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

Fitting metod and FF re-weighting

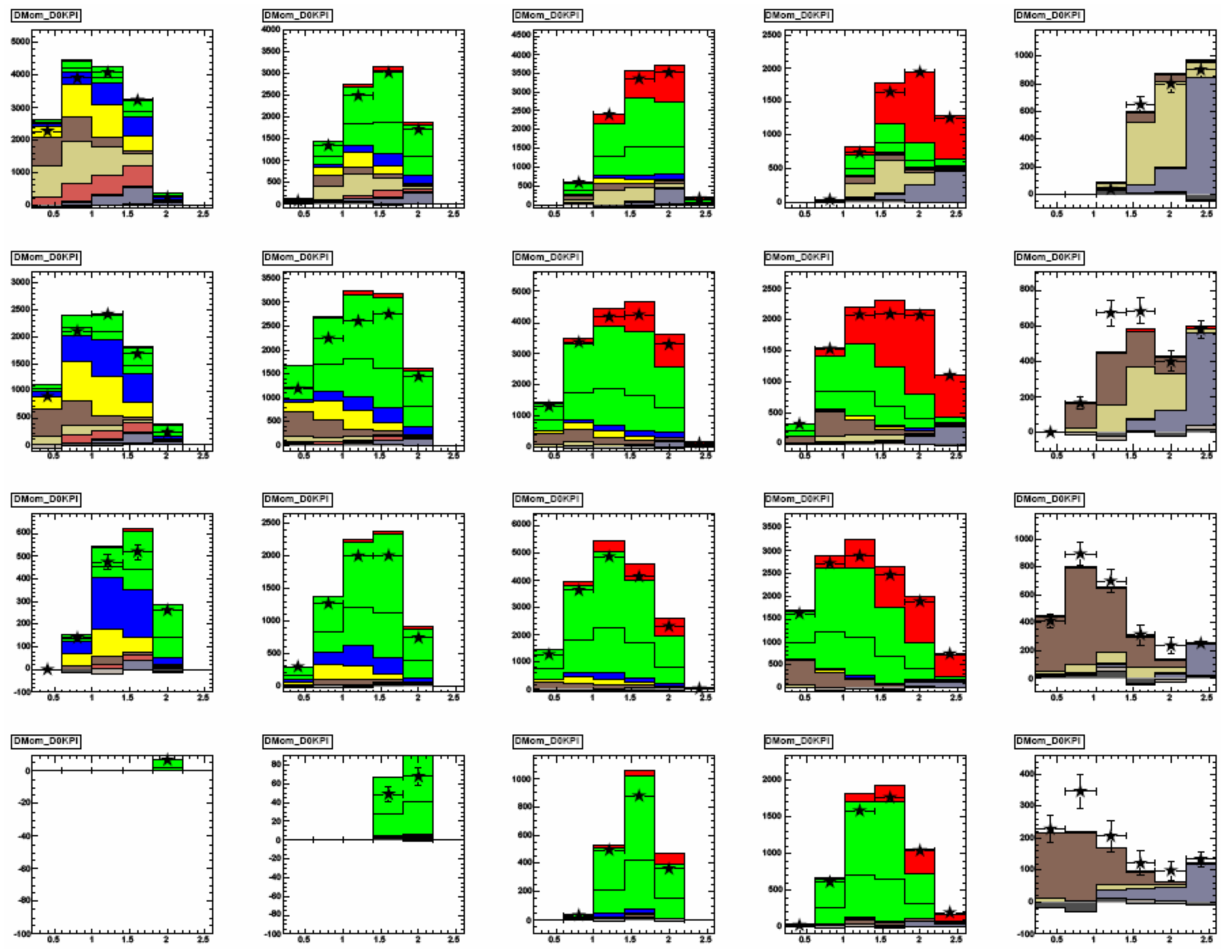
Changes since last September

- Use OffPeak data instead of ccbar, uds and tautau MC
- Use Run2 (59.4 fb^{-1} of data) to get more OffPeak statistics.
- Fixed relative size of background components to get more realistic results.
- D** FF re-weighting

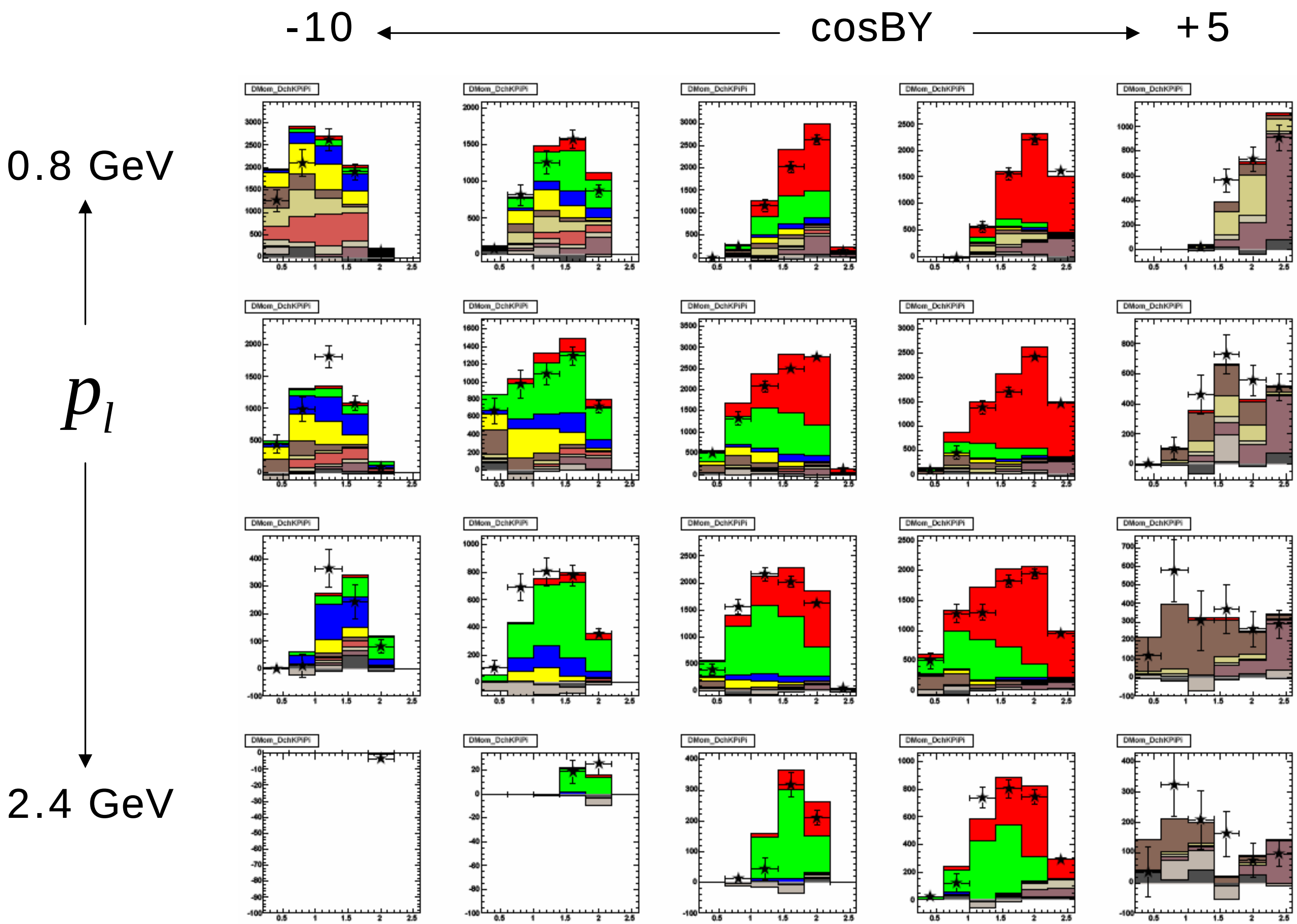
Bin by bin plot : D0 momentum

-10 ← cosBY → +5

0.8 GeV ↑ p_l ↓ 2.4 GeV



Bin by bin plot : D+ momentum



Fitting Method

- 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.
- 8 signal modes and 4 background modes (combinatorial background is almost zero after sideband subtraction)
- Isospin symmetry for B decays.

$N_i^{B\bar{B}MC}$ and C : Signal

- $B\text{->}Dl\nu$: C=BF($B\text{->}Dl\nu$)
- $B\text{->}D^*l\nu$: C=BF($B\text{->}D^*l\nu$)
- $B\text{->}D^{**}l\nu$ & $B\text{->}D^{(*)}\pi l\nu$: BF(B->Other $l\nu$)
  - $B\text{->}D_0^*l\nu$: C= $f_1\times$B(B-> Other $l\nu$)
  - $B\text{->}D_1l\nu$: C= $f_2\times$B(B-> Other $l\nu$)
  - $B\text{->}D_1'l\nu$: C= $f_3\times$B(B-> Other $l\nu$)
  - $B\text{->}D_2^*l\nu$: C= $f_4\times$B(B-> Other $l\nu$)
  - $B\text{->}D\pi l\nu$: C= $f_5\times$B(B-> Other $l\nu$)
  - $B\text{->}D^*\pi l\nu$: C= $f_6\times$B(B-> Other $l\nu$)
- 4 parameters to be determined :
  - 3 BFs and B->D$l\nu$ FF slope.
- Factors f_1 - f_6 are fixed.

$N_i^{B\bar{B}MC}$ and *C* : Background

- Uncorrelated (= *D* and *l* from different *B*) : *C* = fa * f_0
- Uncorrelated (= *D* and *l* from different *B*) and *l* not directly from *B* (i.e. *B*->*D*->*Xl*) : *C* = fb * f_0
- Cascade (= *l* not directly from *B*) and correlated (i.e. B -> D Dbar, Dbar->Xl) : *C* = fc * f_0
- Fake lepton = misidentified *l* : *C* = fd * f_0
- Combinatorial background is almost zero after *D* mass sideband subtraction.
- $f_0(D^0)$ and $f_0(D^+)$ are floated in the fit independently.
- fa = fb = fc = fd = 1.

f_{+0} and c_{+0}

- We also included f_{+0} in the fit with Gaussian constraint

$$f_{+0} = \frac{\mathrm{BR}(e^+e^- \to B^+B^-)}{\mathrm{BR}(e^+e^- \to B^0\overline{B^0})}$$

- To account for possible simulation difference of D^0 and D^+, we multiplied *C* of D^+ MC by c_{+0} (floated with Gaussian constraint). This also allows the fit to adjust for the uncertainties in the relative BFs for $D^0 \to K\pi$ and $D^+ \to K\pi\pi$, and should make us less sensitive to uncertainties from tracking efficiency.

Form Factor Re-weighting

- $B\text{->}Dl\nu$: ISGW2 -> HQFT

$$h_+(w) = h_+(1)[1 - \rho_D^2 (w-1)]$$

- $B\text{->}D^*l\nu$: HQET
  - Babar measurement of R_1, R_2 and slope ρ^2.
- $B\text{->}D^{**}l\nu$: ISGW2 -> HQET
  - Based on LLSW paper (Leibovich, Ligeti, Stewart and Wise, PRD57(1998)308, hep-ph/9705467)
- Normalization
  - Total decay rate should stay same

$$\Gamma = \int \frac{d\Gamma(\text{old FF})}{dq^2} dq^2 = R_N \int \frac{d\Gamma(\text{new FF})}{dw} dw$$

  - R_N is the normalization factor

D_0* FF re-weighting

- Differential decay rate (see also p.14)

$$\frac{d\Gamma}{dw} = \frac{G_F^2 \left|V_{cb}\right|^2 m_B^5}{48\pi^3} r^3 (w^2 - 1)^{3/2} F(w)$$

$$F(w) = [(1+r)g_+ - (1-r)g_-]^2$$

- ISGW2 model

$$F(q^2) = R^2[(1+r)u_+(q^2) - (1-r)u_-(q^2)]^2$$

- LLSW model

slope

$$F(w) = \varsigma^2(1)[s_0 + (w-1)s_1]$$

$$s_0 = (1-r)^2 + 3(1-r^2)(\varepsilon_b + \varepsilon_c)(\overline{\Lambda}^* - \overline{\Lambda})$$

$$s_1 = 2(1-r)^2 \hat{\varsigma}'$$

D_1' FF re-weighting

- Differential decay rate (see also p.14)

$$\frac{d\Gamma}{dw} = \frac{G_F^2 |V_{cb}|^2 m_B^5}{48\pi^3} r^3 (w^2-1)^{1/2} F(w)$$

$$F(w) = [(w-r)g_{V_1} + (w^2-1)(g_{V_3} + rg_{V_2})]^2 + 2(1-2rw+r^2)[g_{V_1}^2 + (w^2-1)g_A^2]$$

- ISGW2 model

$$g_A \to Rm_B(1-r)q,\ g_{V_1} \to \frac{2}{Rm_B(1-r)} l,\ g_{V_3} + rg_{V_2} \to Rm_B(1-r)c_+$$

- LLSW model

$$F(w) = \varsigma^2(1)\{[s_0 + 2(1-2rw+r^2)t_0]$$
$$+(w-1)[s_1 + 2(1-2rw+r^2)t_1] + (w-1)^2[s_2 + 2(1-2rw+r^2)t_2]\}$$
$$s_0 = (1-r)^2(\varepsilon_c - 3\varepsilon_b)^2(\overline{\Lambda}^* - \overline{\Lambda})^2,\ t_0 = (\varepsilon_c - 3\varepsilon_b)^2(\overline{\Lambda}^* - \overline{\Lambda})^2$$
$$s_1 = -2(1-r^2)(\varepsilon_c - 3\varepsilon_b)(\overline{\Lambda}^* - \overline{\Lambda}),\ t_1 = 2 + 4(\varepsilon_c - 3\varepsilon_b)(\overline{\Lambda}^* - \overline{\Lambda})$$
$$s_2 = (1+r^2), t_2 = 2(1+2\hat{\varsigma}')$$

D_1 FF re-weighting

- Differential decay rate (see also p.14)

$$\frac{d\Gamma}{dw} = \frac{G_F^2 \left|V_{cb}\right|^2 m_B^5}{48\pi^3} r^3 (w^2-1)^{1/2} F(w)$$

$$F(w) = [(w-r) f_{V_1} + (w^2-1)(f_{V_3} + r f_{V_2})]^2 + 2(1-2rw+r^2)[f_{V_1}^2 + (w^2-1) f_A^2]$$

- ISGW2 model

$$f_A \to R m_B (1-r) v, \quad f_{V_1} \to \frac{2}{R m_B (1-r)} r, \quad f_{V_3} + r f_{V_2} \to R m_B (1-r) s_+$$

- LLSW model

$$F(w) = \frac{1}{3}\tau^2(1)\{[s_0 + 2(1-2rw+r^2)t_0]$$
$$+(w-1)[s_1 + 2(1-2rw+r^2)t_1] + (w-1)^2[s_2 + 2(1-2rw+r^2)t_2]\}$$

$$s_0 = 32(1-r)^2 \varepsilon_c^{\,2} (\overline{\Lambda}' - \overline{\Lambda})^2, \; t_0 = 32\varepsilon_c^{\,2}(\overline{\Lambda}' - \overline{\Lambda})^2$$

$$s_1 = 32(1-r^2)\varepsilon_c (\overline{\Lambda}' - \overline{\Lambda}), \; t_1 = 4 + 32\varepsilon_c(\overline{\Lambda}' - \overline{\Lambda})$$

$$s_2 = 8(1+r)^2, t_2 = 8(1+\hat{\tau}')$$

D_2* FF re-weighting

- Differential decay rate (see also p.14)

$$\frac{d\Gamma}{dw} = \frac{G_F^2 |V_{cb}|^2 m_B^5}{48\pi^3} r^3 (w^2-1)^{3/2} F(w)$$

$$F(w) = \frac{2}{3}[(w-r)k_{A_1} + (w^2-1)(k_{A_3} + rk_{A_2})]^2 + 2(1-2rw+r^2)[k_{A_1}^2 + (w^2-1)k_V^2]$$

- ISGW2 model

$$k_V \to Rm_B(1-r)h,\ k_{A_1} \to \frac{2}{Rm_B(1-r)}k,\ k_{A_3} + rk_{A_2} \to Rm_B(1-r)b_+$$

- LLSW model

$$F(w) = \frac{1}{3}\tau^2(1)\{[2s_0 + 3(1-2rw+r^2)t_0] + (w-1)[2s_1 + 3(1-2rw+r^2)t_1]\}$$

$$s_0 = 4(1-r)^2,\ t_0 = 4$$

$$s_1 = 4(1-r)^2(1+2\hat{\tau}'),\ t_1 = 2(3+4\hat{\tau}')$$

Numerical Values for LLSW

$$r = \frac{m_D}{m_B},\ R = \frac{2\sqrt{m_B m_D}}{m_B + m_D},\ \varepsilon_c = \frac{1}{2m_c},\ \varepsilon_b = \frac{1}{2m_b}$$

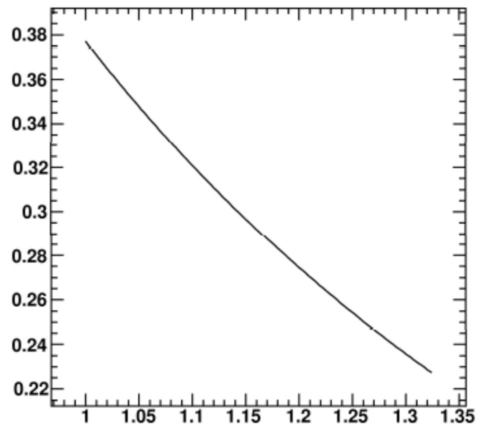
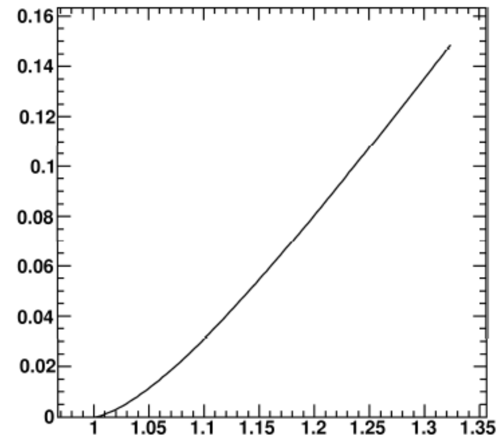
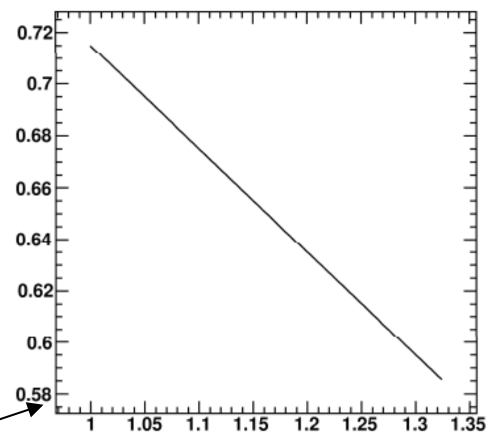
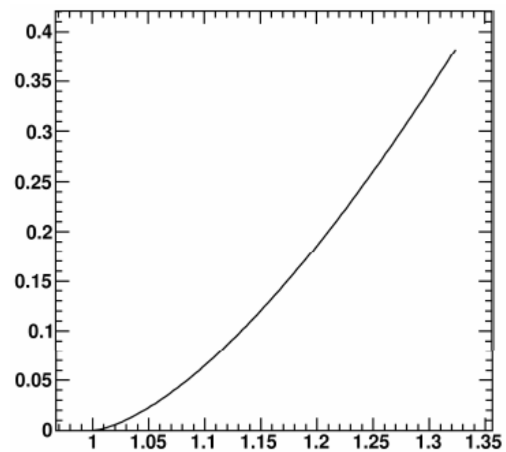
$$\tau(1) = 0.71,\ \varsigma(1) = \frac{2}{\sqrt{3}}\tau(1),$$

$$\hat{\tau}' = -1.5,\ \hat{\varsigma}' = \frac{1}{2} + \hat{\tau}' = -1$$

$$\varepsilon_c(\overline{\Lambda}' - \overline{\Lambda}) = 0.14,\ (\overline{\Lambda}' - \overline{\Lambda} = 0.39\mathrm{GeV})$$

$$\varepsilon_c + \varepsilon_b = 0.92\mathrm{GeV}^{-1},\ \varepsilon_c - 3\varepsilon_b = 0.05\mathrm{GeV}^{-1},\ \overline{\Lambda}^* - \overline{\Lambda} = 0.35\mathrm{GeV}$$

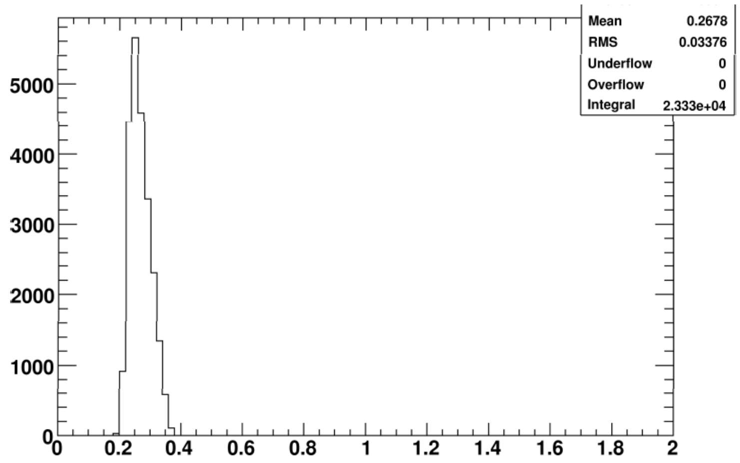
D_0* FF plots : *w* dependence

	$F(w)$	$(w^2\text{-}1)^{3/2} F(w)$
ISGW2		
LLSW		

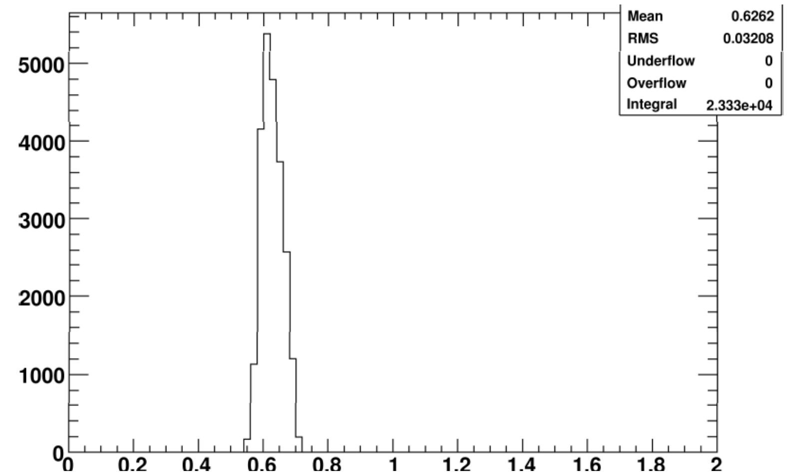
not zero

D_0* FF plots : FF and weights

ISGW2 $F(w)$

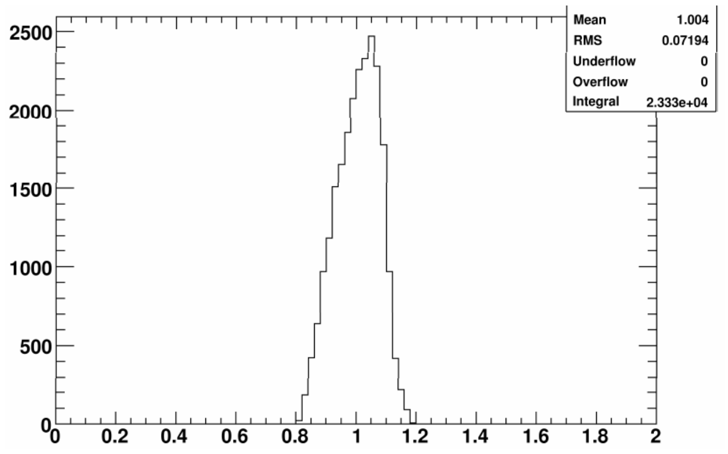


LLSW $F(w)$



Weight

R_N=0.425



D_0* kinematic variables

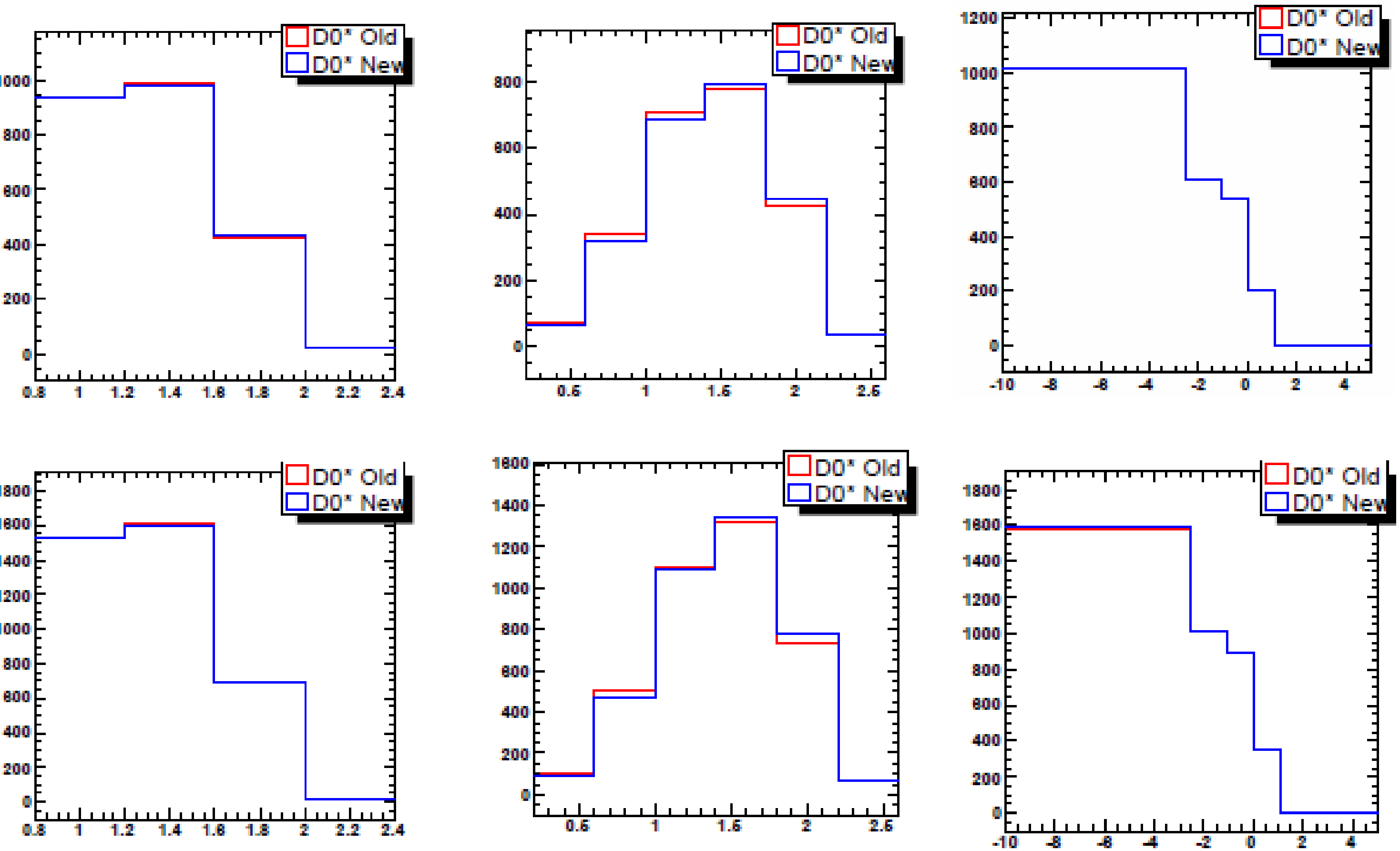
l momentum   *D* momentum   cosBY

D^0

D^+

ISGW2

LLSW

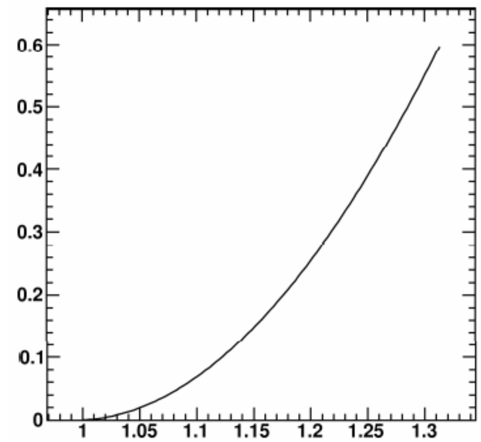


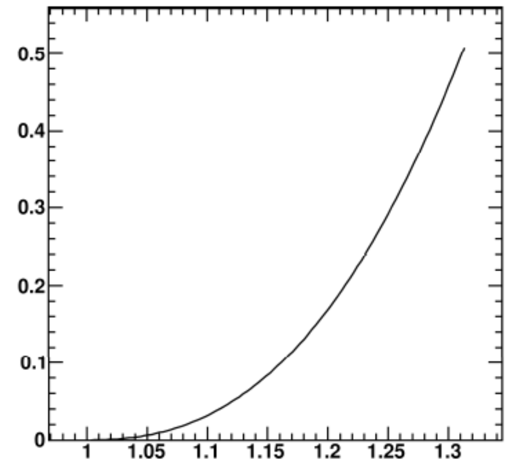
Normalized to OnPeak luminosity.

D_1' FF plots : *w* dependence

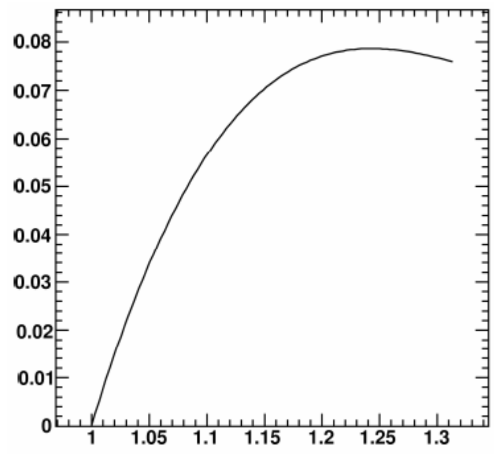
$F(w)$ | $(w^2-1)^{1/2} F(w)$

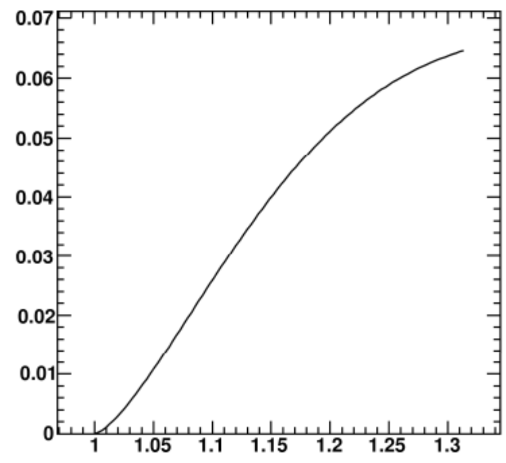
ISGW2





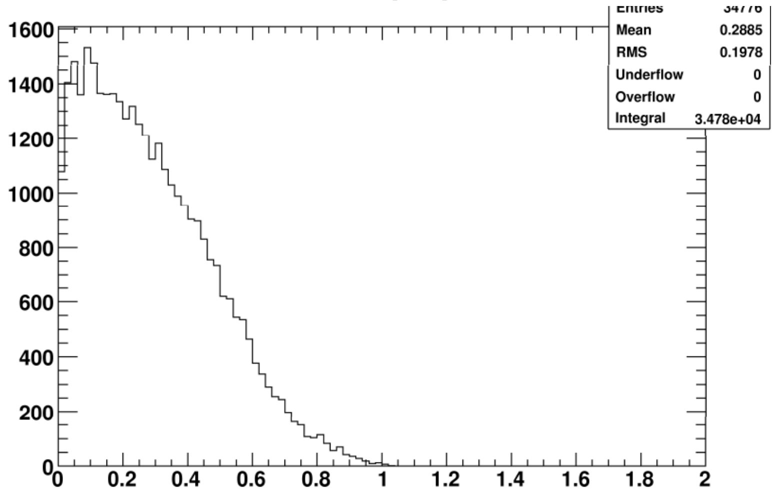
LLSW



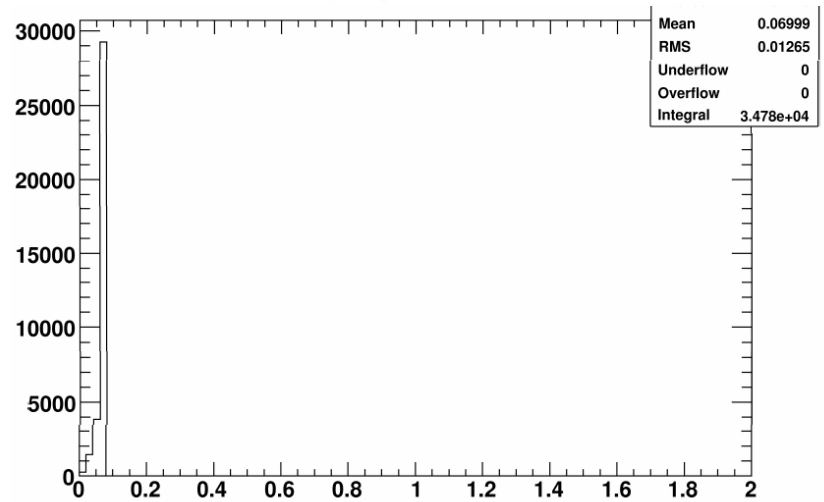


D_1' FF plots : FF and weights

ISGW2 $F(w)$

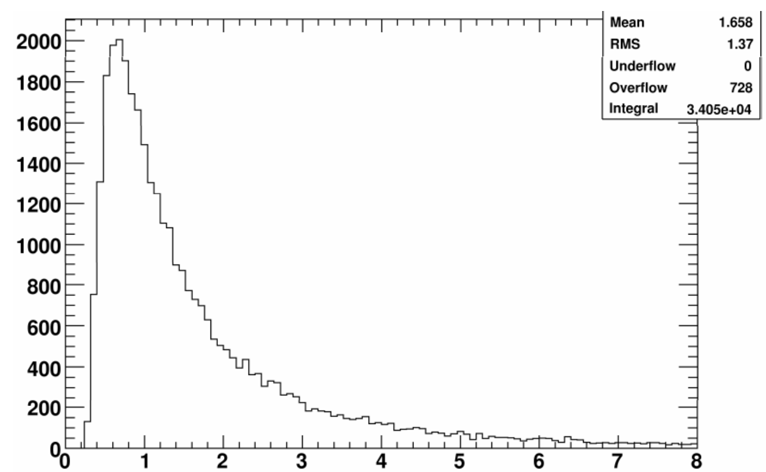


LLSW $F(w)$



Weight

R_N=4.00



D_1' kinematic variables

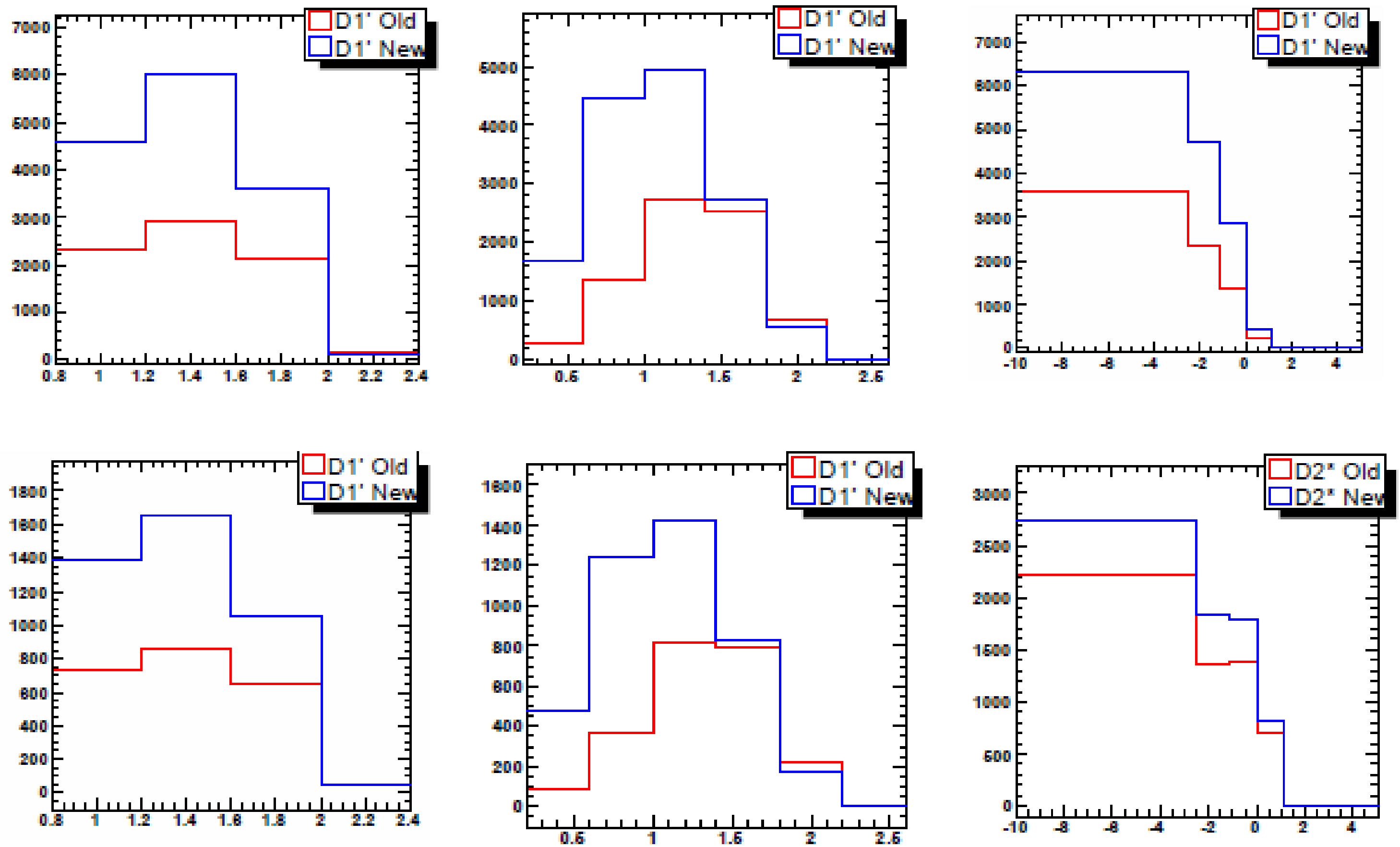
l momentum | *D* momentum | cosBY

D^0

D$^+$

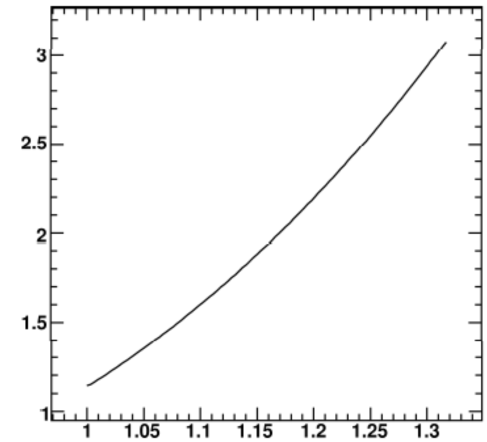
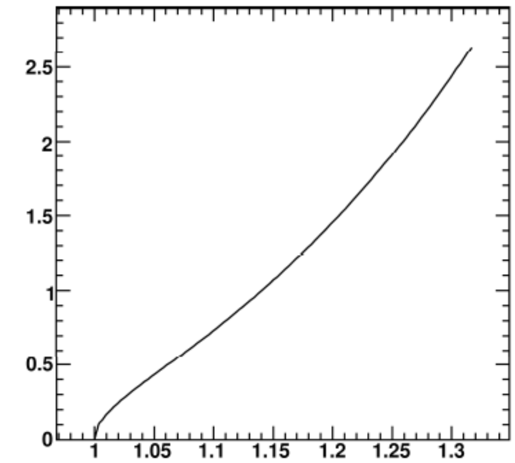
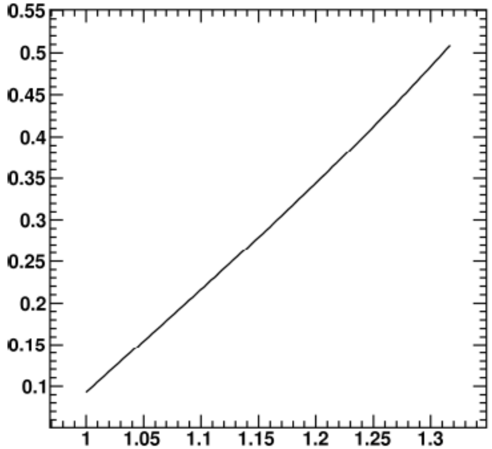
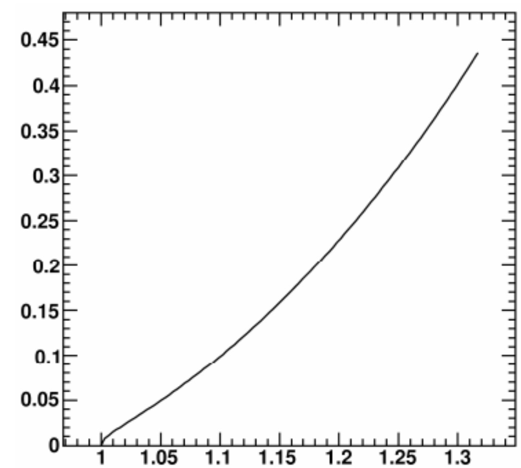
— ISGW2

— LLSW



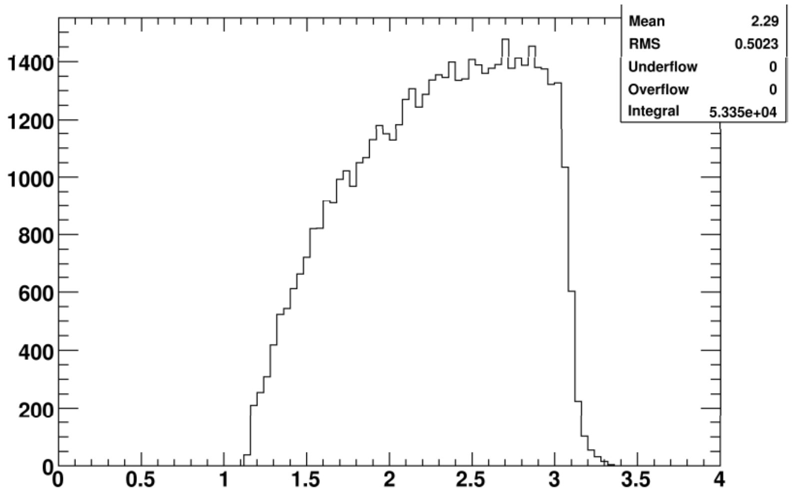
Normalized to OnPeak luminosity.

D_1 FF plots : w dependence

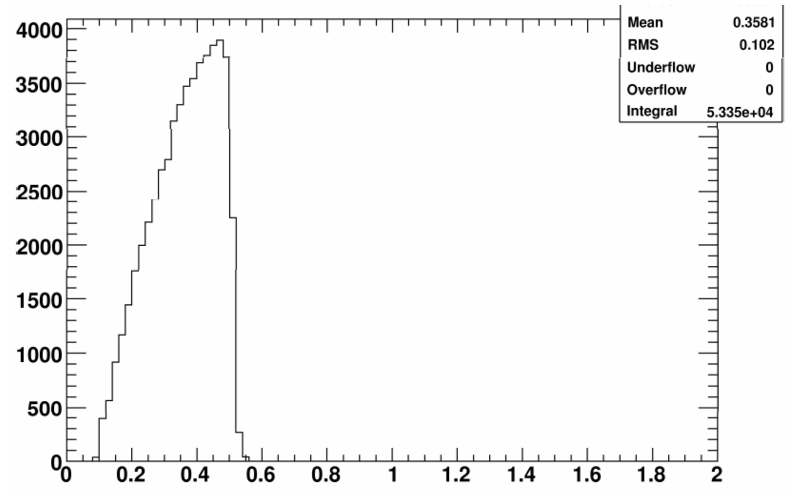
	$F(w)$	$(w^2\text{-}1)^{1/2}\,F(w)$
ISGW2		
LLSW		

D_1 FF plots : FF and weights

ISGW2 $F(w)$

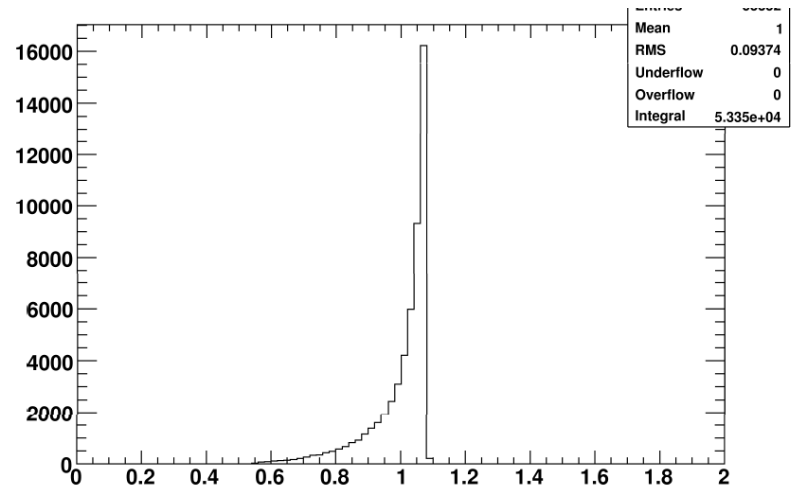


LLSW $F(w)$



Weight

$R_N = 6.51$



D_1 kinematic variables

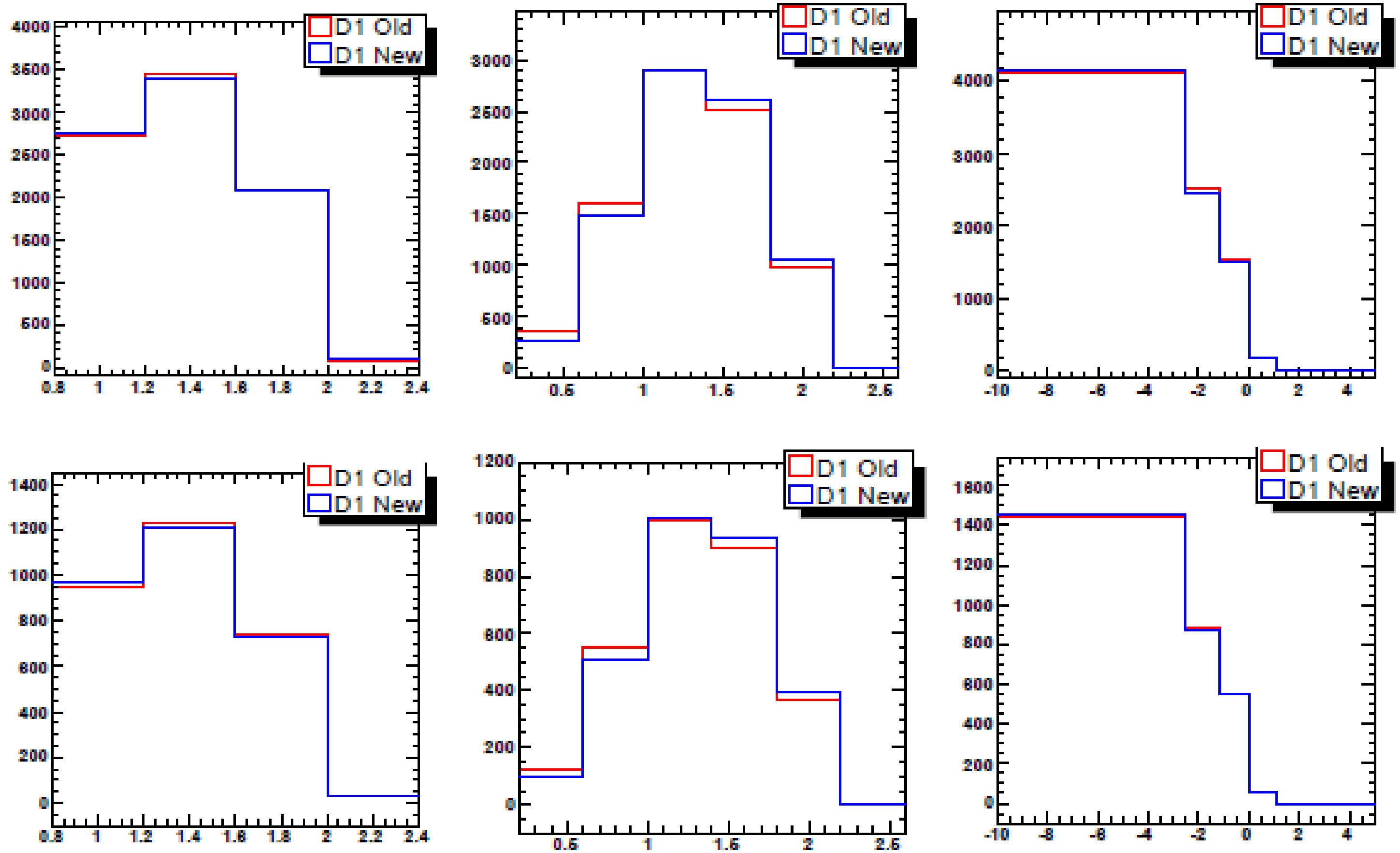
l momentum | *D* momentum | cosBY

D^0

D^+

— ISGW2

— LLSW

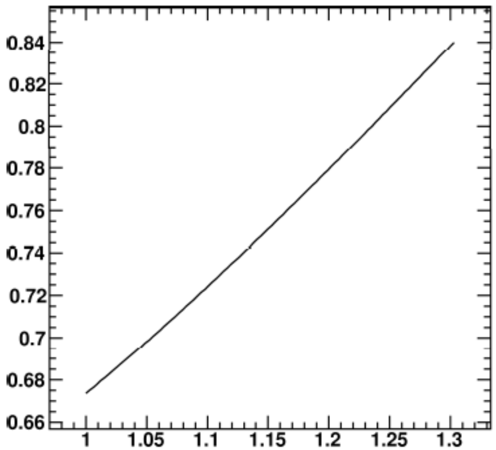


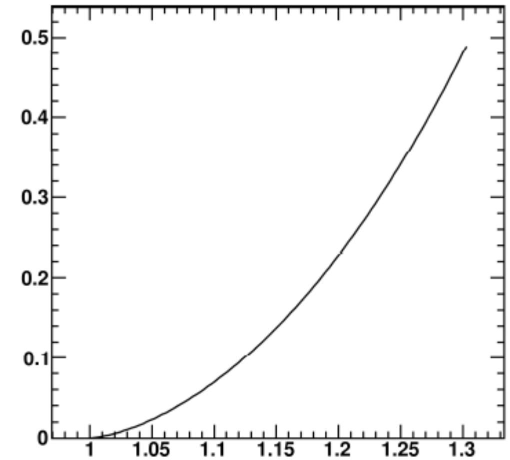
Normalized to OnPeak luminosity.

D_2* FF plots : *w* dependence

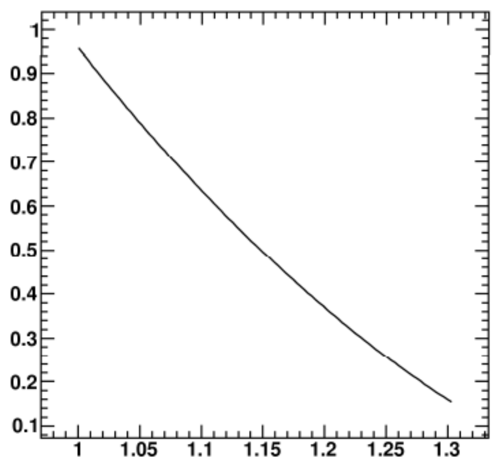
$F(w)$ | $(w^2\text{-}1)^{3/2} F(w)$

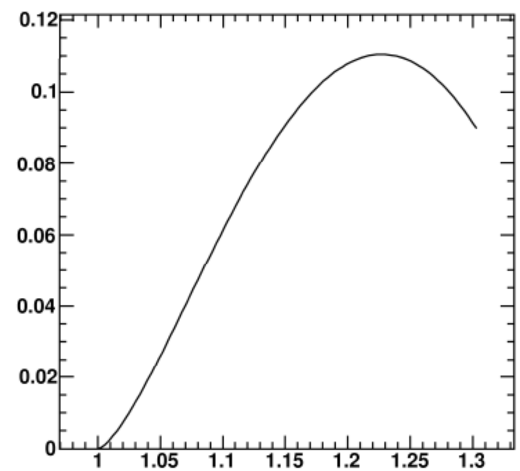
ISGW2





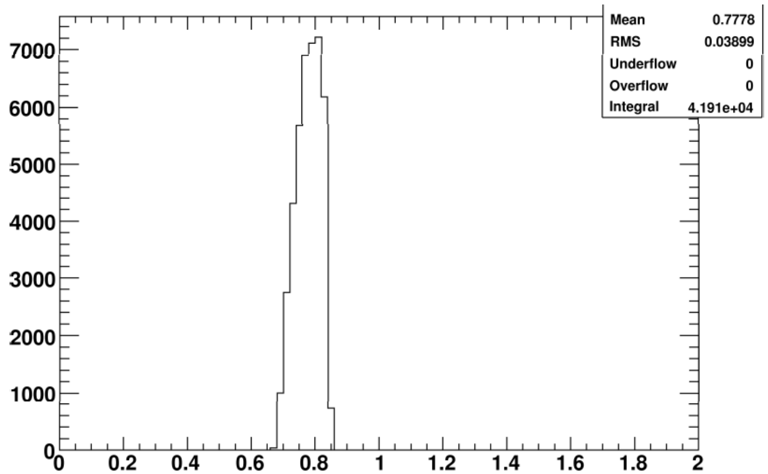
LLSW



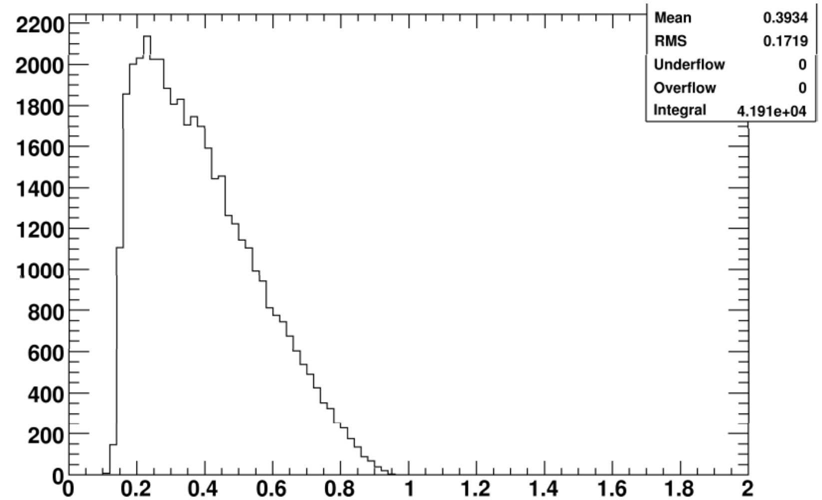


D_2* FF plots : FF and weights

ISGW2 $F(w)$

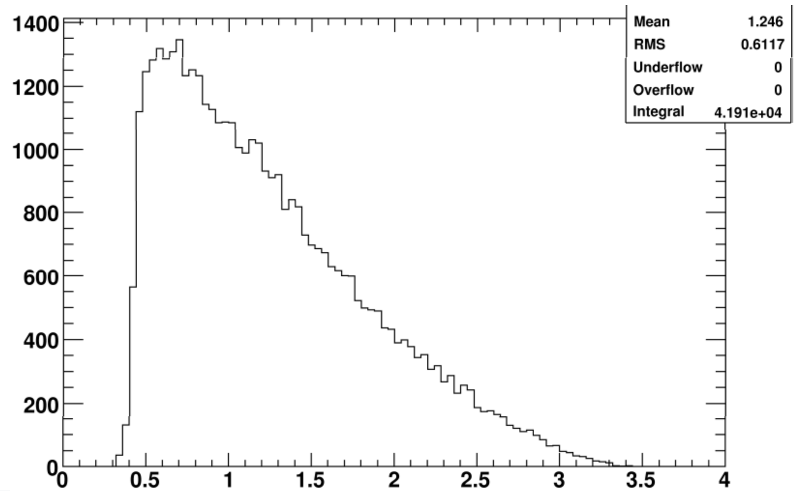


LLSW $F(w)$



Weight

$R_N = 2.40$



D_2* kinematic variables

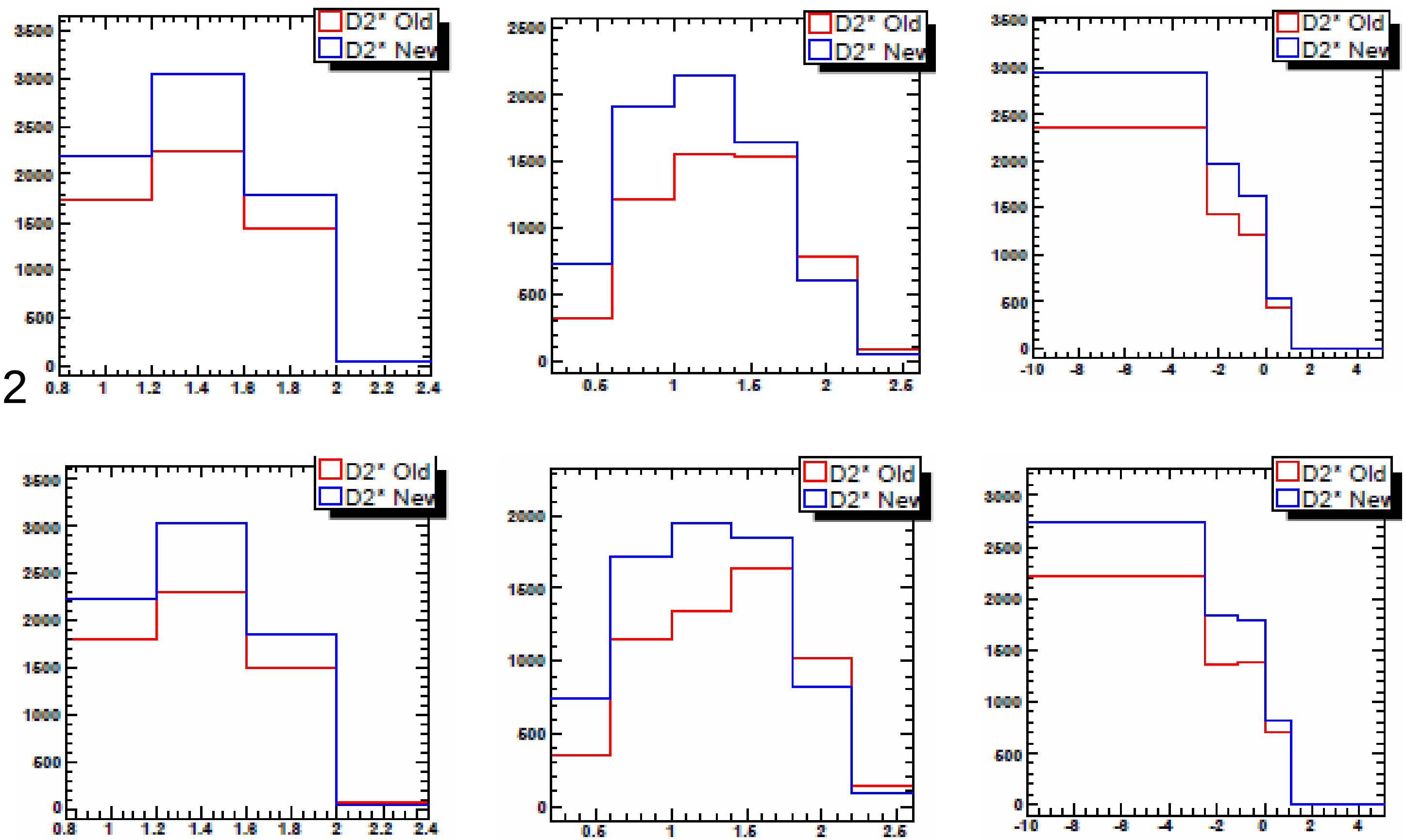
l momentum | *D* momentum | cosBY

D^0

D$^+$

— ISGW2

— LLSW



Normalized to OnPeak luminosity.

Fit Result (Run2 only)

B^+	ISGW2	LLSW
Slope	1.4959 +- 0.0049	1.4524 +- 0.0054
BR($Dl\nu$)	0.0282 +- 0.0011 (4.0%)	0.0295 +- 0.0011
BR($D^*l\nu$)	0.0591 +- 0.0015 (2.5%)	0.0610 +- 0.0015
BR(Other)	0.0221 +- 0.0011 (4.9 %)	0.0189 +- 0.0009

Difference between ISGW2 and LLSW is 3-5% (14% for BR(Other)).
Similar size to statistical uncertainty.

Chi-square did not improve much (346 -> 334, ndof=180).

ISGW2 : D^0 momentum

-10 ← cosBY → +5

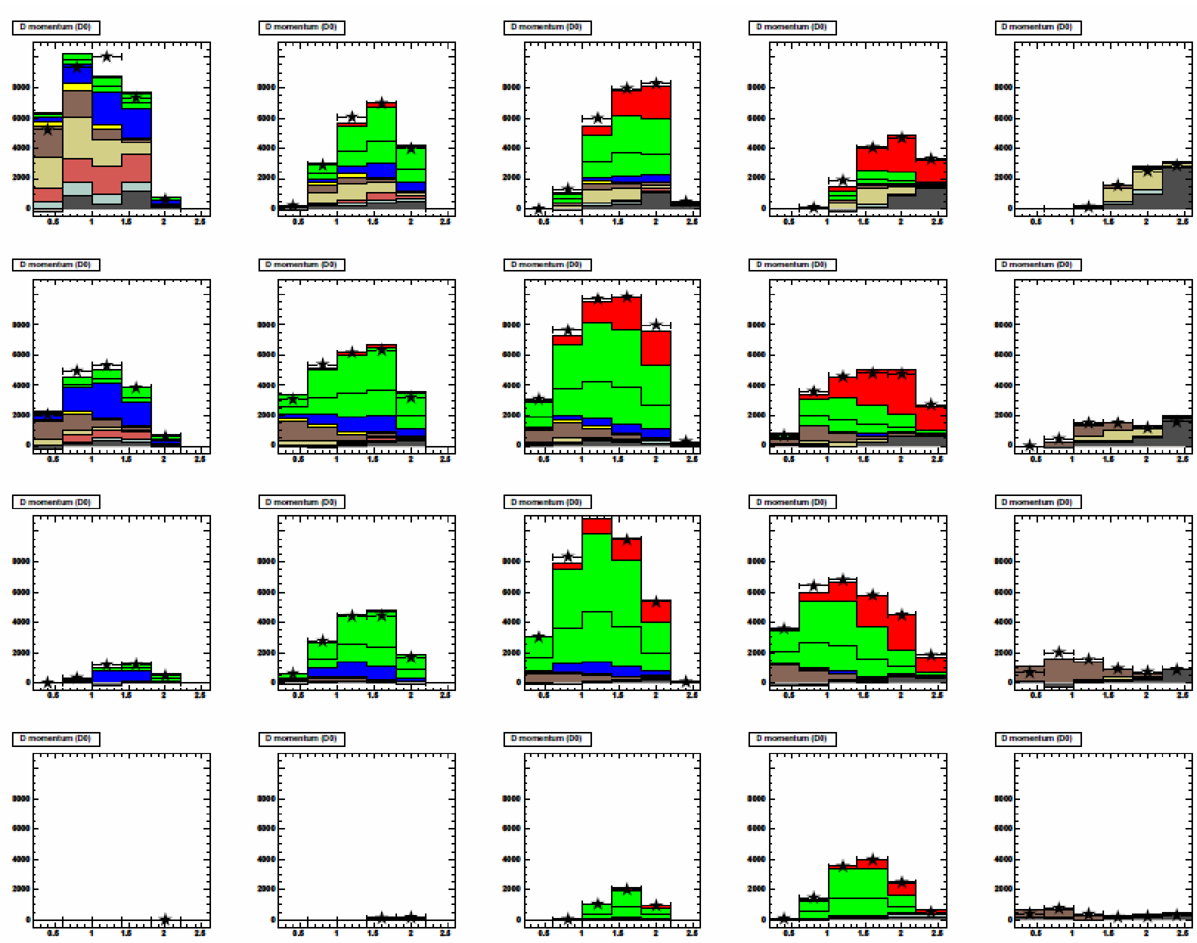
0.8 GeV

↑

p_l

↓

2.4 GeV



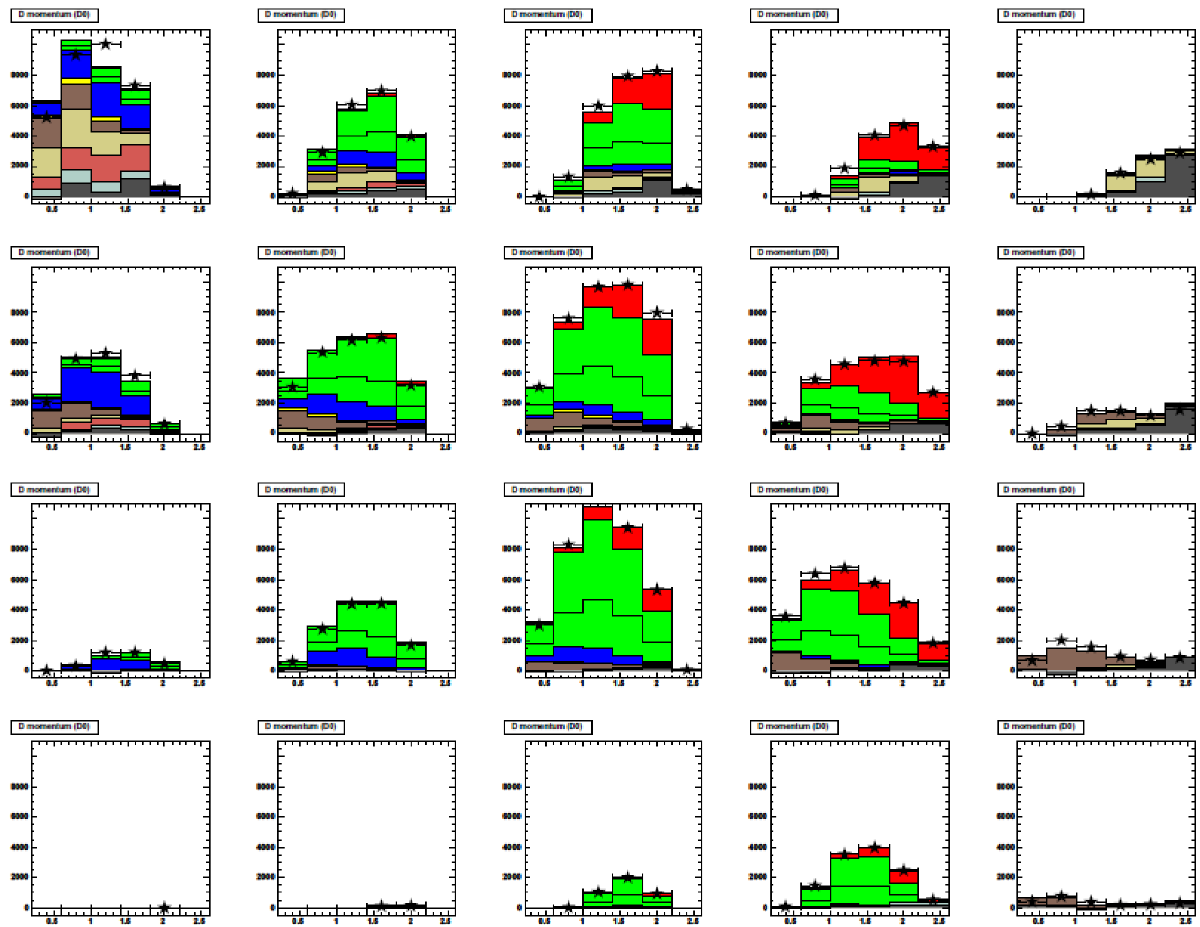
LLSW : D^0 momentum

-10 ← cosBY → +5

0.8 GeV

p_l

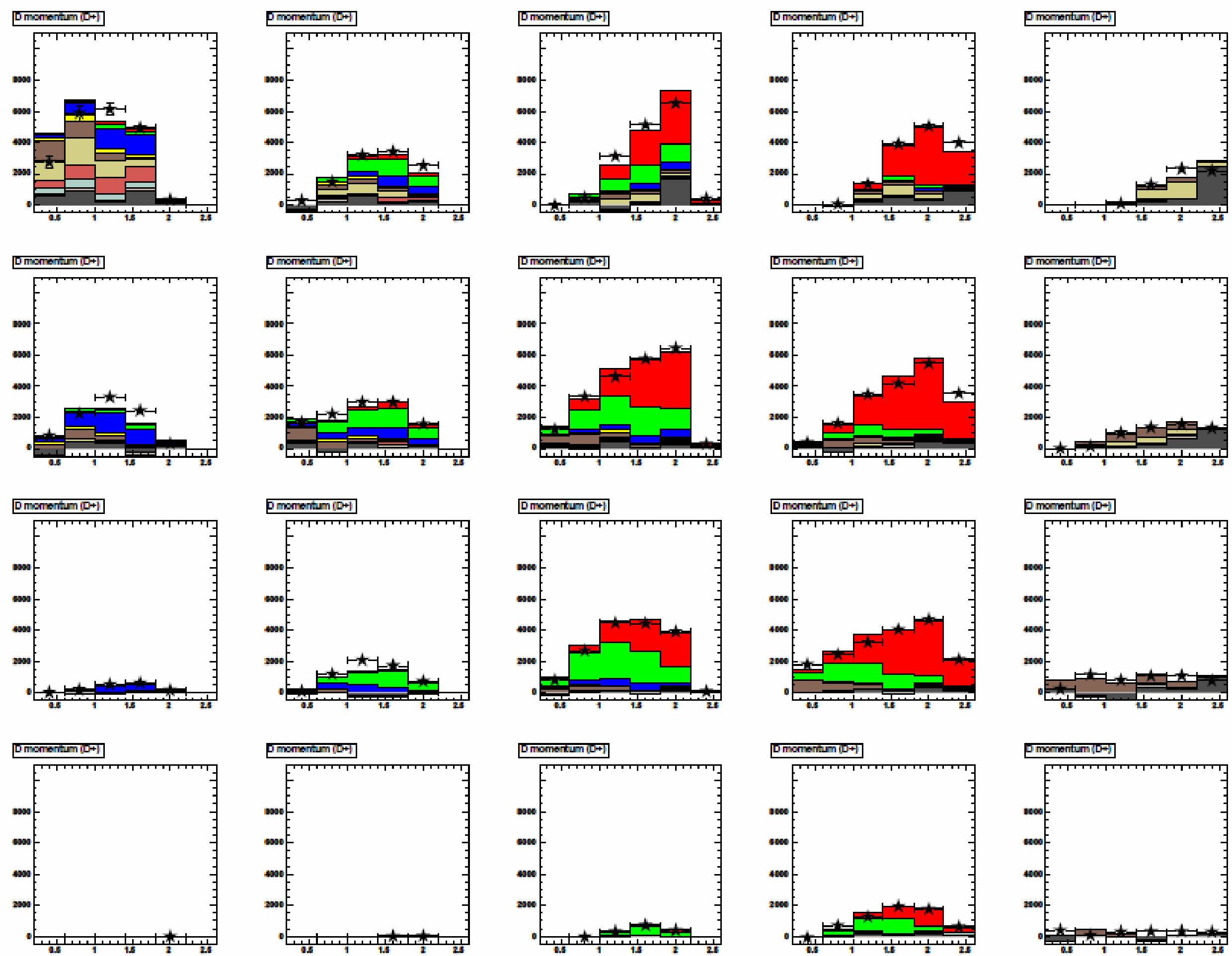
2.4 GeV



ISGW2 : D^+ momentum

-10 ⟵ cosBY ⟶ +5

0.8 GeV ↑ p_l ↓ 2.4 GeV



LLSW : D^+ momentum

-10 ← cosBY → +5

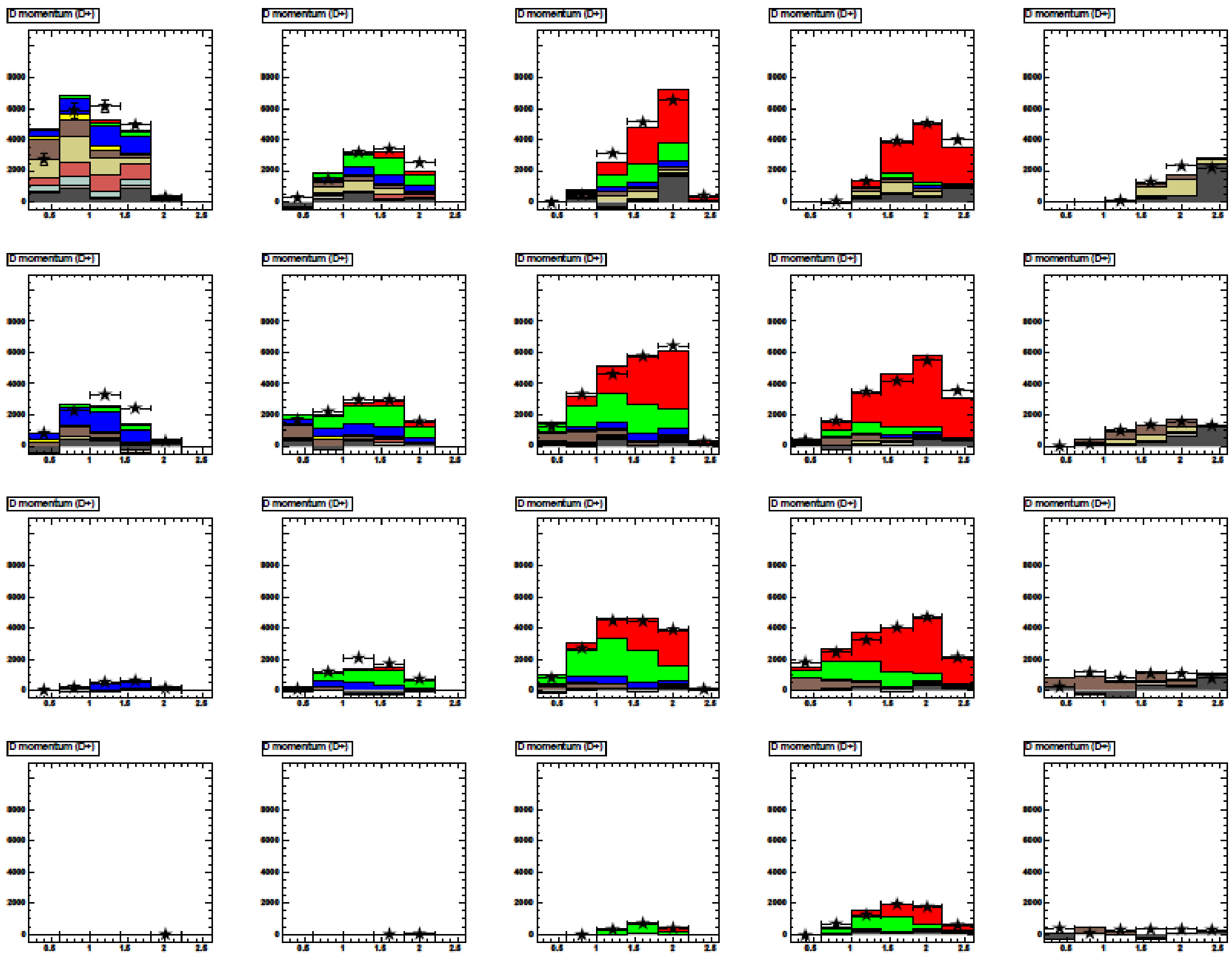
0.8 GeV

↑

p_l

↓

2.4 GeV



Summary

- A lot of questions on LLSW model:
  - Plots look as those should do?
  - Best formula?
  - Appropriate numerical values?
  - How much those values can be varied?
- 3-5% effect on fit results
  - Current fit code may have a small bug....
- BAD1586 V2 will be ready soon.
  - Details of FF and re-weighting are in the BAD.