF}(B^0 \rightarrow D/\nu)$	Isospin	0.0199 $\pm$ 0.0005
$\text{BF}(B^+ \rightarrow D^*/\nu)$	0.056	0.0579 $\pm$ 0.0019
$\text{BF}(B^0 \rightarrow D^*/\nu)$	Isospin	0.0552 $\pm$ 0.0022
$\text{BF}(B^+ \rightarrow D^{**}/D^{(*)}\pi/\nu)$	0.072	0.0269 $\pm$ 0.0009
$B \rightarrow D$ FF slope	1.4	1.347 $\pm$ 0.058
$B \rightarrow D^*$ FF : slope	1.145	1.270 $\pm$ 0.056
R_1	1.396	1.448 $\pm$ 0.077
R_2	0.855	0.777 $\pm$ 0.065
$\text{BF}(D^{*+} \rightarrow D^0 \pi^+)$	0.71	0.71 (Fixed)
f_{+-}/f_{00}	1.024	1.019 $\pm$ 0.023
Chi-square/ndof		224/255

Fit Result (not final) (1)

- We use isospin constraint on $B \rightarrow D^{(*, **)} (\pi) l \nu$ decays

$\text{BF}(B^+ \rightarrow D l \nu)$	0.0291 ± 0.0012 (4 %)
$\text{BF}(B^+ \rightarrow D^* l \nu)$	0.0586 ± 0.0023 (4 %)
$\text{BF}(B^+ \rightarrow D^{**} / D^{(*)} \pi l \nu)$	0.0216 ± 0.0011 (5 %)
$B \rightarrow D$ FF slope	1.437 ± 0.058 (4 %)

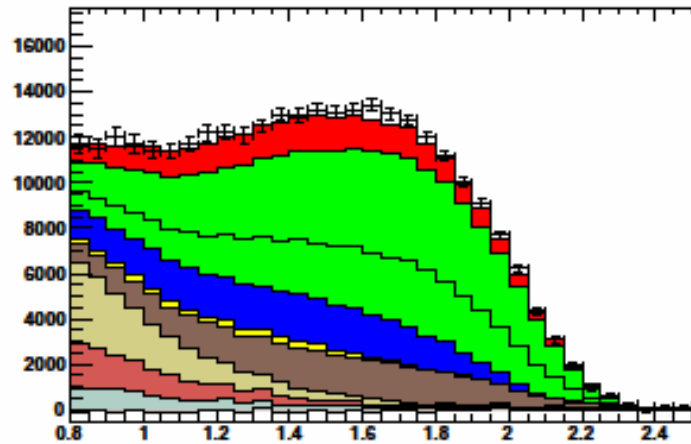
- Branching fractions are normalized by using
 - $\text{BF}(B^+ \rightarrow X_c l \nu) = 0.1094$
- This is only Run2 data. Run1-Rnu4 has 3.5 times more statistics $\Rightarrow$ statistical error will be $\sim 1/2$.

Fit Result (not final) (2)

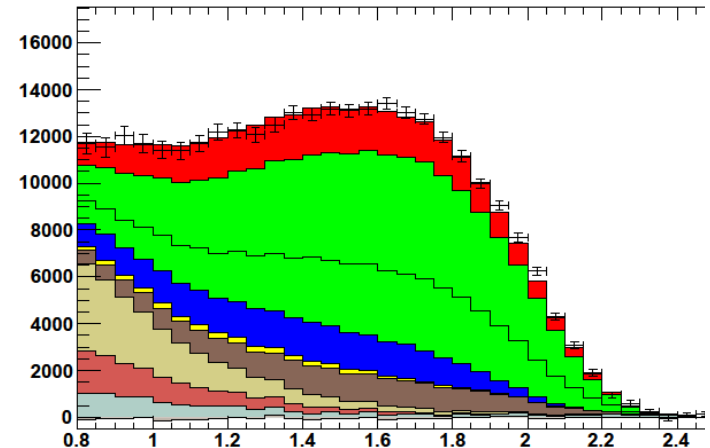
$B \rightarrow D^* \text{ FF : slope}$	$1.309 \pm 0.069 \text{ (5 \%)}$
R_1	$1.079 \pm 0.070 \text{ (7 \%)}$
R_2	$0.839 \pm 0.076 \text{ (9 \%)}$
$\text{BF}(D^{*+} \rightarrow D^0 \pi^+)$	0.7065 ± 0.010
Backgrounds : UncorrDL	0.678 ± 0.044
UncorrCL	0.990 ± 0.068
Cascade	0.909 ± 0.098
D+/D0 ratio	1.054 ± 0.070
f_{+-}/f_{00}	1.063 ± 0.019
Chi-square/ndof	420/255
$(R_1 = 1.396 \pm 0.075)$	$(D^* \text{ slope} = 1.145 \pm 0.075)$
$(R_2 = 0.885 \pm 0.047)$	$(\text{BF}(D^{*+} \rightarrow D^0 \pi^+) = 0.677)$

Fitted p_l^*

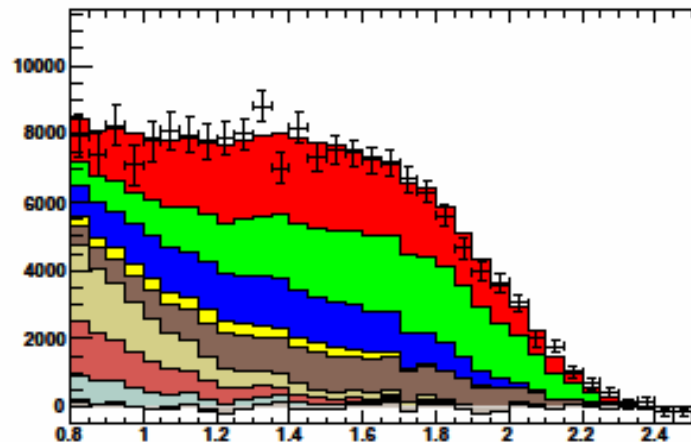
Lepton momentum (D0)



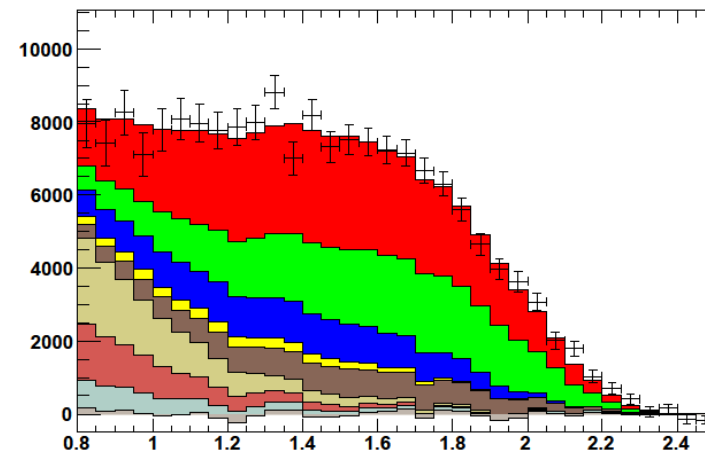
Lepton momentum (D0)



Lepton momentum (D+)

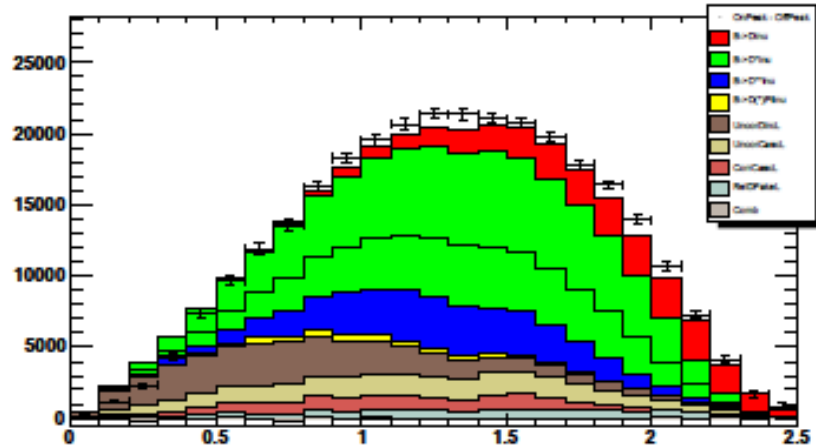


Lepton momentum (D+)

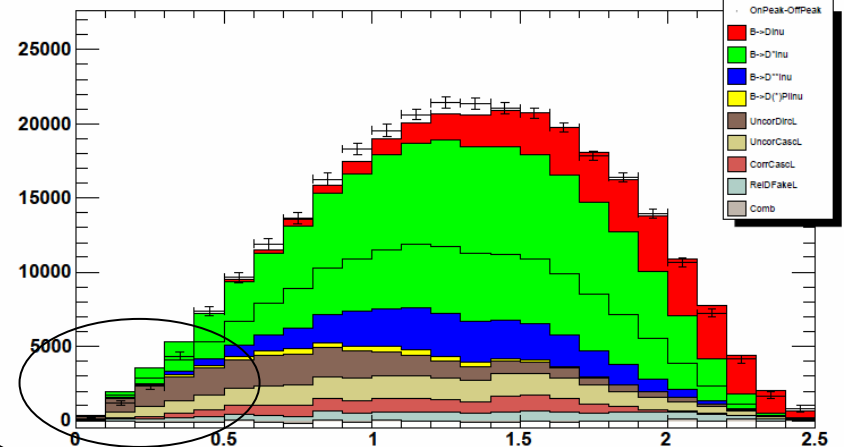


Fitted p_D^*

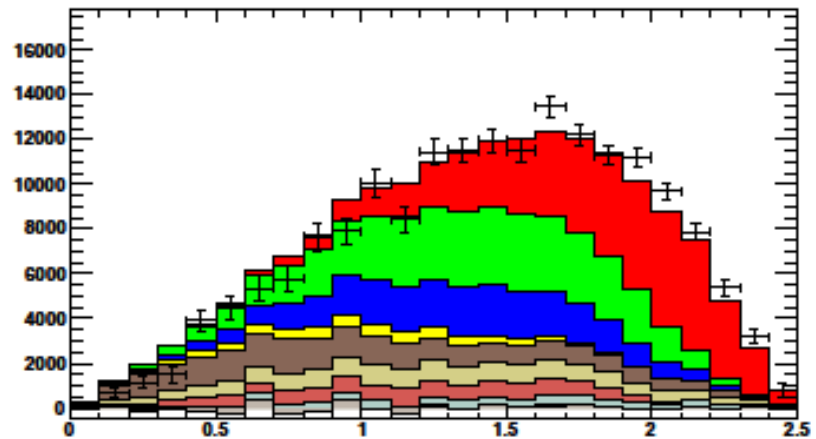
D momentum (D0)



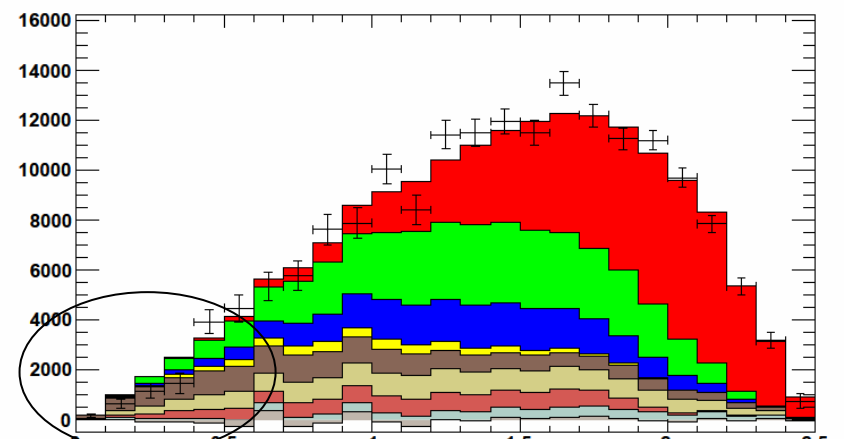
D momentum (D0)



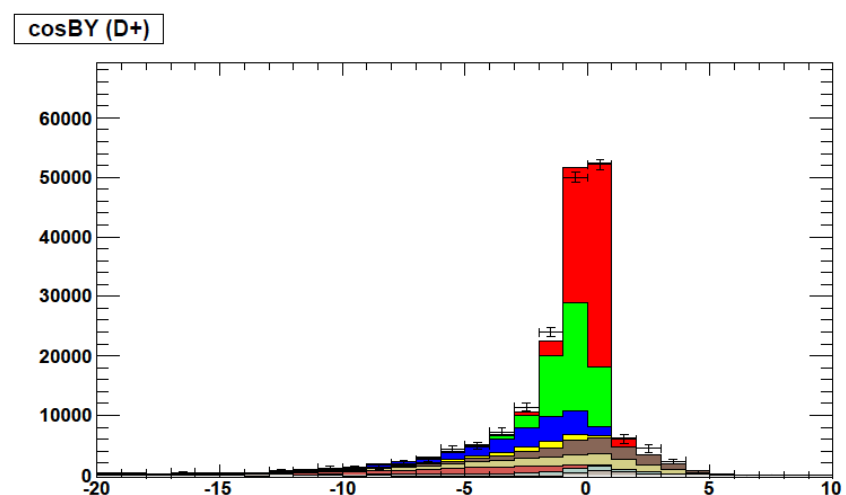
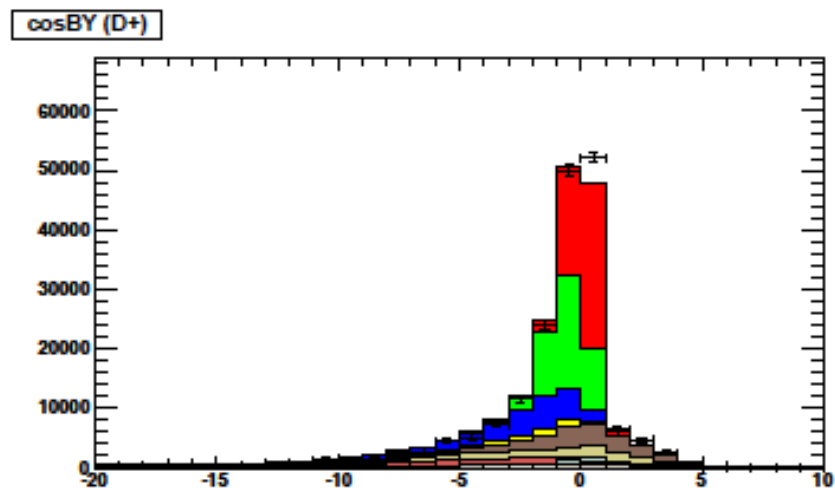
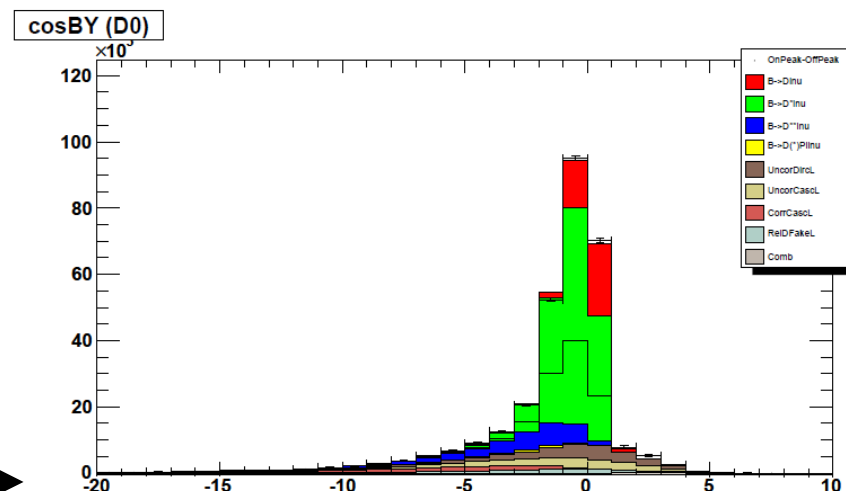
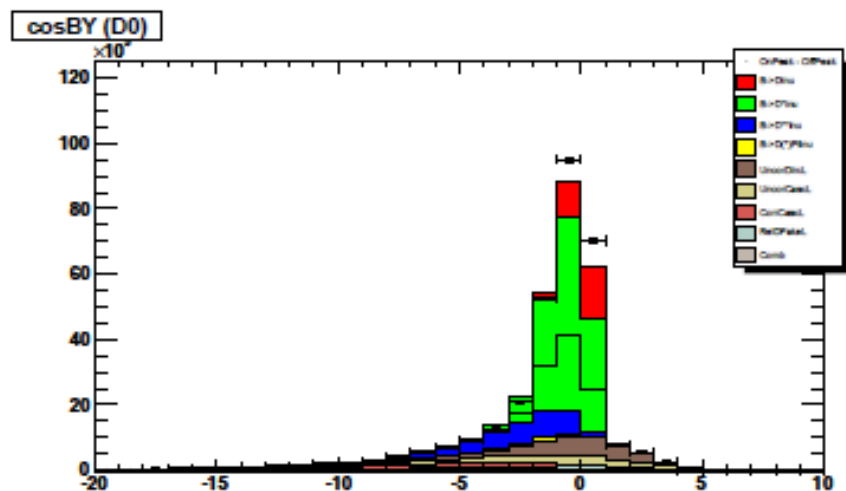
D momentum (D+)



D momentum (D+)



Fitted cosBY



Bin by Bin (Fitted): D^0

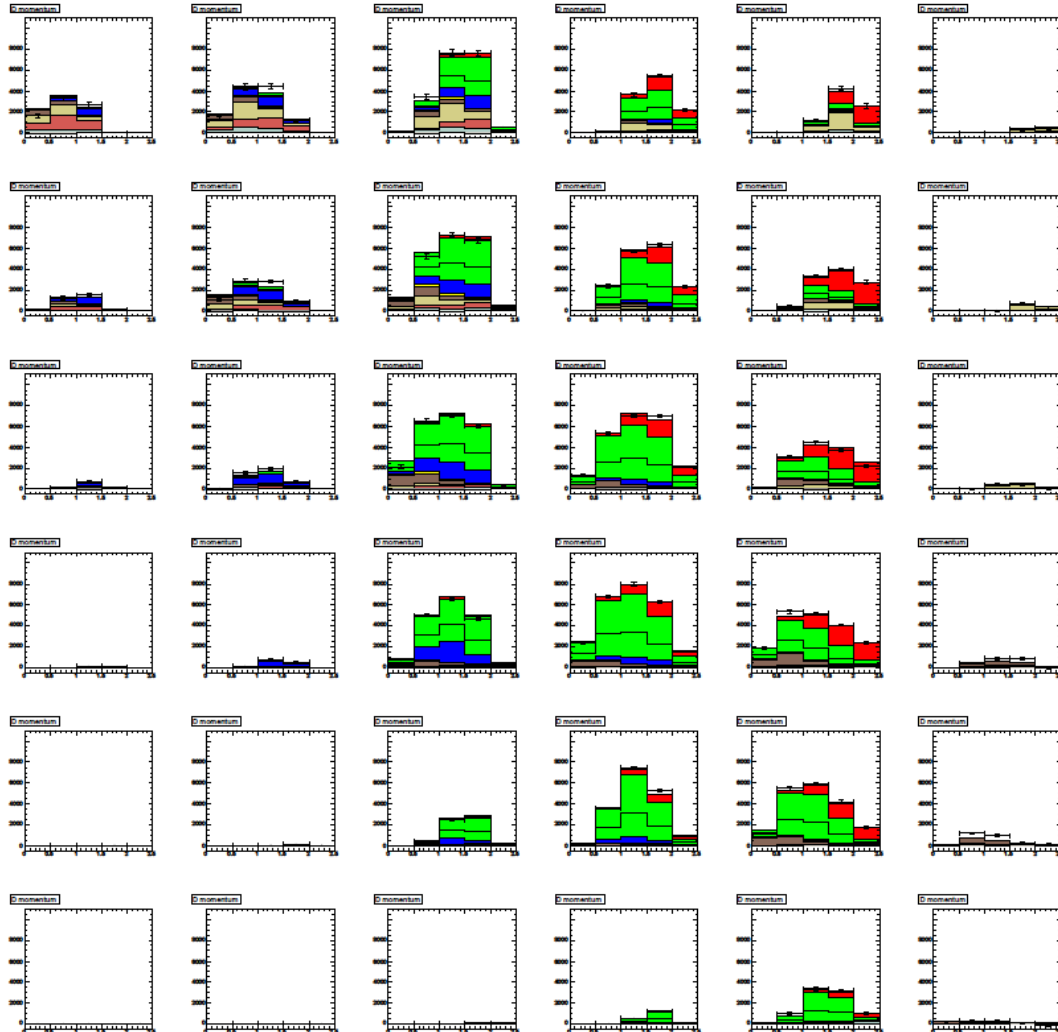
cosBY = -20

cosBY = +10

0.8

p_l^*

2.3



Bin by Bin (Fitted): D^+

cosBY = -20

cosBY = +10

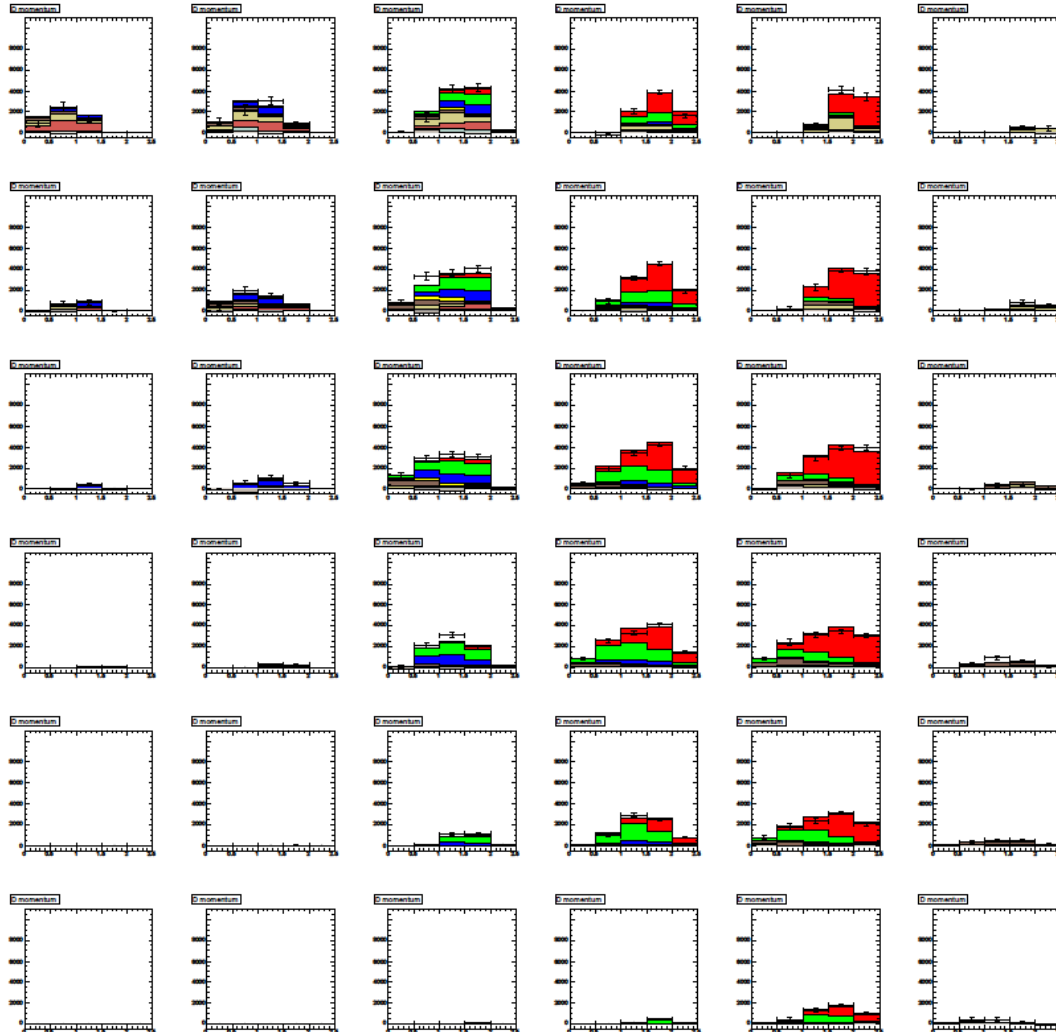
0.8



p_l^*



2.3



Summary

- $B \rightarrow D^{*+} \ell \bar{\nu}$ FF angle dependence is included.
 - Effect is small, but toward a good direction.
 - Did not solve D^* isospin symmetry problem.
- Validation fit results look reasonable.
- $D^{*+} \rightarrow D \pi$ decay BF may be responsible for $B \rightarrow D^{*+} \ell \bar{\nu}$ isospin symmetry problem.
- BAD1586 V2 will be ready soon.
- Next steps (will be done soon)
 - Systematic study
 - More background study.
 - Inclusive $B \rightarrow D$ BF re-weighting need to include D momentum dependence.