Global Fit for Branching Fractions and Form Factor Slope of $B->D^{(*)}l\nu$ Decays

- More validation fits
- Justification of isospin constraints
- $F(1)V_{cb}$ and $G(1)V_{cb}$
- $D^{*}l\nu$ FF parameter results

Fit Result (Run2 only)

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

$Dl\nu$ FF slope	1.350 ± 0.066 (4.9 %)
$D^*l\nu$ FF slope	1.373 ± 0.076 (5.6 %)
R_1	1.542 ± 0.123 (8.0 %)
R_2	0.584 ± 0.103 (17.7 %)
BF($B^+ \to Dl\nu$)	0.02554 ± 0.00082 (3.2 %)
BF($B^+ \to D^*l\nu$)	0.05287 ± 0.00122 (2.3 %)
BF($B^+ \to D^{**}/D^{(*)}\pi\, l\nu$)	0.02148 ± 0.00106 (4.9 %)

- Chi-square/ndof = 220/215
- Normalization to inclusive $B \to X_c e\nu$ BF ($p^* > 1.5$ GeV) has not yet done. BFs will be increased by ~10%.

Systematic Error (%)

	D slope	D^* slope	R_1	R_2	BF($Dl\nu$)	BF($D^*l\nu$)	BF(Other)
$B->D^{**}$ FF	0.76	2.53	2.44	3.10	0.14	0.25	4.27
$B->D^{**}$ $D\pi$ BF ratios	0.25	0.63	2.18	2.34	0.26	0.49	4.29
D^{**} decay BF	0.08	0.10	0.14	0.32	0.03	0.04	0.38
t_{+0}	0.02	0.07	0.08	0.10	0.32	0.38	0.46
Trk, PID	0.61	1.12	3.69	2.22	3.73	4.21	2.60
Total	**1.01**	**2.84**	**4.93**	**4.48**	**3.75**	**4.27**	**6.61**

Trk PID systematic on BF will decrease after BF renormalization.

Validation Fit Method

- Split Run2 MC into two halves.
- Use one half to make fake OnPeak-OffPeak data.
- Can change input values to make fake data.
- Use the other half for MC histograms.
- We test 3 different input parameter sets.

  -> see table on next page.
- We use 5 different MC splitting.
  - Even and odd number events.
  - Use 3 different random numbers to separate events.
  - First half and second half.

Validation Fits – Input values

Set a = PDG; Set c = Nominal values; Set b = mixture

parameter	Set a (PDG)	Set b (Half Nominal)	Set c (Nominal)
$Dl\nu$ FF slope	1.20	1.350	1.350
$D^*l\nu$ FF slope	1.145	1.373	1.373
R_1	1.396	1.542	1.542
R_2	0.855	0.584	0.584
BF($B^+ \to Dl\nu$)	0.0215	0.0255	0.0255
BF($B^+ \to D^*l\nu$)	0.0650	0.0529	0.0529
BF($B^+ \to D^{**}/D^{(*)}\pi\, l\nu$)	0.0232	0.0215	0.0215
BF($D^{*+} \to D^0\pi^+$)	0.677	0.677	0.678
BF($D^+ \to K^-\pi^+\pi^-$)	0.0951	0.0951	0.0908
BF($D^0 \to K^-\pi^+$)	0.0380	0.0380	0.0384
f_{+-}/f_{00}	1.024	1.024	1.065

Pulls (5 MC splitting, Set a)

Chi^2/ndf	209/209	207/209	208/213	203/209	241/207
$Dl\nu$ FF slope	-0.69	0.58	-0.19	-1.42	0.11
$D^*l\nu$ FF slope	-0.37	0.62	-0.05	-0.03	-0.55
R_1	-1.42	-0.01	-0.20	0.75	-0.08
R_2	1.35	-0.53	0.06	-0.30	0.52
BF($B^+ \to Dl\nu$)	1.10	0.18	-0.78	0.36	-0.52
BF($B^+ \to D^*l\nu$)	0.61	0.32	-0.64	-1.10	-1.35
BF($B^+ \to D^{**}/D^{(*)}\pi\, l\nu$)	-1.00	-1.42	1.95	1.71	0.78
BF($D^{*+} \to D^0\pi^+$)	-0.08	0.08	0.46	-0.25	0.34
BF($D^+ \to K^-\pi^+\pi^-$)	0.67	-0.81	0.04	-0.17	-0.17
BF($D^0 \to K^-\pi^+$)	-0.18	0.26	0.08	0.10	0.15
f_{+-}/f_{00}	-0.35	0.43	-0.21	0.32	0.11

Pulls (5 MC splitting, Set b)

Chi^2/ndf	210/207	202/207	206/211	203/209	238/207
$Dl\nu$ FF slope	-0.68	0.51	-0.18	-1.55	0.23
$D^*l\nu$ FF slope	-0.62	0.68	0.10	0.42	-1.03
R_1	-1.47	-0.03	-0.12	1.21	-0.41
R_2	1.51	-0.49	-0.09	-0.78	0.92
BF($B^+ \to Dl\nu$)	1.02	0.20	-0.85	0.48	-0.72
BF($B^+ \to D^*l\nu$)	0.60	0.31	-0.56	-1.25	-1.12
BF($B^+ \to D^{**}/D^{(*)}\pi\, l\nu$)	-0.92	-1.41	1.83	1.61	0.85
BF($D^{*+} \to D^0\pi^+$)	-0.08	0.07	0.32	-0.25	0.32
BF($D^+ \to K^-\pi^+\pi^-$)	0.63	-0.81	0.08	-0.16	-0.15
BF($D^0 \to K^-\pi^+$)	-0.15	0.28	0.03	0.12	0.13
f_{+-}/f_{00}	-0.31	0.46	-0.24	0.37	0.05

Pulls (5 MC splitting, Set c)

Chi^2/ndf	211/206	207/207	208/210	206/208	242/207
$Dl\nu$ FF slope	-0.78	0.35	-0.30	-1.70	0.12
$D^*l\nu$ FF slope	-0.73	0.62	0.02	0.47	-1.13
R_1	-1.55	-0.12	-0.18	1.13	-0.47
R_2	1.54	-0.50	-0.10	-0.87	0.90
BF($B^+ \to Dl\nu$)	0.54	-0.20	-1.35	0.07	-1.63
BF($B^+ \to D^*l\nu$)	0.96	0.70	-0.16	-0.85	-0.80
BF($B^+ \to D^{**}/D^{(*)}\pi\, l\nu$)	-1.12	-1.57	1.69	1.41	0.78
BF($D^{*+} \to D^0\pi^+$)	0.01	0.15	0.39	-0.16	0.39
BF($D^+ \to K^-\pi^+\pi^-$)	1.05	-0.47	0.45	0.21	0.35
BF($D^0 \to K^-\pi^+$)	-0.24	0.17	-0.07	0.02	0.01
f_{+-}/f_{00}	-1.05	-0.32	-1.00	-0.41	-0.72

Electrons and Muons

Fit electrons and muons separately.

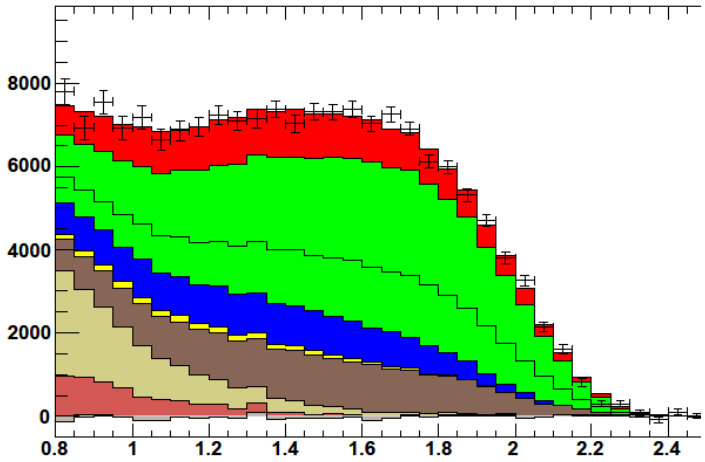
	Electrons		Muons	
	fit result	pull	fit result	pull
ρ_D^2	1.268 ± 0.092	-0.90	1.434 ± 0.090	0.93
ρ^2	1.415 ± 0.095	0.44	1.272 ± 0.109	-0.93
R_1	1.702 ± 0.178	0.90	1.343 ± 0.154	-1.29
R_2	0.558 ± 0.141	-0.18	0.667 ± 0.137	0.61
$\mathcal{B}(B \to D\ell\nu)$	0.0261 ± 0.0010	0.58	0.0246 ± 0.0010	-0.97
$\mathcal{B}(B \to D^*\ell\nu)$	0.0532 ± 0.0014	0.23	0.0527 ± 0.0015	-0.11
$\mathcal{B}(B \to D^{**}/D^{(*)}\pi\ell\nu)$	0.0214 ± 0.0013	-0.06	0.0206 ± 0.0015	-0.56
χ^2/ndof	196/206		199/206	

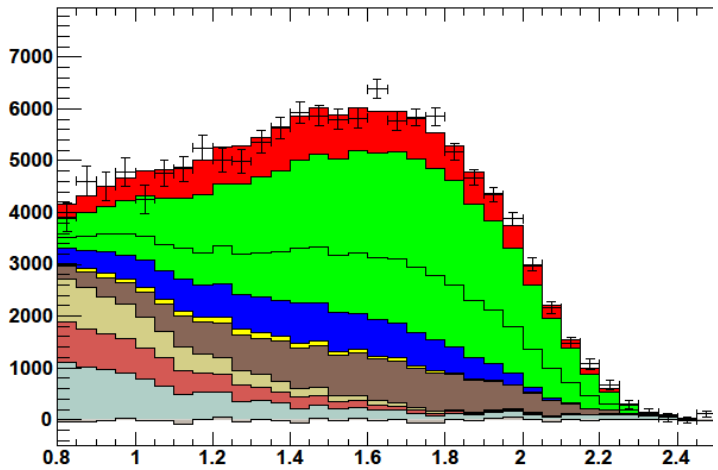
Lepton momentum plots

Electron

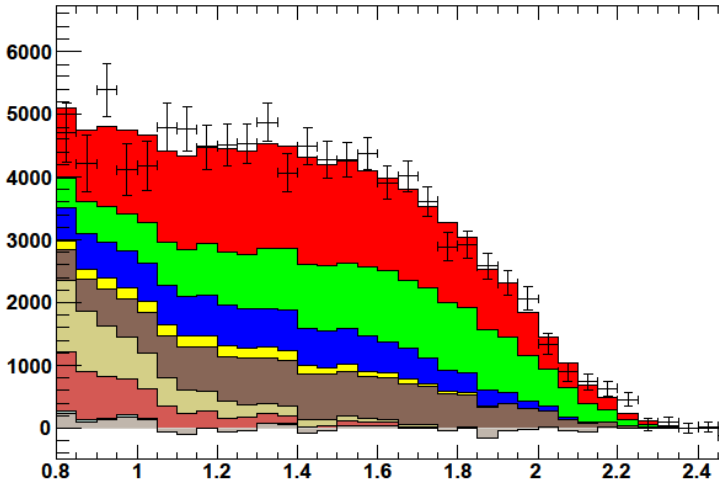
Muon

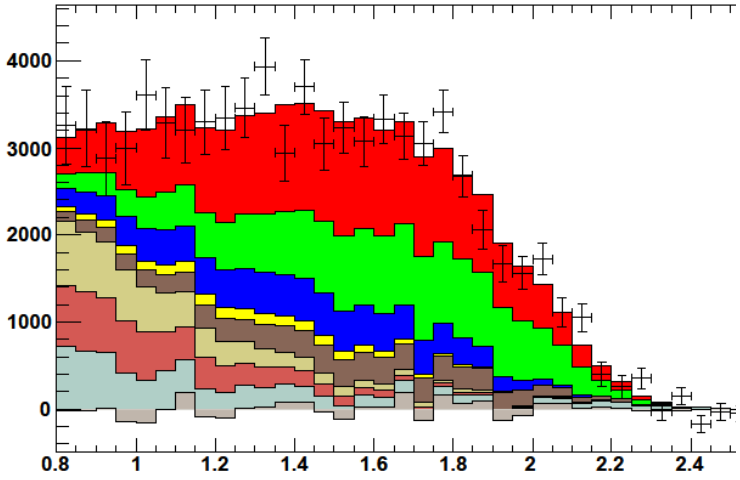
D^0





D^+





$B \to D^* l \nu$ isospin constraint

- We move isospin part into the validation section (BAD 1586).
- We apply isospin symmetry constraints because
  - No physical reason to violate isospin symmetry.
  - To reduce statistical uncertainty.

    (5.1 % -> 2.3 % on BF($B^+ \to D^* l \nu$) (Run2 only))
  - Our fit does not have the sensitivity to determine BF($B^+ \to D^{*0} l \nu$) and BF($B^0 \to D^{*+} l \nu$) simultaneously.
  - Our fit gives a good χ^2 with this constraint.
  - We can recover isospin symmetry by small change of D^* and D decay BF and f_{+-}/f_{00}. So, we float these values in our fit.

Floating D^* and D decay BF

- If we fix D and D^* BF and f_{+-}/f_{00} to PDG value.
  - BF($B^+ \to D^* l \nu$) = 0.05711 ± 0.00173
  - BF($B^0 \to D^* l \nu$) = 0.04460 ± 0.00230
  - χ^2/ndf = 213/213
- If we float D and D^* BF and f_{+-}/f_{00} with Gaussian constraints and isospin symmetry constraints.
  - BF($D^{*+} \to D^0 \pi^+$) : 0.677 -> 0.678 (0.2σ off)
  - BF($D^+ \to K^- \pi^+ \pi^-$) : 0.0951 -> 0.0908 (1.2σ off)
  - BF($D^0 \to K^- \pi^+$) : 0.0380 -> 0.0384 (0.6σ off)
  - f_{+-}/f_{00} : 1.024 -> 1.065 (1.3σ off)
- If we fix these 4 parameters to fit results, we can recover isospin symmetry.
  - Fit results without isospin constraint on BF($B \to D^* l \nu$)

    BF($B^+ \to D^* l \nu$) = 0.05307 ± 0.00175

    BF($B^0 \to D^* l \nu$) = 0.04828 ± 0.00244

    Correlation = -0.709 (covariance = -3.027E-6)
  - BF($B^+ \to D^* l \nu$)/ BF($B^0 \to D^* l \nu$) = 1.099 ± 0.065
  - Consistent with lifetime ratio 1.071 ± 0.009 (PDG)
  - χ^2/ndf = 215/213

$F(1)V_{cb}$ and $G(1)V_{cb}$

- BF($B^+ \to D l \nu$) and slope -> $G(1)V_{cb}$
  - $G(1)V_{cb}$ = 0.04841 ± 0.00194 ±0.00110
- BF($B^+ \to D^* l \nu$) and FF parameters -> $F(1)V_{cb}$
  - $F(1)V_{cb}$ = 0.03493 ± 0.00059 ± 0.00098
- Correlation between these is -0.098
- Values will change after BF renormalization.
- Systematic uncertainty will be increased by adding more items, but BF-renormalization will significantly decrease tracking and PID systematic error.

$B->D^{*}l\nu$ FF parameters

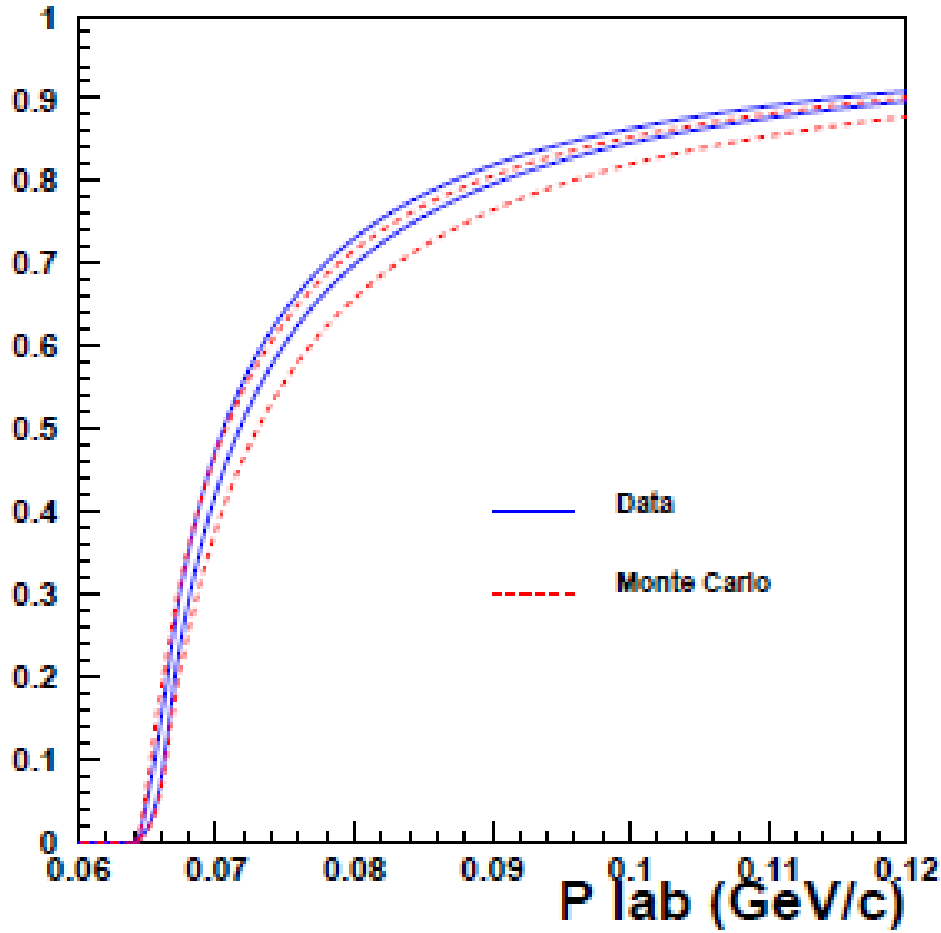
- Previous Babar measurements :
- hep-ex/0607076v1
  - $B^0->D^{*-}l^+\nu$, $D^{*-}->D^0\pi_s^-$ ($D^{*-}->D^-\pi^0/\gamma$ is not included)
  - $p_T(\pi_s^+) > 50$ MeV, $p_l^* > 1.2$ GeV
  - $\rho^2 = 1.179 \pm 0.048 \pm 0.028$
  - $R_1 = 1.417 \pm 0.061 \pm 0.044$
  - $R_2 = 0.836 \pm 0.037 \pm 0.022$
  - BF($B^0->D^{*-}l^+\nu$) = $0.0477 \pm 0.0004 \pm 0.0039$
  - $F(1)V_{cb} = (34.68 \pm 0.32 \pm 1.15)\times 10^{-3}$
- arXiv:0707.2655v1 [hep-ex]
  - $B^-->D^{*0}l^-\nu$, $D^{*0}->D^0\pi^0$ ($D^{*0}->D^0\gamma$ is not included)
  - E_γ (from π^0) > 30 MeV, $p_l^* > 1.2$ GeV
  - Use R_1 and R_2 from hep-ex/0607076v1
  - $\rho^2 = 1.15 \pm 0.06 \pm 0.08$
  - BF($B^-->D^{*0}l^-\nu$) = $0.0571 \pm 0.0008 \pm 0.0041$
  - $F(1)V_{cb} = (36.3 \pm 0.6 \pm 1.4)\times 10^{-3}$

Our $B->D^{*}l\nu$ FF parameters

- Include all decay modes.
- Cover larger and more uniform phase space.
  - No cuts on soft π.
  - $p_l^{*} > 0.8$ GeV
- Our results
  - $\rho^2 = 1.373 \pm 0.076 \pm 0.039$
  - $R_1 = 1.542 \pm 0.123 \pm 0.076$
  - $R_2 = 0.584 \pm 0.103 \pm 0.026$
  - BF($B^{-}->D^{*0}l^{-}\nu$) $= 0.0529 \pm 0.0012 \pm 0.0010$
    BF re-normalization has not yet been done.
    May increase fitted BFs by ~10%.
  - $F(1)V_{cb} = 0.03493 \pm 0.00059 \pm 0.00098$
  - Run2 only -> Statistical uncertainty will decrease.
  - Systematic uncertainty may increase.

Soft π relative efficiency

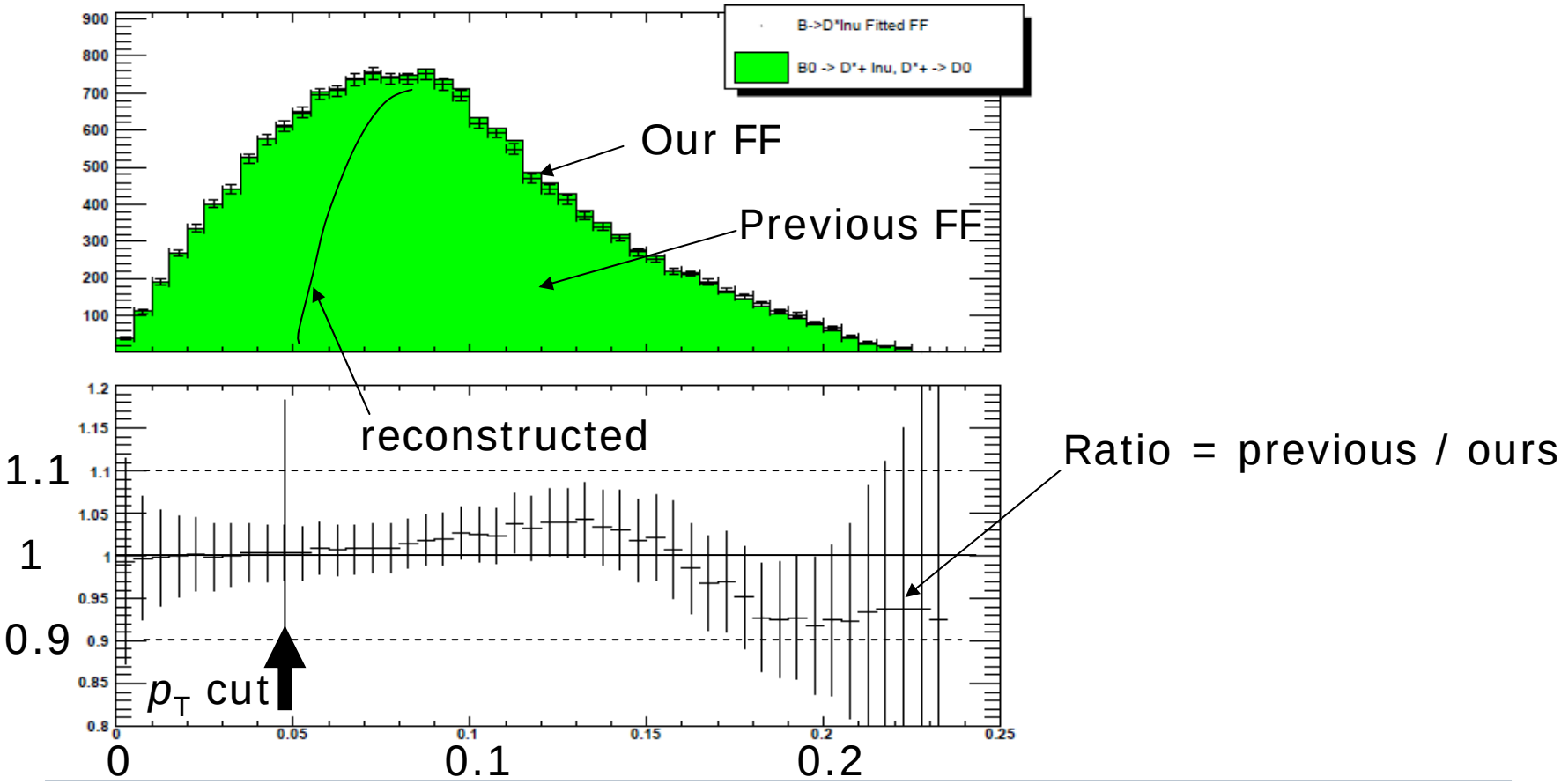
BAD 1113 V10



Efficiency drops rapidly at low momentum

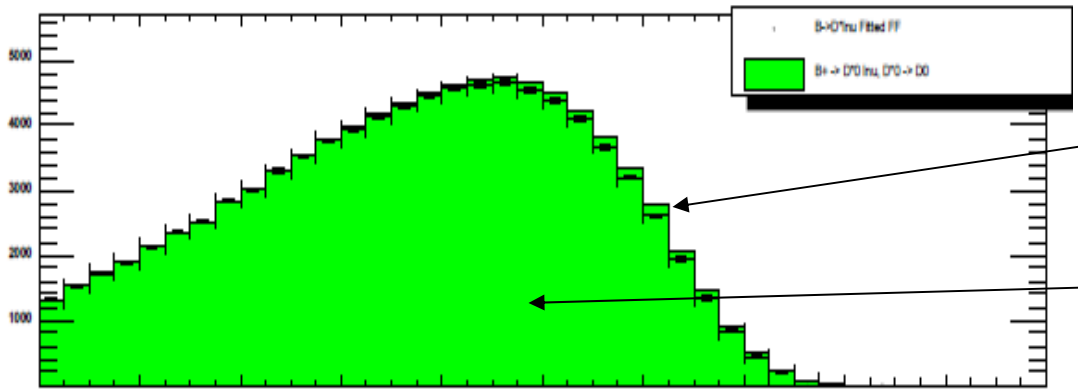
Soft π transverse momentum

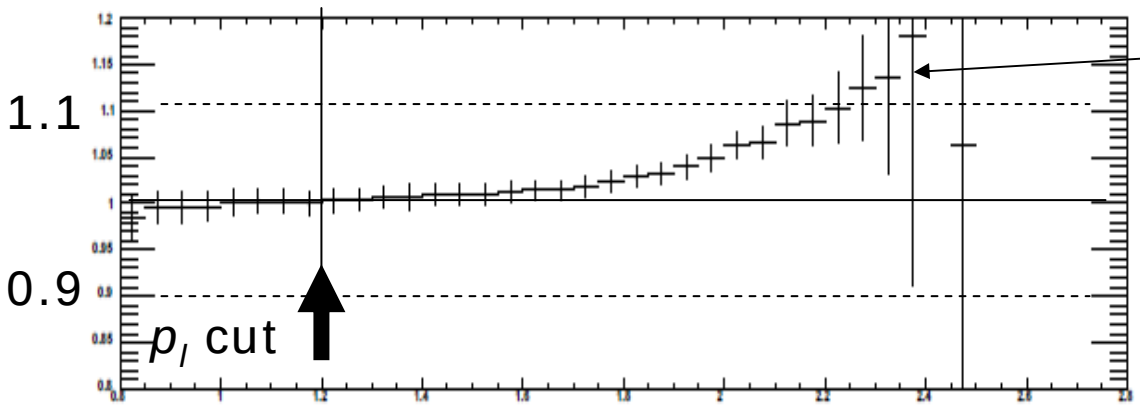
- $B^0 -> D^{*-} l^+ \nu$, $D^{*-} -> D^0 \pi_s^-$ mode
- All selection cuts and corrections are applied.



Lepton momentum

- $B^0 -> D^{*-} l^+ \nu$, $D^{*-} -> D^0 \pi_s^-$ mode
- All selection cuts and corrections are applied.





Comparison of FF parameters

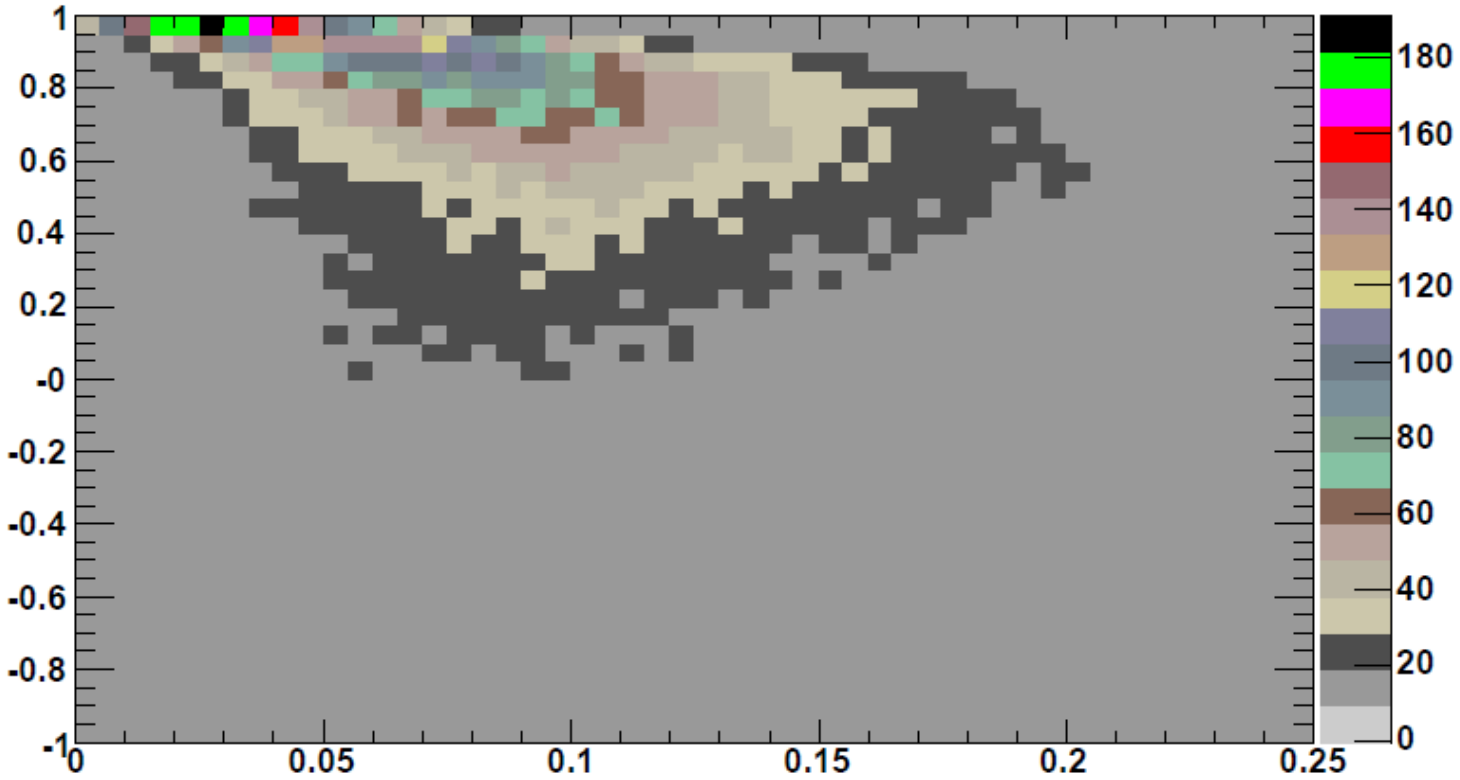
- What if they use our R_1 and R_2 values?
  (Thanks, Art, for providing these numbers.)
- hep-ex/0607076v1
  - $\rho^2 = 1.331 \pm 0.0033$
  - $F(1)V_{cb} = (34.50 \pm 0.58) \times 10^{-3}$
  - BF($B^0 \to D^{*-} l^+ \nu$) = 0.0491 ± 0.004 (error is a rough estimation)
- arXiv:0707.2655v1 [hep-ex]
  - $\rho^2 = 1.466$
  - $F(1)V_{cb} = 35.9 \times 10^{-3}$
  - BF($B^- \to D^{*0} l^- \nu$) = 0.0556 ± 0.004 (with PDG 2006 B lifetime)
- Our fit results
  - $\rho^2 = 1.373 \pm 0.076 \pm 0.039$
  - $F(1)V_{cb} = (34.93 \pm 0.59 \pm 0.98) \times 10^{-3}$
  - BF($B^- \to D^{*0} l^- \nu$) = 0.0529 ± 0.0016 (BF will increase ~10%)
  - BF($B^0 \to D^{*-} l^+ \nu$) = 0.0494 ± 0.0015 (isospin, will increase ~10%)
- Both results are consistent with ours.
- But, difference of R_1 and R_2 need to be understood.

To do list

- Toy MC study on the way.
- BF renormalization will be done soon.
- More systematic to be done.
  - Luminosity normalization (B counting)
  - Radiative correction (PHOTOS)
  - Background BF re-weighting
  - BF re-normalization
  - $D^* l \nu$ FF parameterization (R_1, R_2 : w dependence).
  - Effect of $B \to D_s^{(*)} K^{(*)} l \nu$ contribution.

Slow π : p_T vs $\cos\theta$

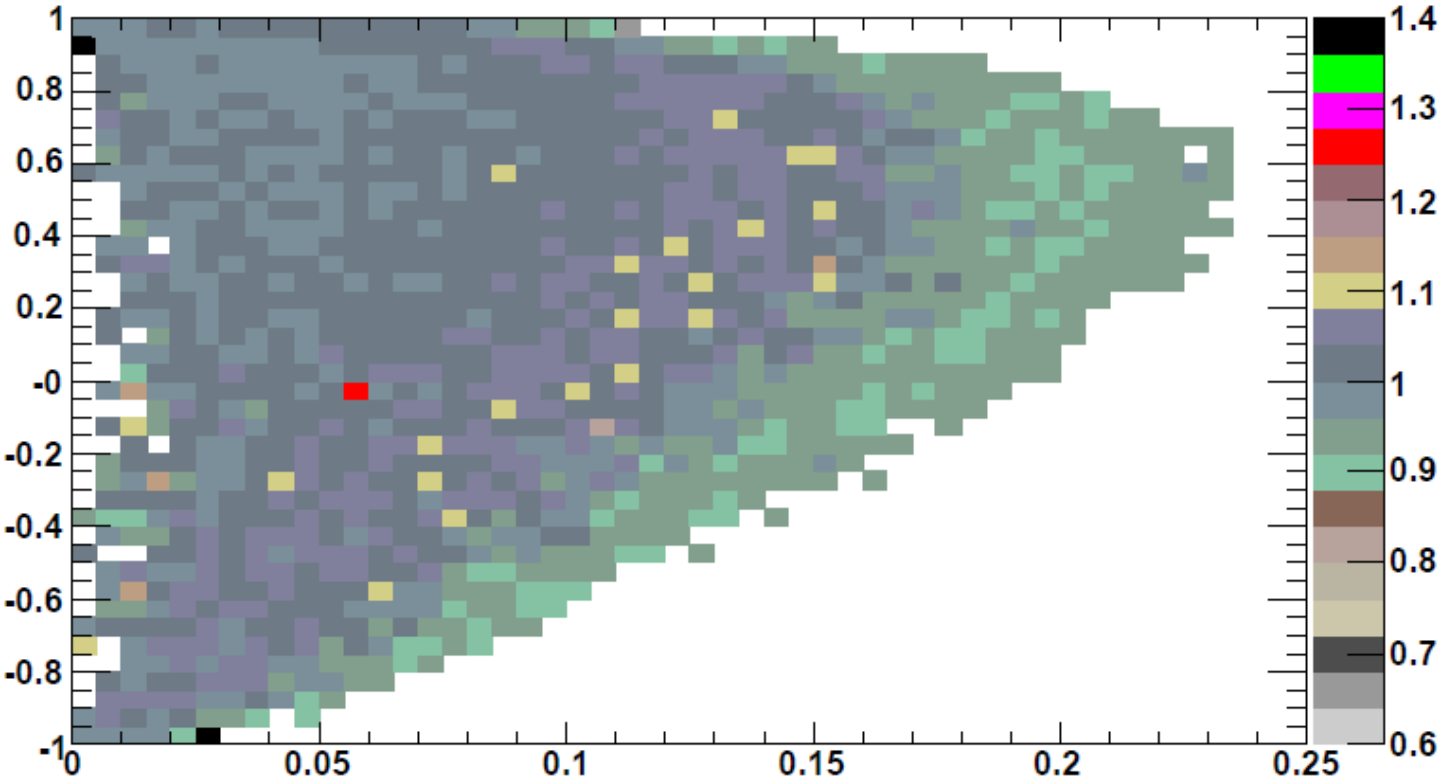
- $B^0 \to D^{*-} l^+ \nu$, $D^{*-} \to D^0 \pi_s^-$ mode
- All selection cuts and corrections are applied
- $\cos\theta > 0.92$ is out of DCH full coverage.



Slow π : p_T vs $\cos\theta$ (Ratio)

- $B^0 \to D^{*-} l^+ \nu$, $D^{*-} \to D^0 \pi_s^-$ mode
- All selection cuts and corrections are applied

Ratio = old/new



Correlations

	D slope	D^* slope	R_1	R_2	BF($Dl\nu$)	BF($D^*l\nu$)	BF(Other)
D slope	1						
D^* slope	-0.31	1					
R_1	-0.20	0.83	1				
R_2	0.26	-0.91	-0.93	1			
BF($Dl\nu$)	0.37	0.07	0.05	0.02	1		
BF($D^*l\nu$)	-0.28	0.13	0.01	-0.15	-0.01	1	
BF(Other)	0.09	-0.19	-0.15	0.19	0.27	-0.10	1

BF re-normalization

- We will re-normalize or re-scale fitted BF to reduce systematic uncertainties.
- Re-normalize to the measured inclusive BF($p_l^* > 1.5$GeV).
- Re-normalization factor, F_N, is given by

  Inclusive BF($p_l^* > 1.5$GeV) =

  $F_N \times$ [BF($B^+ \to D l \nu$, $p_l^* > 1.5$GeV)

  + BF($B^+ \to D^* l \nu$, $p_l^* > 1.5$GeV)

  + BF($B^+ \to D^{**}/D^{(*)} \pi\, l \nu$, $p_l^* > 1.5$GeV)]
- In $p_l^* > 1.5$GeV region, the contributions from higher D mass states are small.