A simultaneous analysis of $B \to D\ell\nu$ and $B \to D^*\ell\nu$ decays

M. Dorigo and M. Mantovano
(University and INFN Trieste)

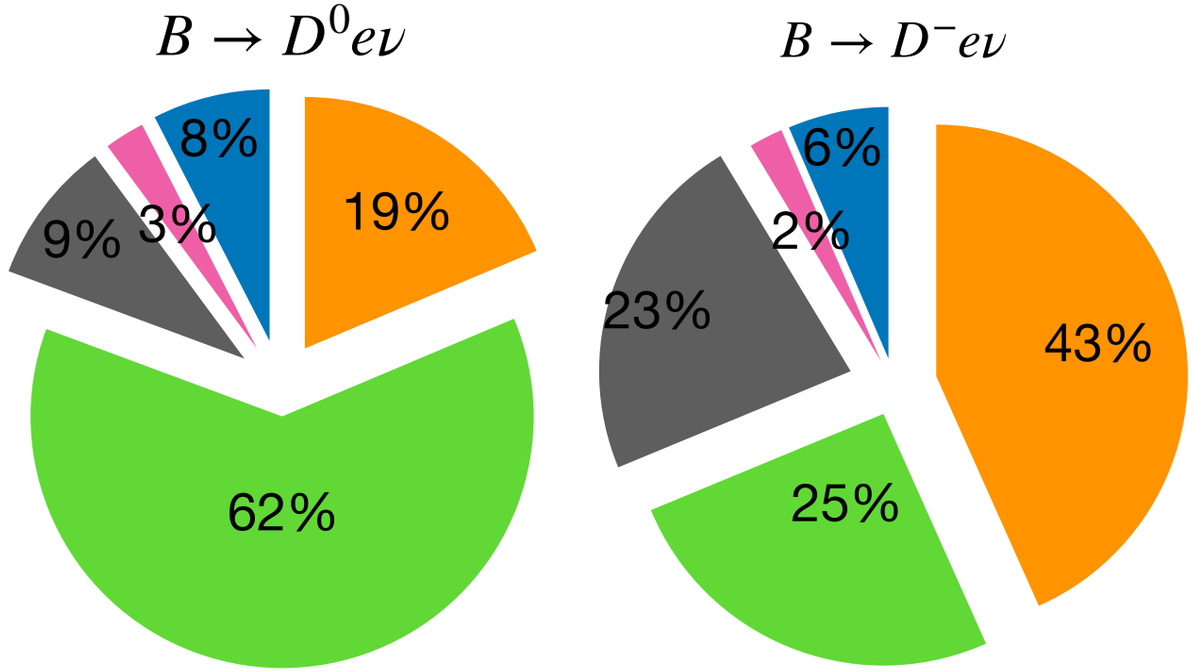
TS Analysis Meeting
June 24, 2024

Sample composition

Divide $B \to D\ell\nu$ samples in 6 components:

1. $B \to D\ell\nu$;
2. $B \to D^*\ell\nu$;

signal



3. $B \to X\ell\nu$ + gap modes, where X is D^{**}, $D^{(*)}\tau\nu$ + lepton (real or fake);

need a validation

4. Real D: real D + lepton (real or fake);

Detailed composition study using a wrong charge channel

5. Fake D: a random $K\pi/K\pi\pi$ combination + lepton (real or fake);
6. Continuum: background from $e^+e^- \to q\bar{q}$, $q \in [u, d, c, s]$.

constrained from data:
using D mass sideband + off-res

New selection

Full selection in backup

- Removed cuts on variables with a large data/MC disagreement:

  1. M(ROE)<5.2 GeV for $D^{-}\ell\nu$, M(ROE)<6 GeV for $D^{0}\ell\nu$.

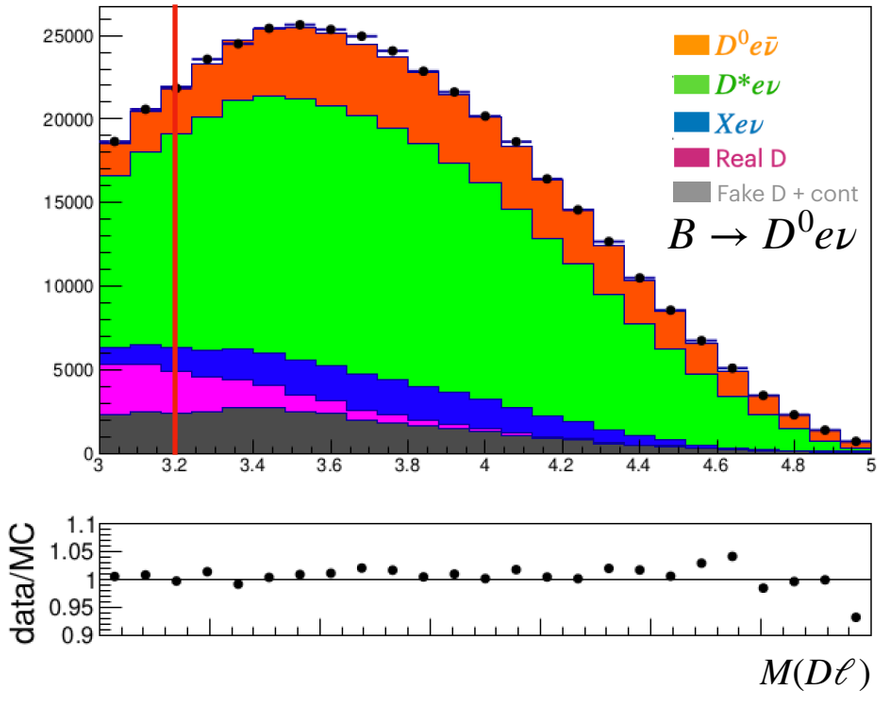
  2. KakunoFoxWolfram(h20)>0.18 (removed only for $D^{0}\ell\nu$ sample).

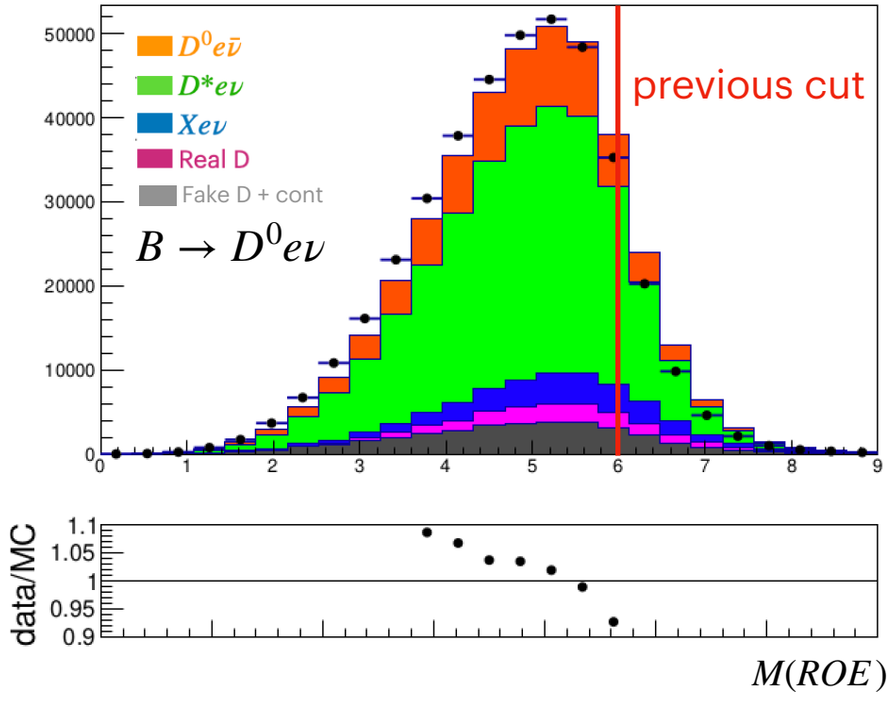
- New cut on $M(D\ell)$>3.2 GeV to further reduce the real D component.

- Removed the tight cut on TreeFitter χ^2 (> 5%) probability; replaced by χ^2 > 1%.

- Cut on $p(\pi)$>0.35 GeV (only for $D^{-}\ell\nu$ sample) to remove the systematic due to slow tracks.

- Removed nCDCHits>20 cut for mesons (K/π): not required anymore for PID corrections.





$X\ell\nu$ component
Electron sample

$X\ell\nu$ composition

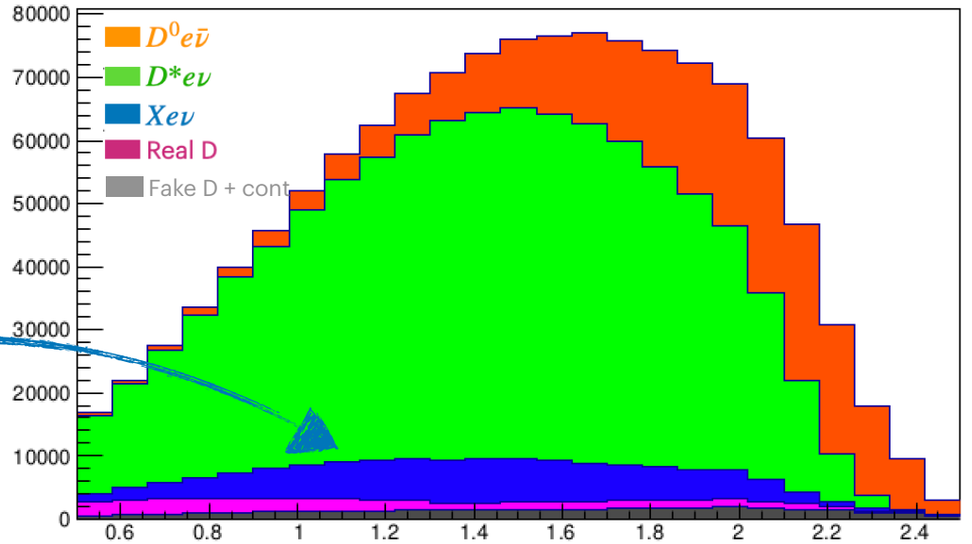
Studied the $X\ell\nu$ component after the BR and gap modes corrections.

Divided the $X\ell\nu$ component in different sub-components:

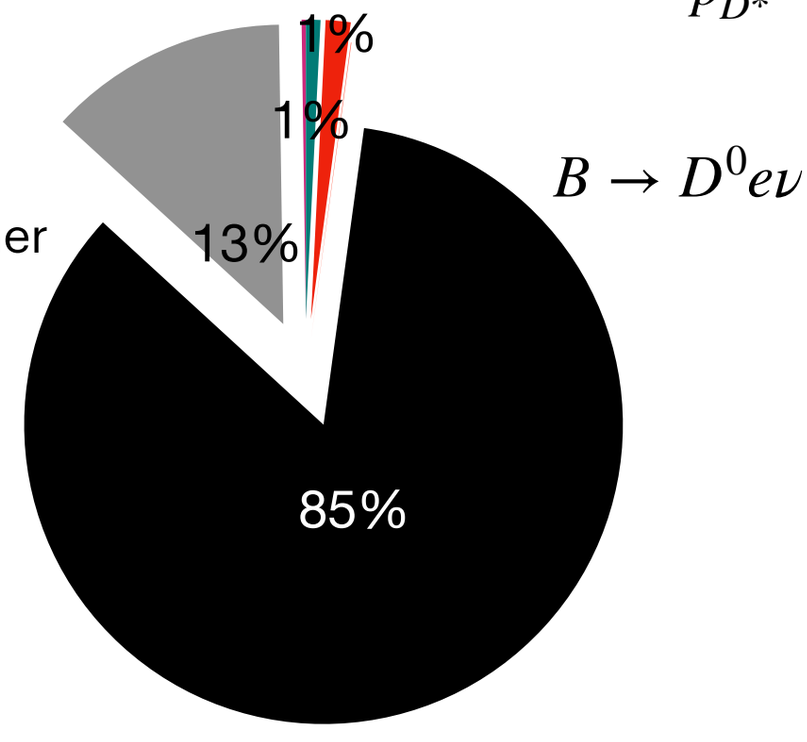
1. $D^{**}\ell\nu$
2. Gap modes
3. $D^{*}\tau\nu$
4. $D\tau\nu$
5. $D^{(*)}\ell\nu$, ℓ= misID lepton
6. $D^{**}\tau\nu$

$X\ell\nu$ component

$B \to D^0 e\nu$



Similar proportions for the other samples (see backup)



$X\ell\nu$ component dominated by $D^{**}\ell\nu$ and gap modes decays.

$X\ell\nu$ validation

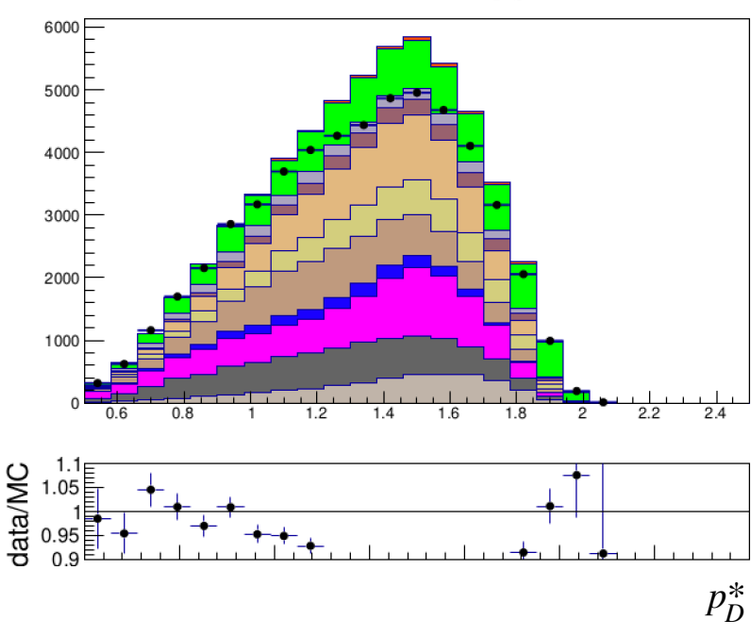
Found a $cos\theta_{BY}$ sideband region [-12,-3] to validate these decays.

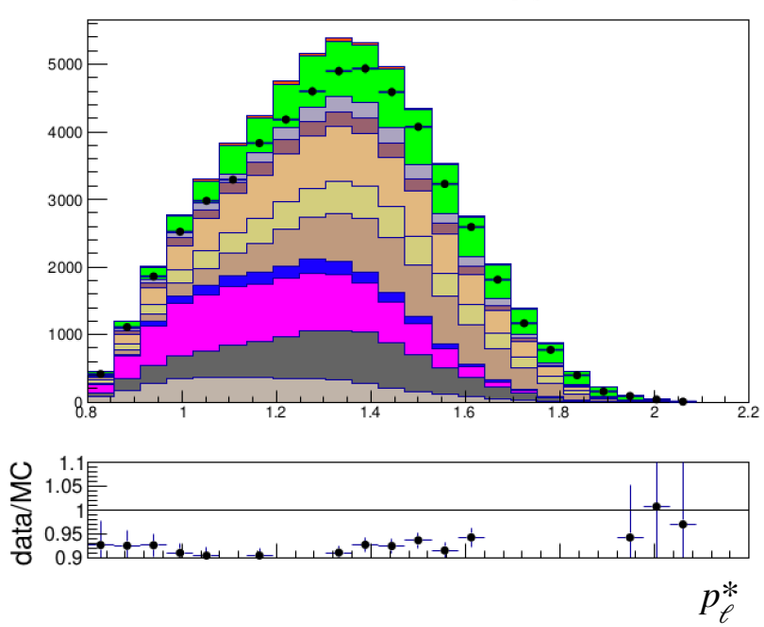
continuum
fake D
$D\ell\nu$
$D^*\ell\nu$
$D_1\ell\nu$
$D_0^*\ell\nu$ (no gap)
$D_1\ell\nu$ (no gap)
$D_2^*\ell\nu$
gap modes
$X\ell\nu$ (rest)
real D

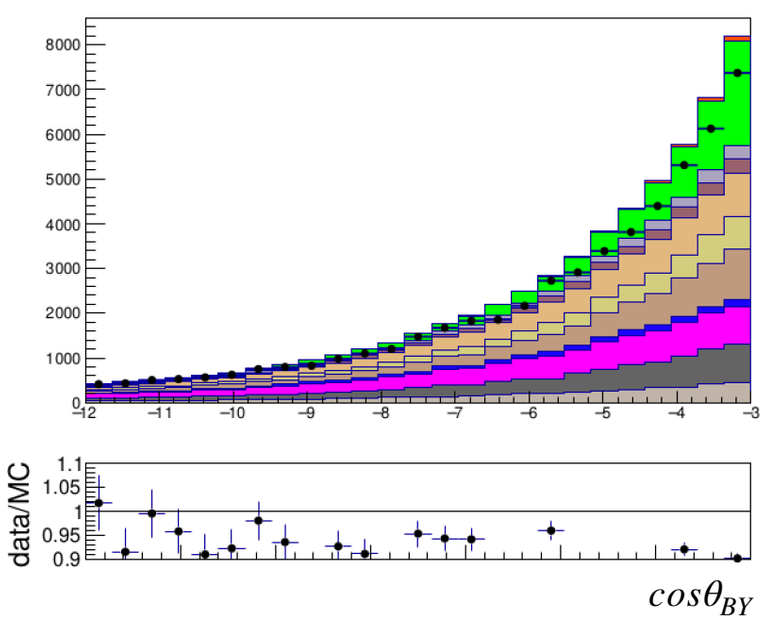
Take them from off-res data and InvM(D) sideband.

$D^{**}\ell\nu$

enriched $X\ell\nu$ decays in the $cos\theta_{BY}$ sideband







Data/MC disagreement observed in the $cos\theta_{BY}$ sideband.

Simultaneous fit

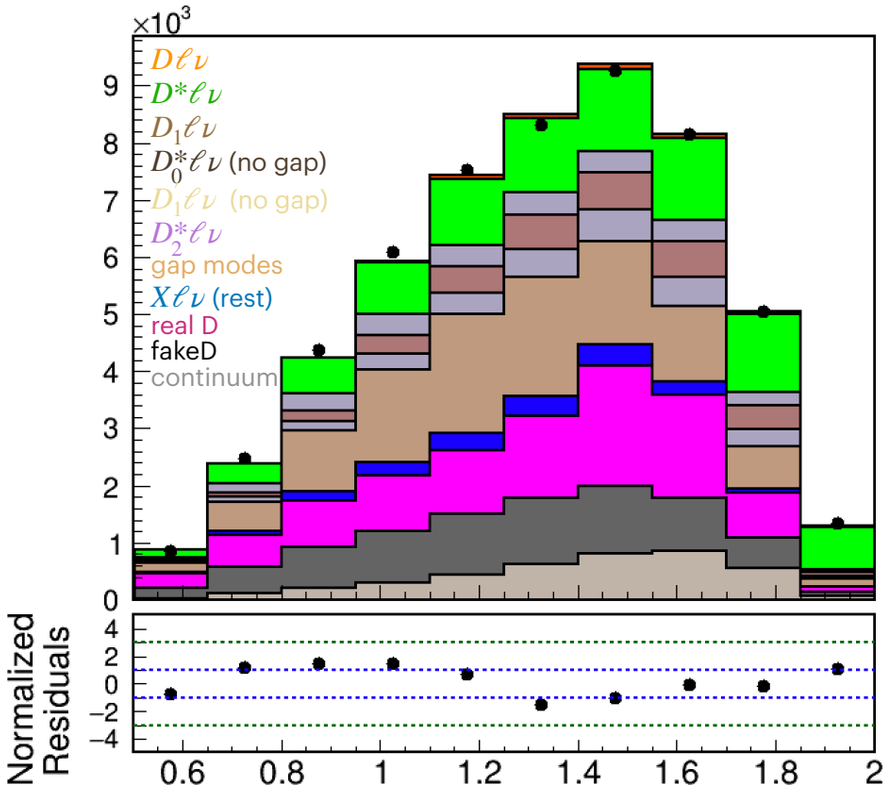
- Fit the $X\ell\nu$ component in the $cos\theta_{BY}$ sideband region to constrain these decays.
- Perform a 2D simultaneous fit between D^0 and D^- samples using (p^*_D, p^*_ℓ) variables.
- Real D components free in the fit, all the others are fixed.
- Gaussian constraints on $D_1, D_1^{'}, D_2, D_0^*$ BR with the corresponding uncertainties:

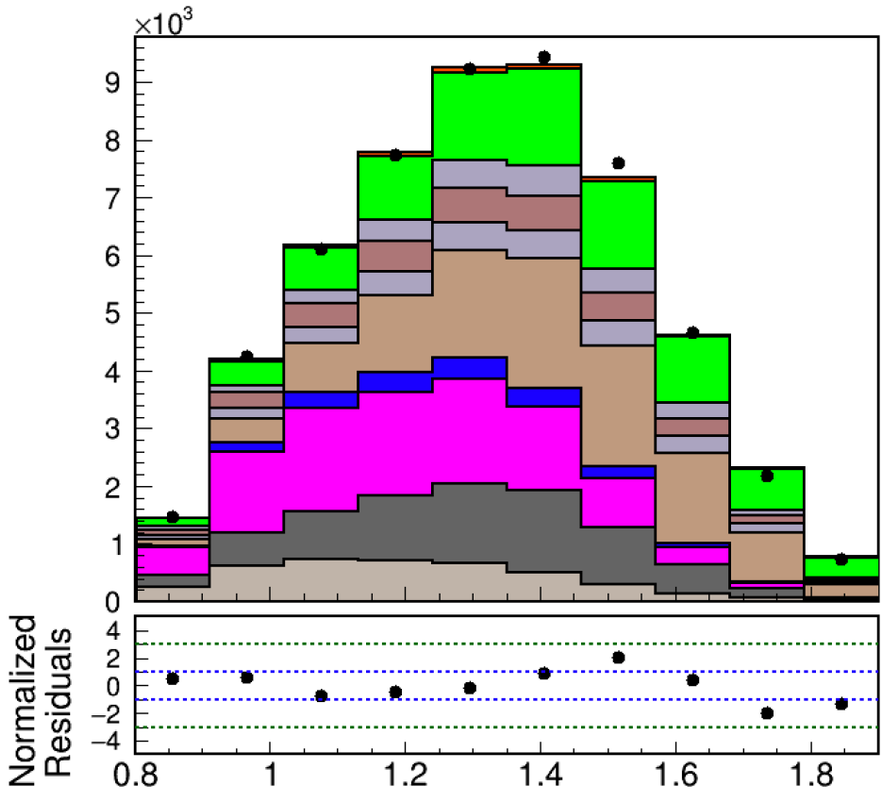
  1. D_1 gaussian constraint (unc. 16%)
  2. D_0 gaussian constraint (unc. 18%)
  3. $D_1^{'}$ gaussian constraint (unc. 21%)
  4. D_2 gaussian constraint (unc. 11%)

- Assume isospin symmetry to link the BR on the constraints between B^+ and B^0 samples.
- For this test, the BR of gap modes is fixed to 0 since a fit using it as gaussian constraint (unc. 100%) returns a value compatibile with 0.

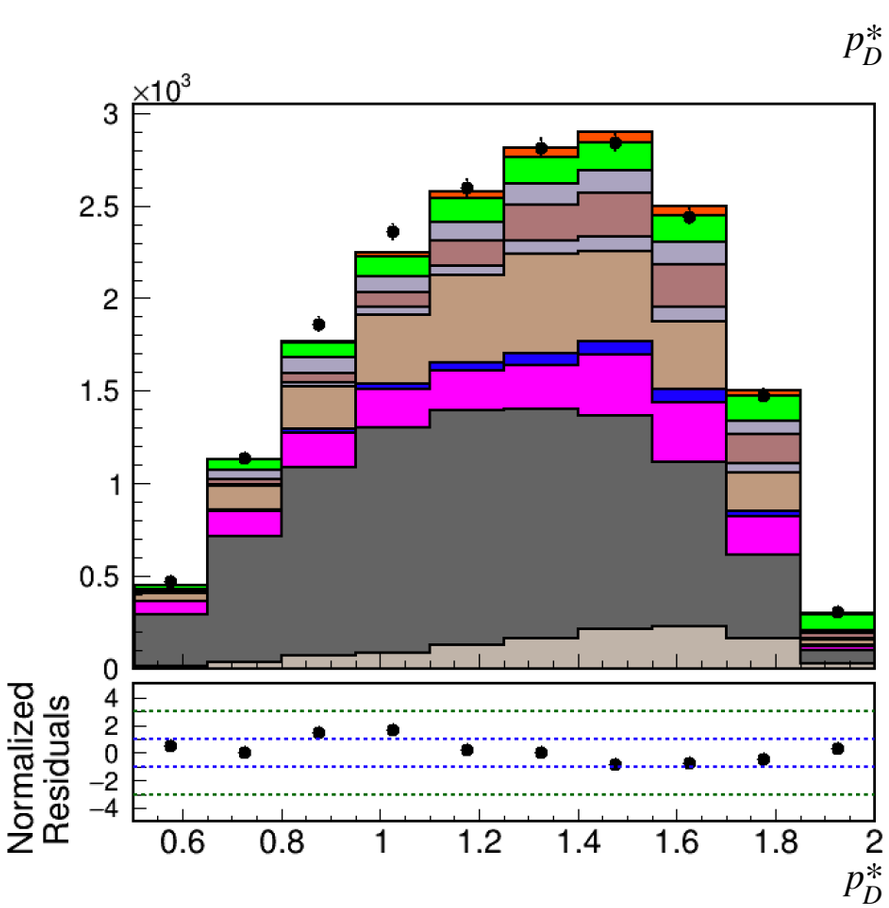
Projections

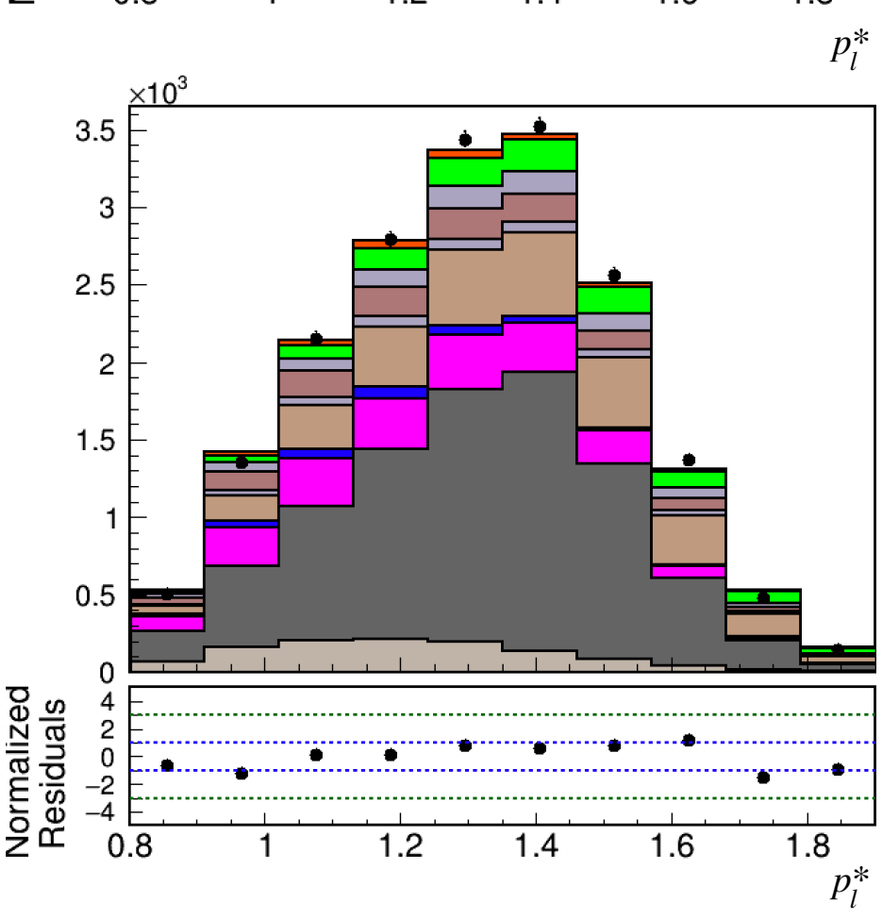
$D^0 e\nu$





$D^- e\nu$





Fit results

The simultaneous fit returns the following results:

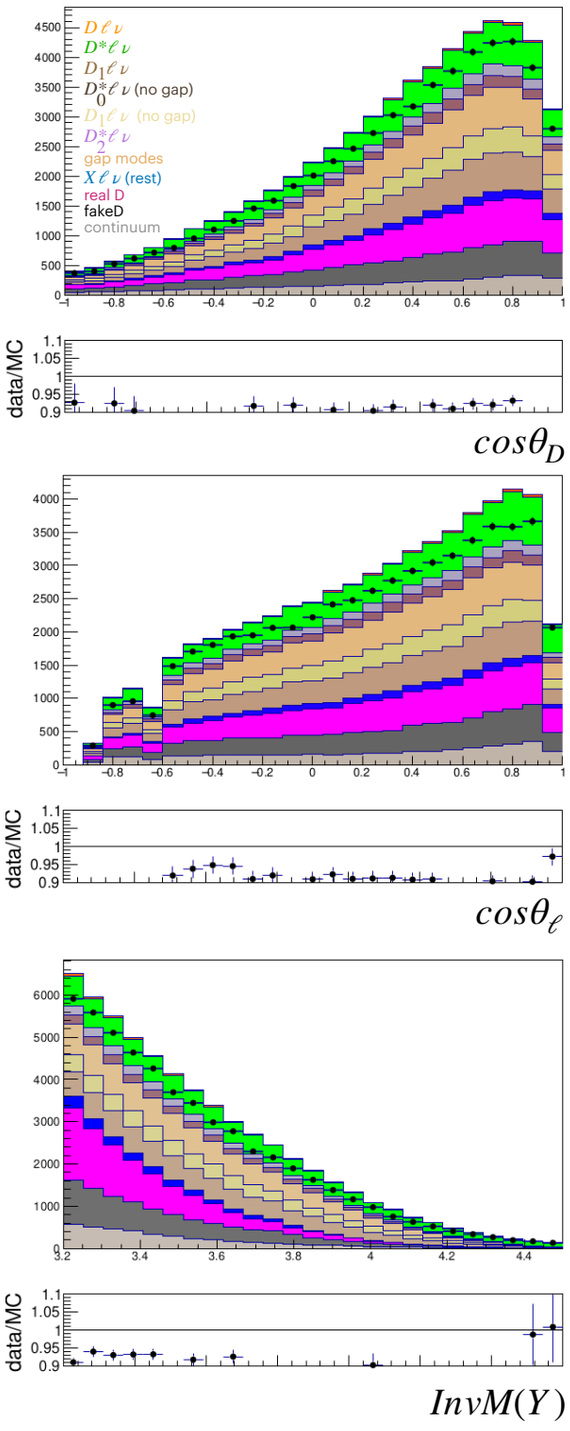
Fit parameters	Expected values	Fit results	relative unc.	Fitted/Expected
$\mathcal{B}(B \to D_1 \ell \nu)$	0.66%	(0.97 +- 0.05)%	5.4%	1.38
$\mathcal{B}(B \to D_1^{'} \ell \nu)$	0.42%	(0.33 +- 0.07)%	21.1%	0.84
$\mathcal{B}(B \to D_0^{*} \ell \nu)$	0.42%	(0.30 +- 0.05)%	16.2%	0.75
$\mathcal{B}(B \to D_2 \ell \nu)$	0.29%	(0.32 +- 0.03)%	9.9%	1.08
$realD(D^0 e\nu)$	9268	9998.5 +- 540.5	5.4%	1.08
$realD(D^- e\nu)$	1890	1936.2 +- 190.9	9.8%	1.02

Use the fit results to scale the D^{**} and real D components.

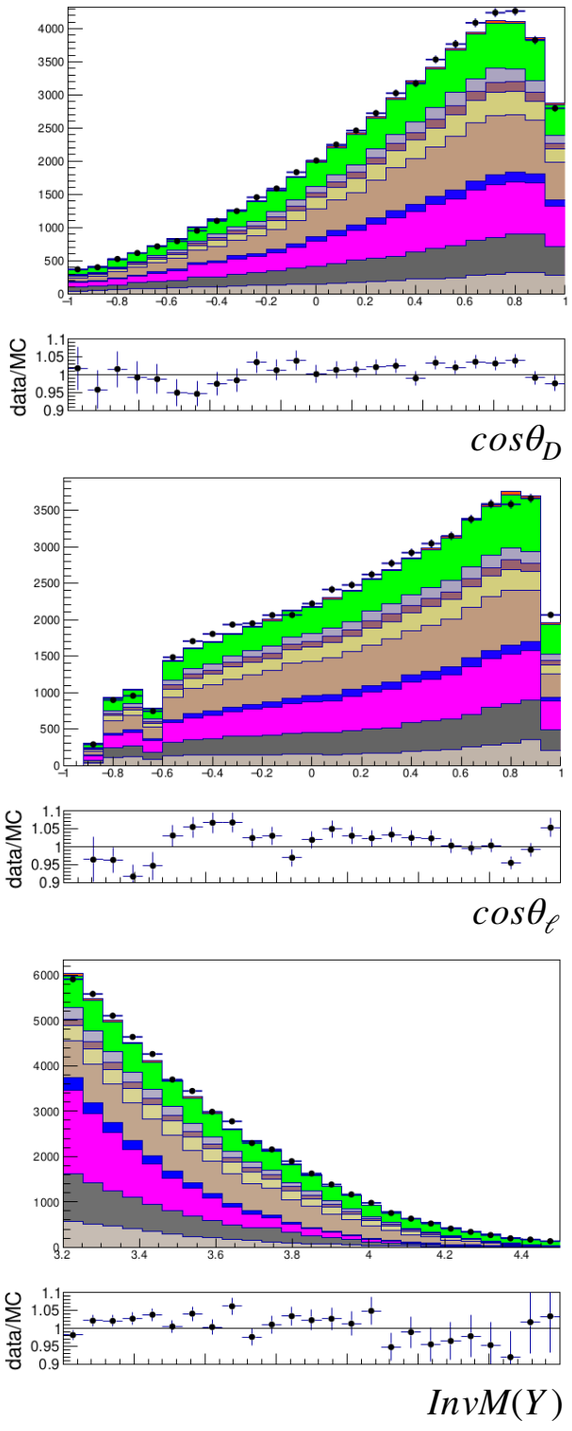
Data/MC agreement: $D^0 e\nu$ sample

Check data/MC agreement after scaling D^{**} and real D components according to the fit results.

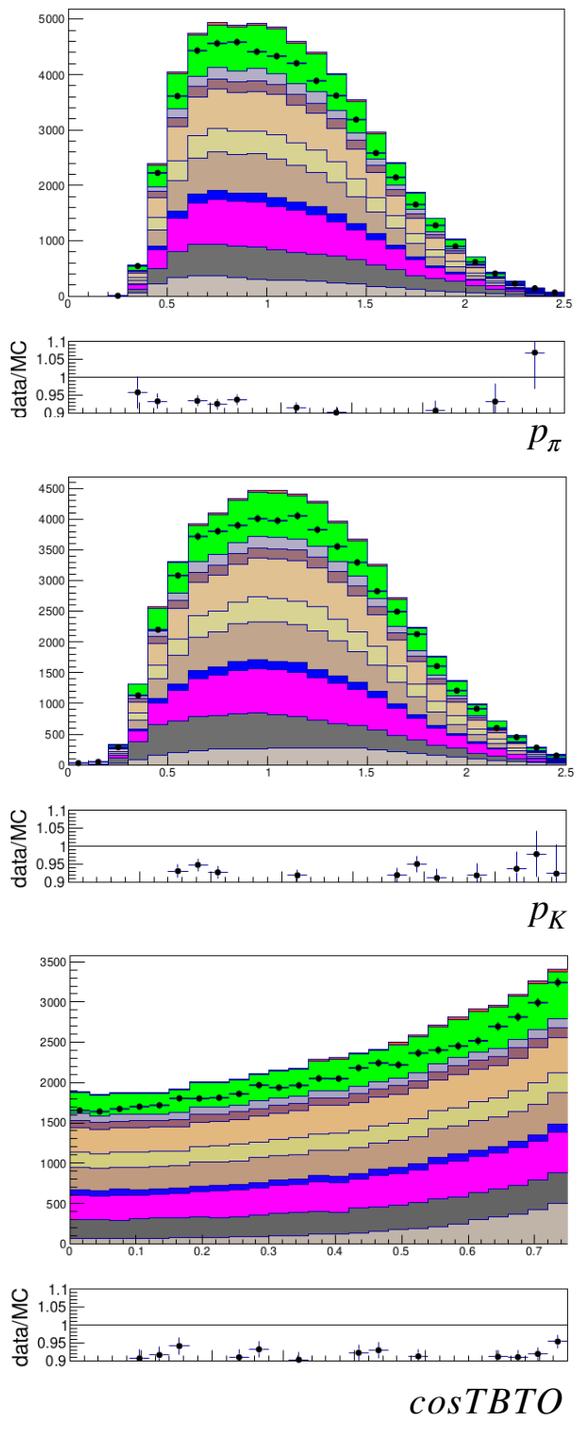
Before



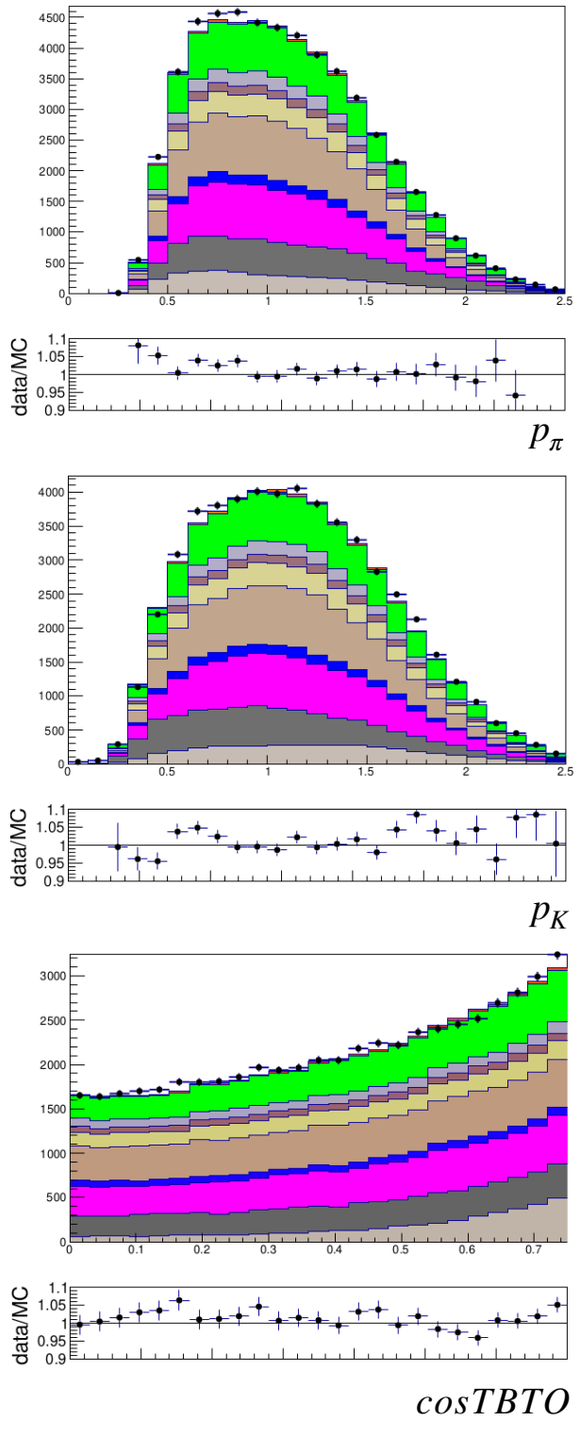
After



Before



After

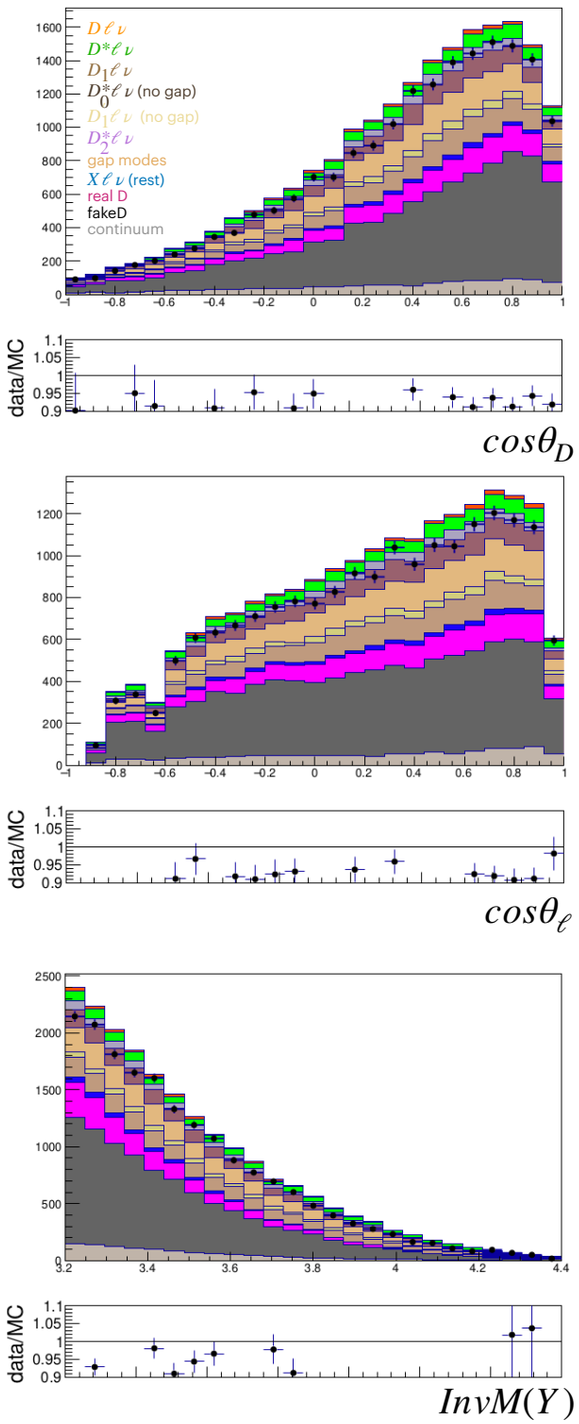


Data/MC agreement improves after scaling D^{**} and real D components.

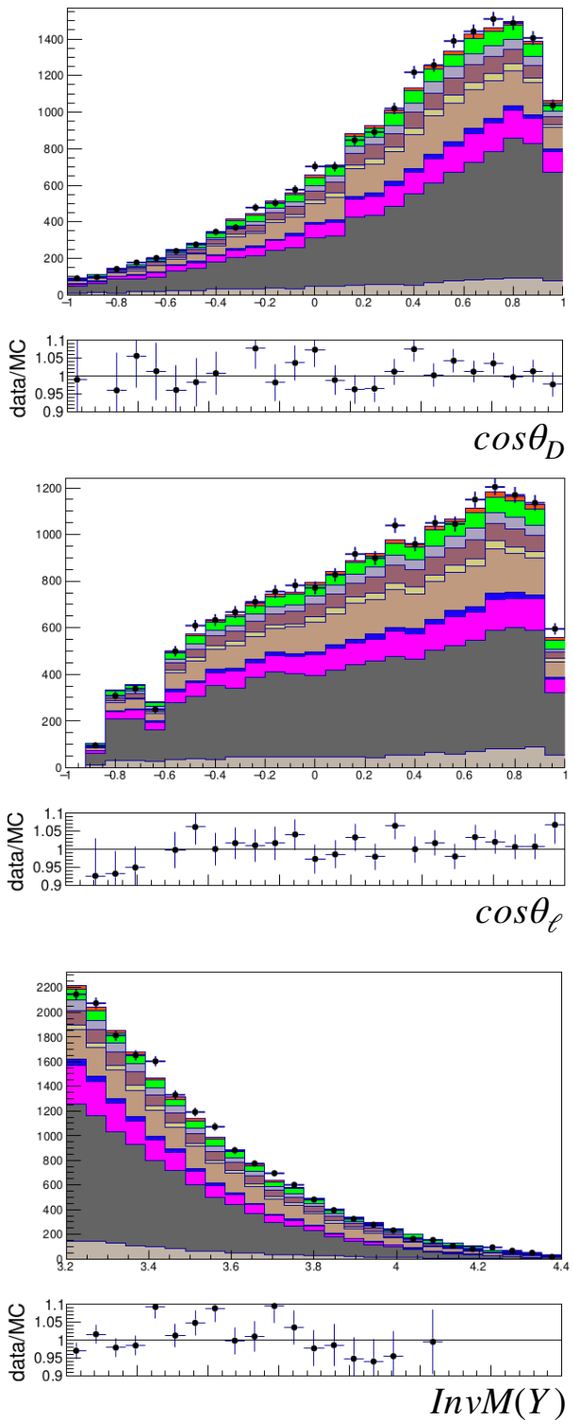
Data/MC agreement: $D^{-}e\nu$ sample

Check data/MC agreement after scaling D^{**} and real D components according to the fit results.

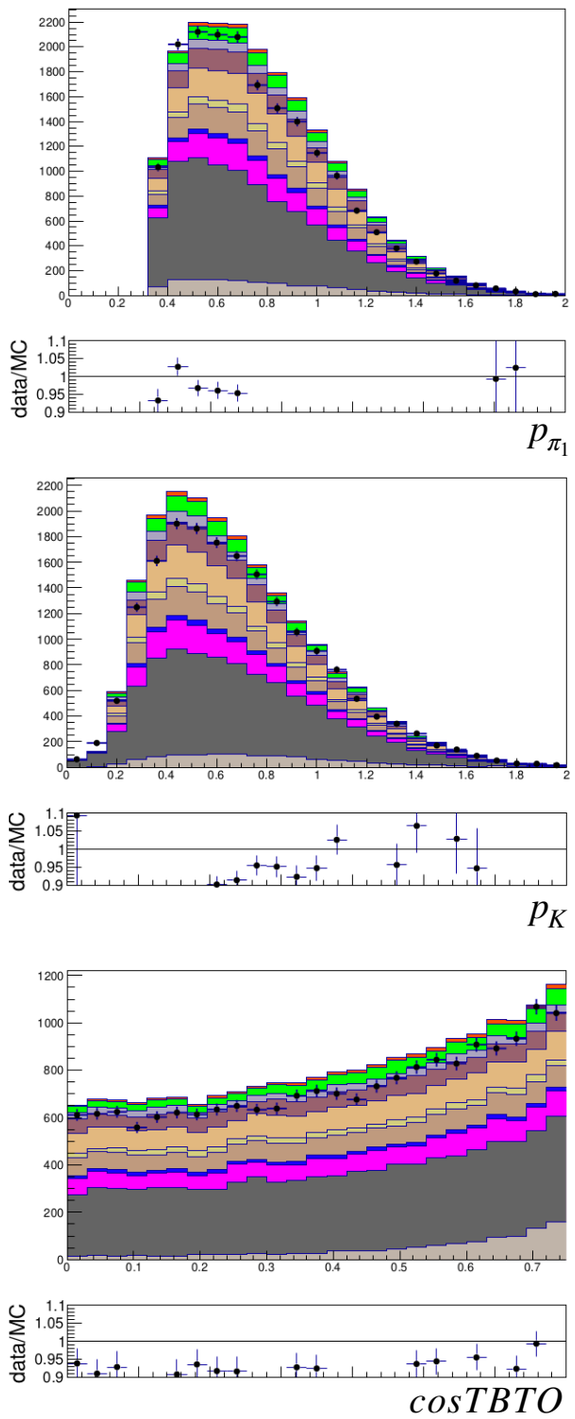
Before



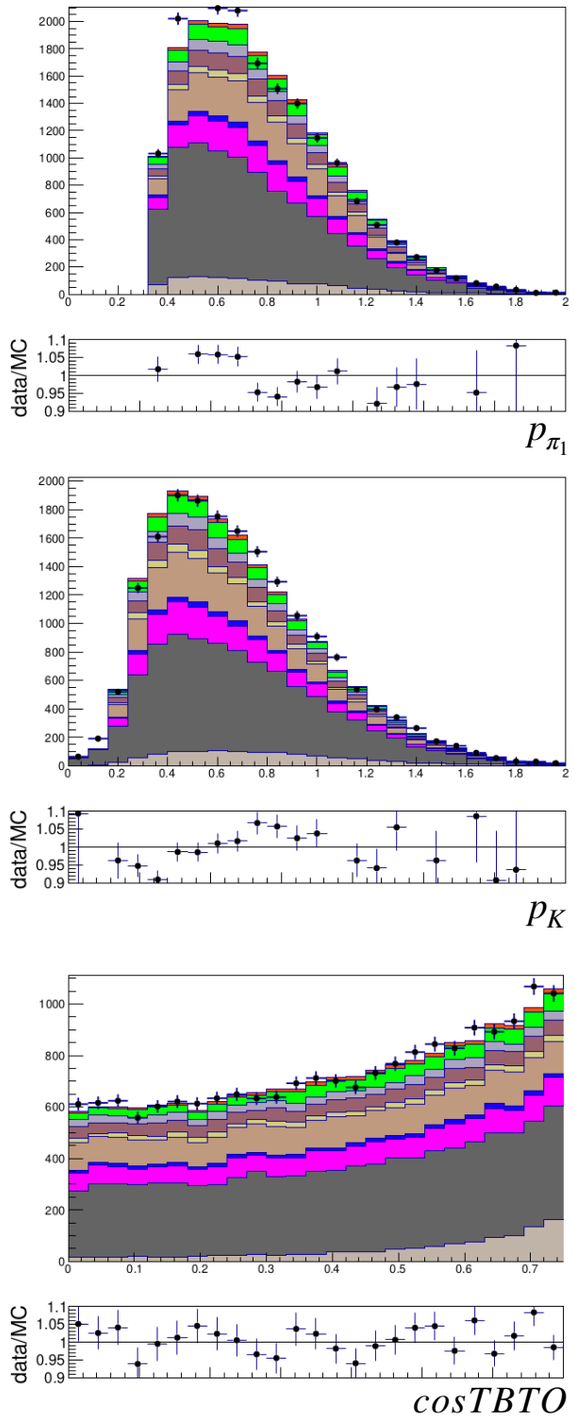
After



Before



After



Data/MC agreement improves after scaling D^{**} and real D components.

Muon sample

Simultaneous fit

- Studied the $X\ell\nu$ component after the BR and gap modes corrections.
  Divided the $X\ell\nu$ component in different sub-components.

- Fit the $X\ell\nu$ component in the $cos\theta_{BY}$ sideband region to constrain these decays.

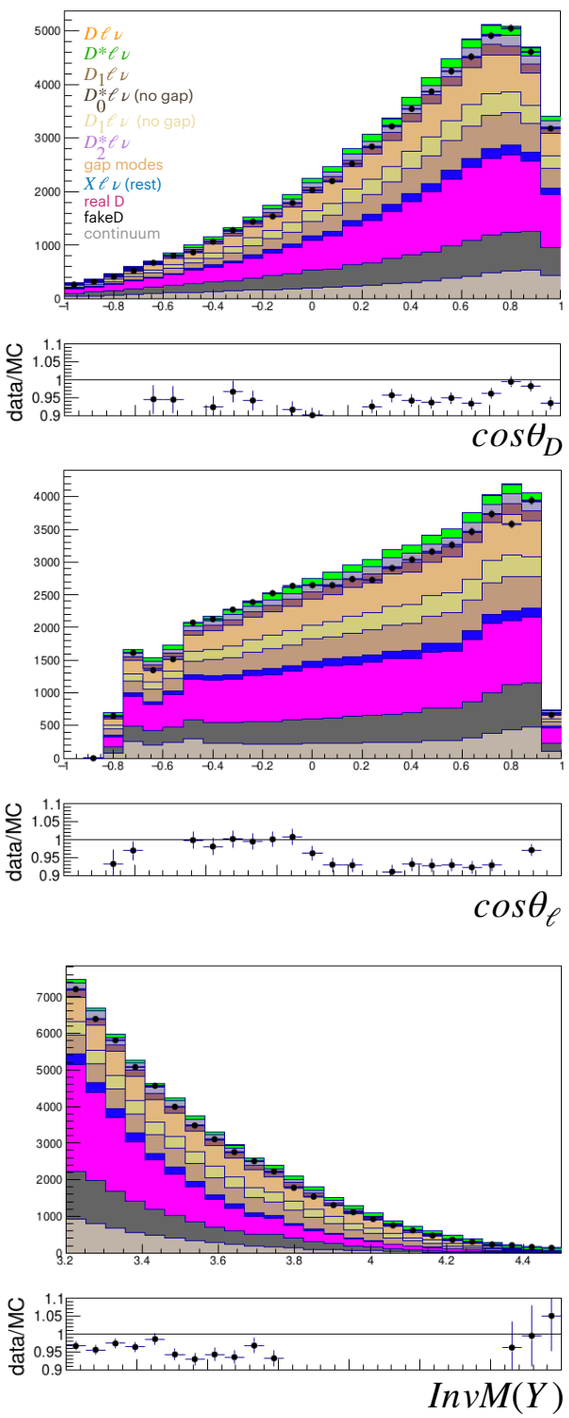
- Perform a 2D simultaneous fit between D^0 and D^- samples using (p^*_D, p^*_ℓ) variables.

- Real D components free in the fit, all the others are fixed.
- Gaussian constraints on $D_1, D_1^{'}, D_2, D_0^*$ BR with the corresponding uncertainties:

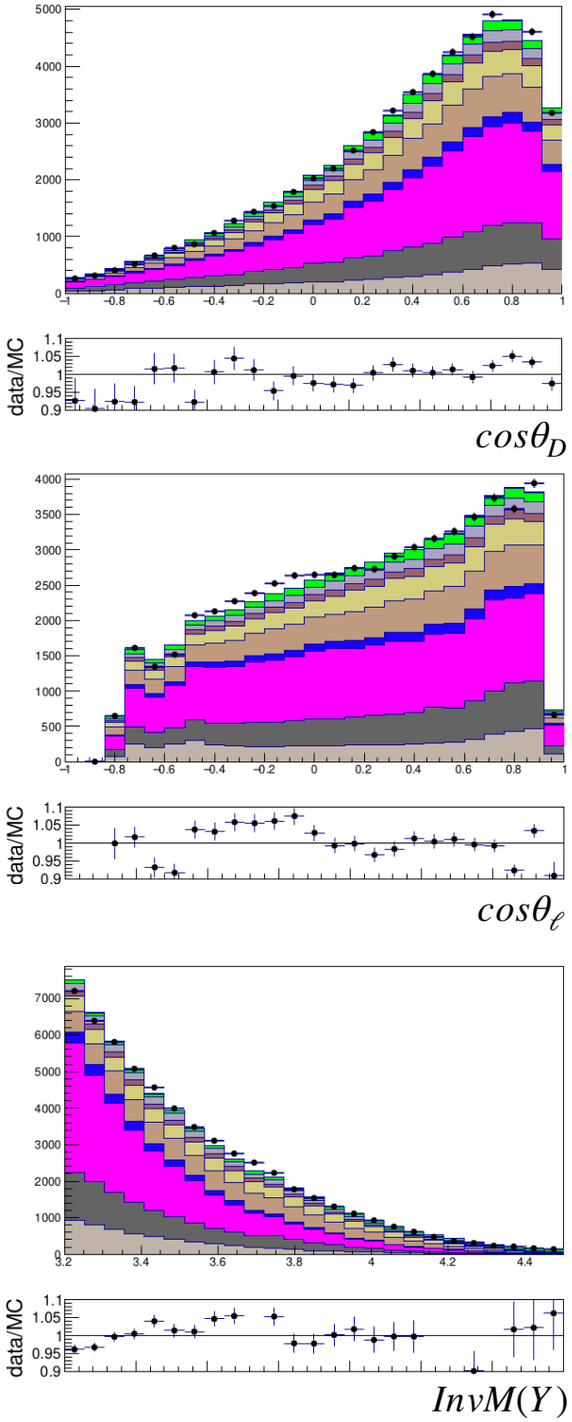
Data/MC agreement: $D^0\mu\nu$ sample

Check data/MC agreement after scaling D^{**} and real D components according to the fit results.

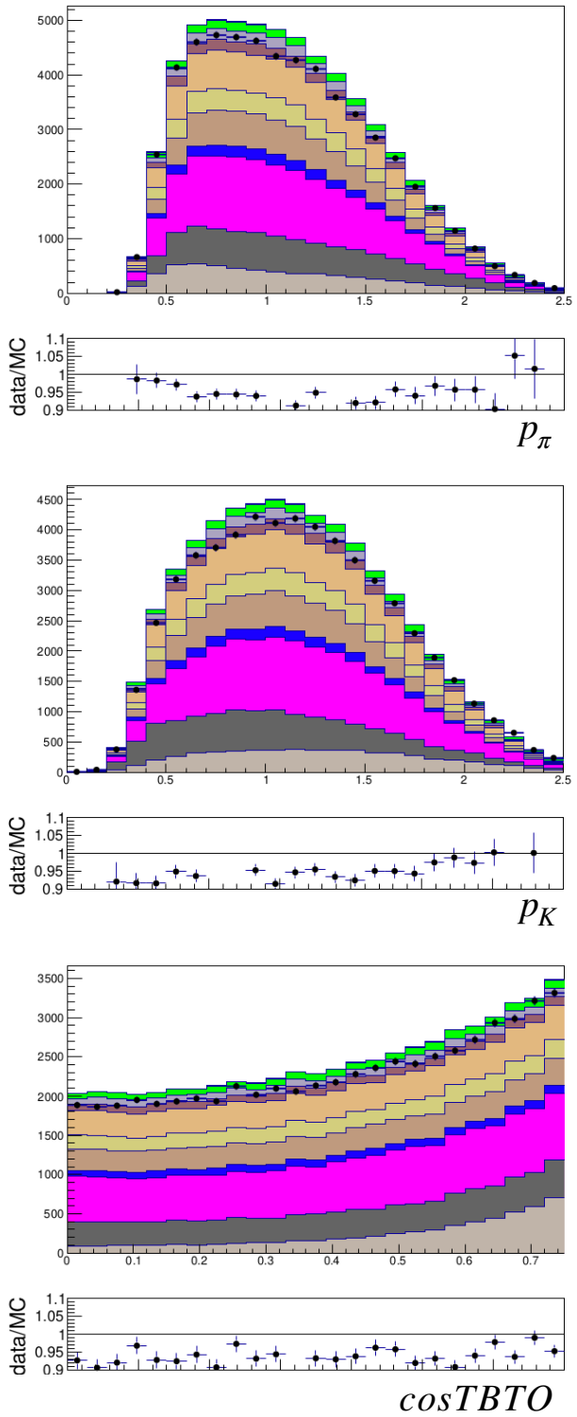
Before



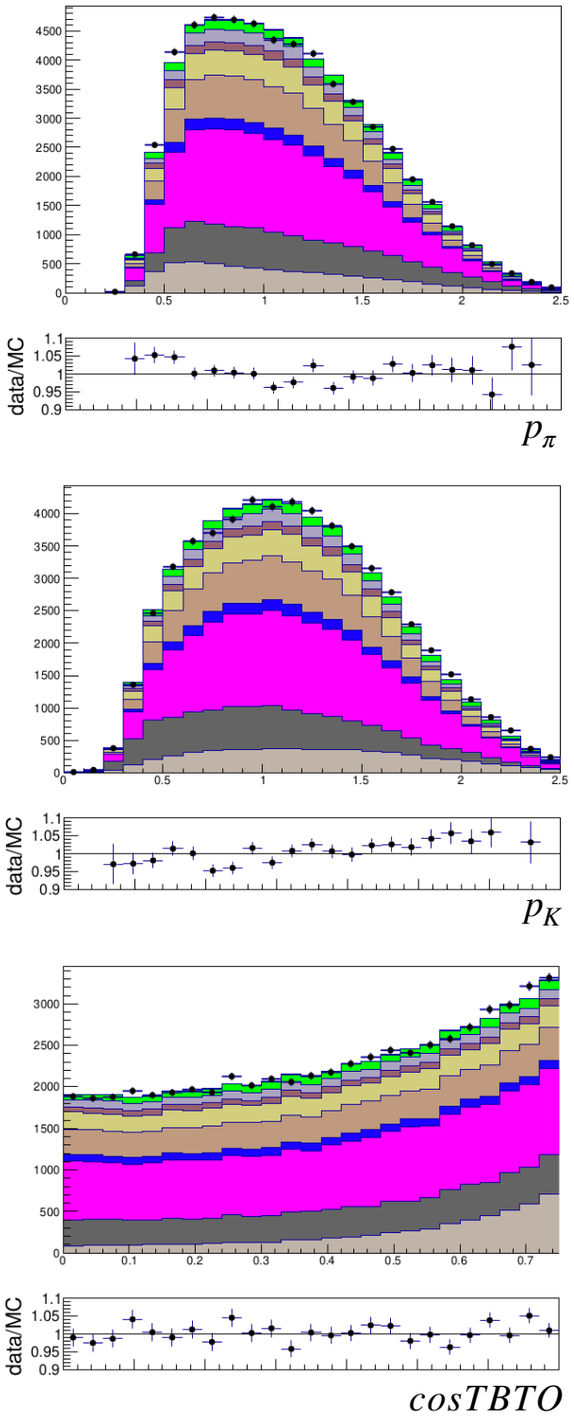
After



Before



After

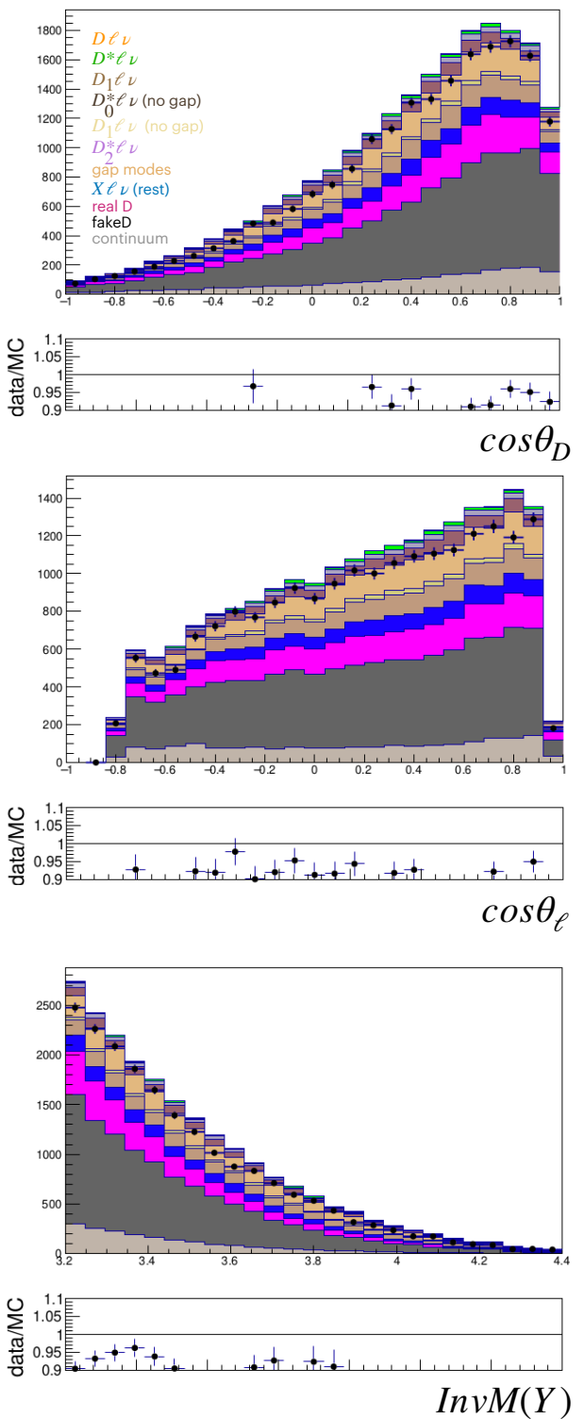


Data/MC agreement improves after scaling D^{**} and real D components.

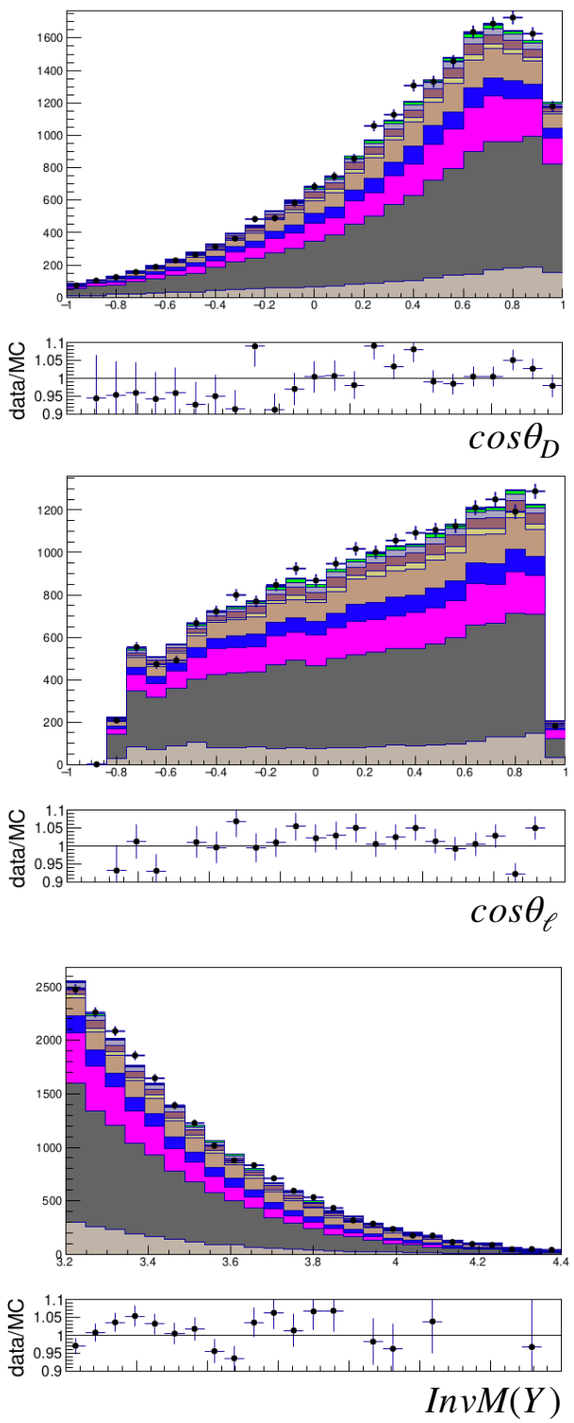
Data/MC agreement: $D^{-}\mu\nu$ sample

Check data/MC agreement after scaling D^{**} and real D components according to the fit results.

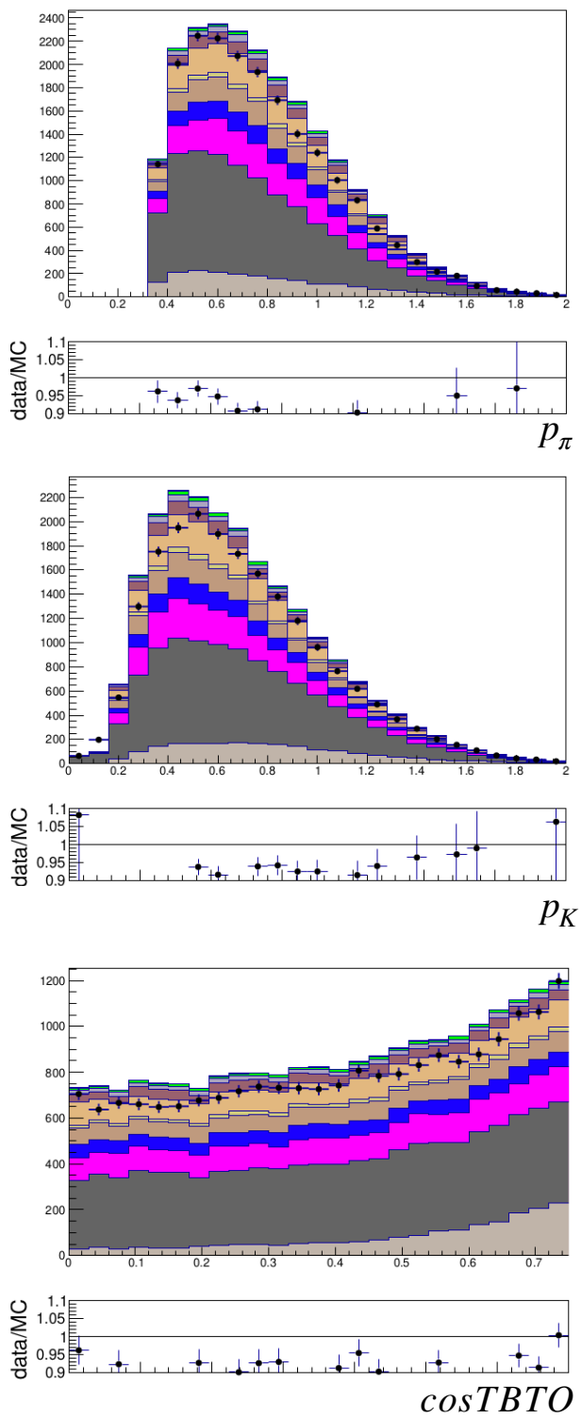
Before



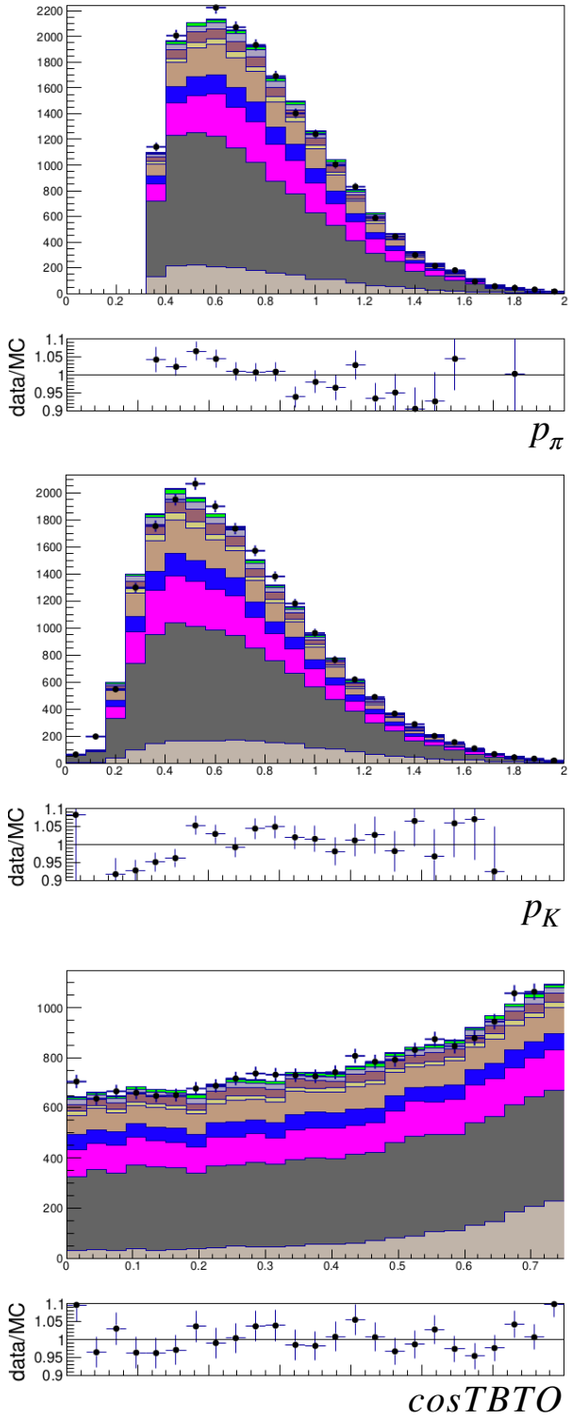
After



Before



After



Data/MC agreement improves after scaling D^{**} and real D components.

Summary

- Improved the selection by removing cuts with a large data/MC disagreement.

  Apply cuts to further reduce background components.

- Applied all the corrections to MC: update the branching fractions and fill the gap.

- Found a $cos\theta_{BY}$ sideband to validate the $X\ell\nu$ decays.

  Performed a 2D simultaneous fit between D^0 and D^- to constrain the $X\ell\nu$ decays.

  Observed a good data/MC agreement after scaling $X\ell\nu$ and real D components according to the fit results.

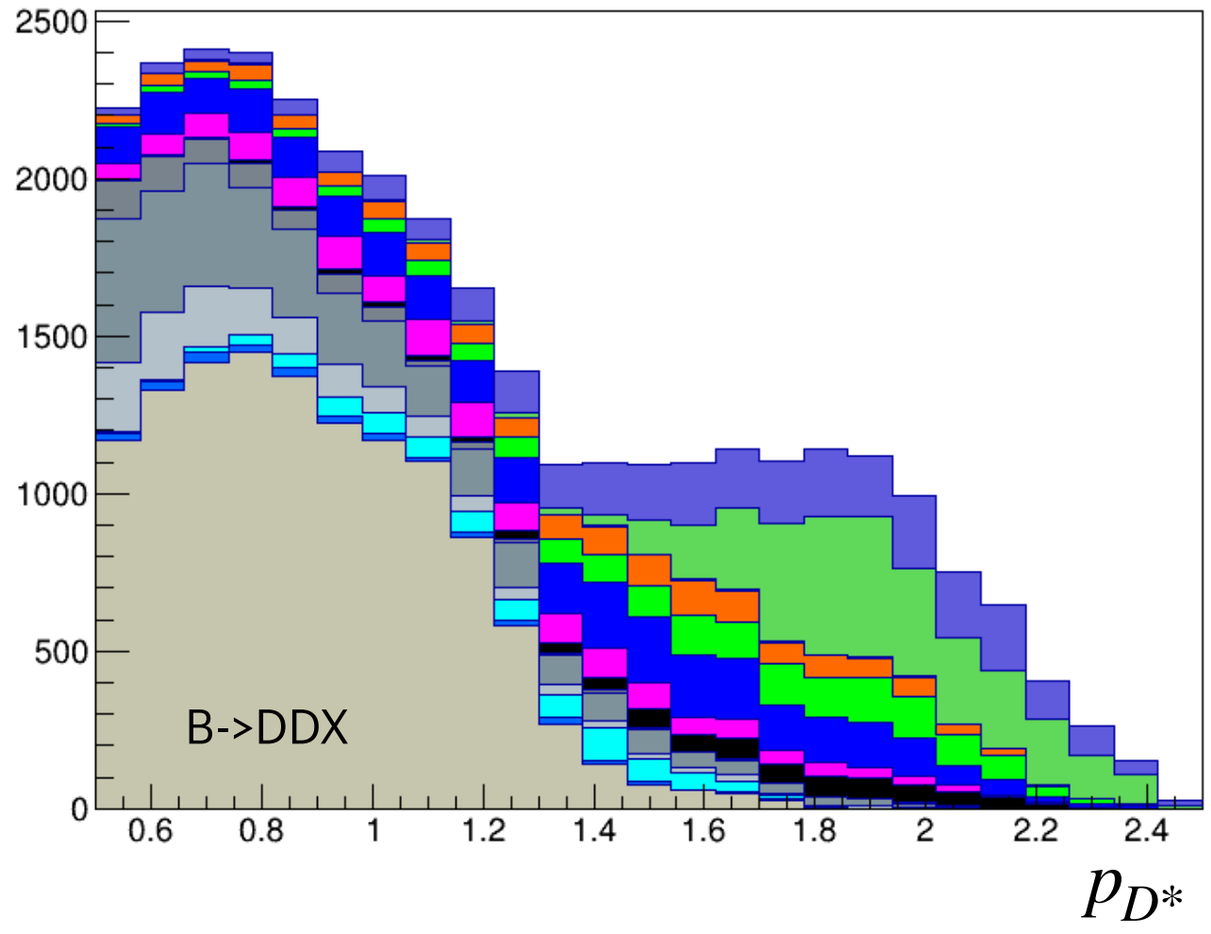
Next steps

- Test further configuration for the sideband fit (split $D^{(*)}\pi\pi\ell\nu$ and $D^{(*)}\eta\ell\nu$ templates). (done)
- Divide the real D component in sub-components to constraint better these decays. (done)
- Perform a simultaneous fit between the signal and control region to constrain the $X\ell\nu$ decays. (ongoing)

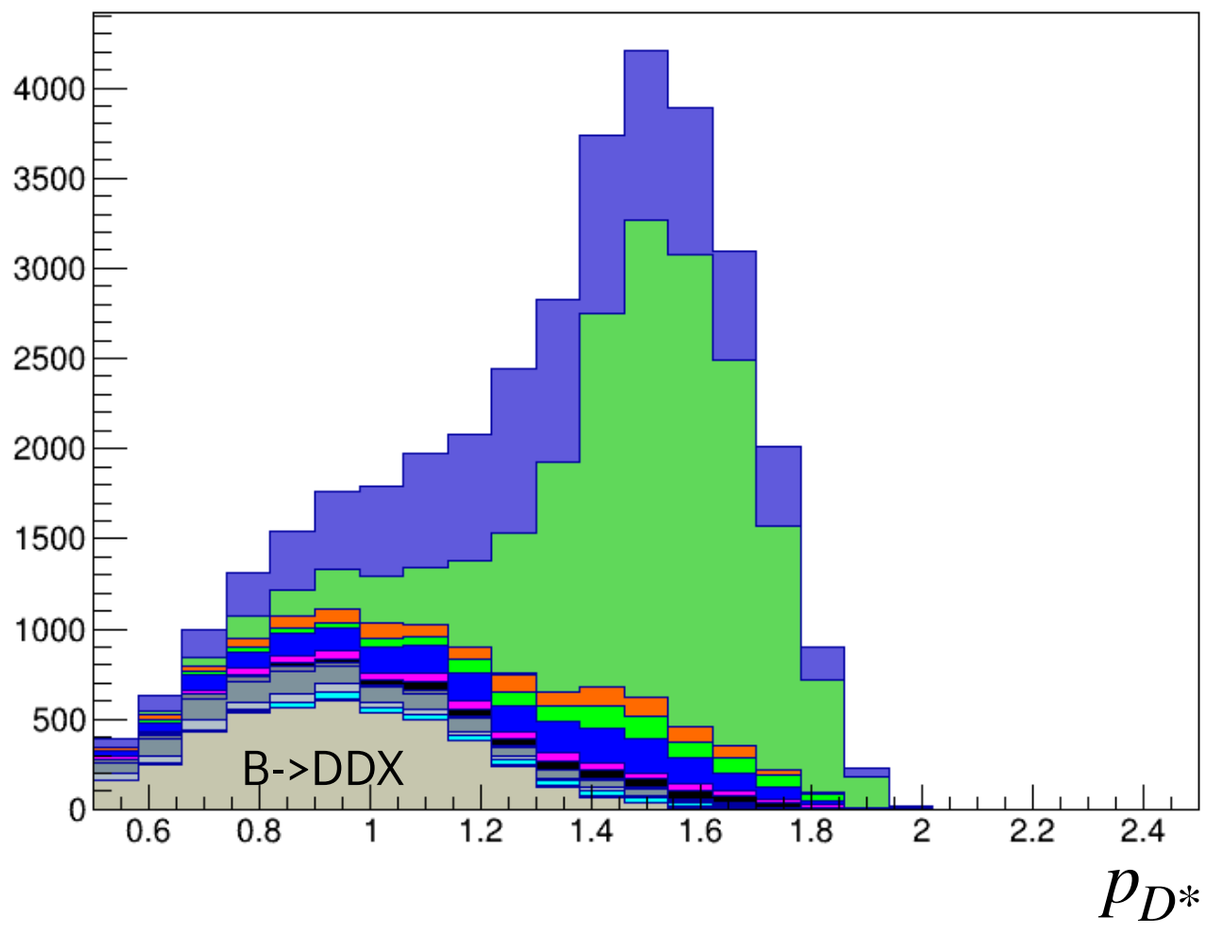
Backup

Real D validation: $D^0 e\nu$ sample

Signal region



Control region



1. From a true lepton (secondary) and a D from the same B.
2. Events with a D and a fake lepton (same/different B).

Selection of $D\ell\nu$ samples

- |dr|<1 + |dz|<3 for all tracks
- binaryKaonID>0.6 (for $D^{-}\ell\nu$) + binaryKaonID>0.1 (for $D^{0}\ell\nu$)
- MuonID_noSVD>0.9, $PID_{BDT}(e)$ >0.9
- Treefit : $\chi^2 > 1\,\%$
- ROE mask: |dr|<1 + |dz|<3 + $p_{CMS} < 3.2$
- VisibleEnergyCMS>4 GeV, thetainCDCacceptance
- R2<0.4
- cosTBTO<0.75
- $p_{\ell}^{CMS} \in [0.8,2.2]$
- $p_{D}^{CMS} \in [0.5,2.5]$
- $InvM(D) \in [1.865,1.874]$ for $D^{-}\ell\nu$, $InvM(D) \in [1.86,1.87]$ for $D^{0}\ell\nu$
- $InvM(Y) > 3.2GeV$
- $cos\theta_{BY} \in [-2,1.1]$
- Cut on $p(\pi)$>0.35 (remove the systematics for slow tracks)
- KakunoFoxWolfram(h20)>0.18 (only for $D^{-}\ell\nu$ samples)
- $p_{ROE}^{CMS} < 2.8GeV$

Branching fractions corrections

- Update the MC branching fractions according to the PDG:

Decay	$\mathcal{B}(B^+)(MC)$	$\mathcal{B}(B^+)(update)$	$\mathcal{B}(B^0)(MC)$	$\mathcal{B}(B^0)(update)$	D** FF model
$B \to D_1 \ell \nu$	0.76%	(0.66 +- 0.11)%	0.71%	(0.62 +- 0.10)%	BLR
$B \to D_0^* \ell \nu$	0.39%	(0.42 +- 0.08)%	0.36%	(0.39 +- 0.07)%	BLR
$B \to D_1^{'} \ell \nu$	0.43%	(0.42 +- 0.09)%	0.40%	(0.39 +- 0.08)%	BLR
$B \to D_2 \ell \nu$	0.37%	(0.29 +- 0.03)%	0.35%	(0.27 +- 0.03)%	BLR
$B \to D \pi \pi \ell \nu$	0.53%	(0.62 +- 0.89)%	0.49%	(0.58 +- 0.82)%	PHSP
$B \to D^* \pi \pi \ell \nu$	0.26%	(0.22 +- 0.10)%	0.25%	(0.20 +- 0.10)%	PHSP
$B \to D \eta \ell \nu$	0.20%	(0.38 +- 0.38)%	0.22%	(0.41 +- 0.41)%	PHSP
$B \to D^* \eta \ell \nu$	0.20%	(0.38 +- 0.38)%	0.22%	(0.41 +- 0.41)%	PHSP

The correction of the branching fractions leads to a modification of the form:

$$N_j^{new} = N_j^{MC} \frac{\mathcal{B}_j^{new}}{\mathcal{B}_j^{MC}}$$

N_j^{MC} = # of events in MC for the j-component, $\mathcal{B}_j^{MC}$ = BR in MC, $\mathcal{B}_j^{new}$ = update BR.

Gap modes

- In our MC, the gap modes $D^{(*)}\pi\pi\ell\nu$ and $D^{(*)}\eta\ell\nu$ have been generated with phase-space leading to a very soft lepton momentum.
- It seems physically less plausibile than a decay kinematic in which the hadronic particles are more correlated to each other.
- Remove these gap modes in our MC sample and replaced them by

$$B \to D^{**}[\to D^{(*)}\pi\pi]\ell\nu \qquad B \to D^{**}[\to D^{(*)}\eta]\ell\nu$$

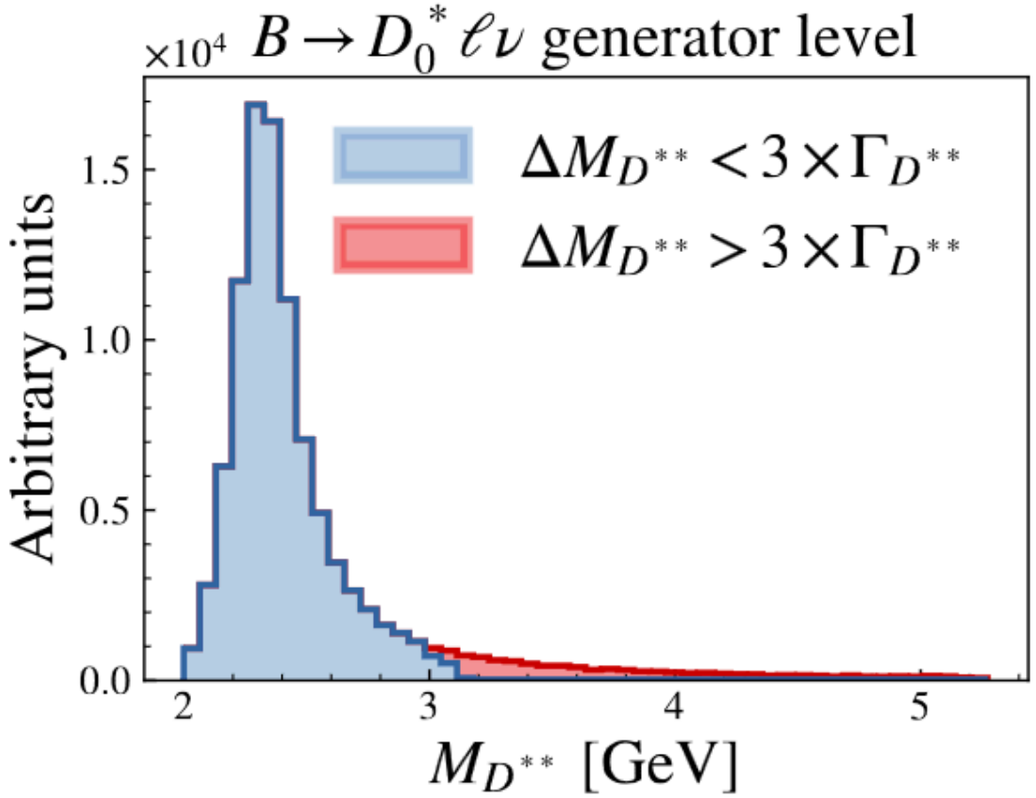
Decay	Sim.events	Lumi (ab-1)	D** FF model
$B \to D_1'[\to D\pi\pi]\ell\nu$	$8 \cdot 10^6$	B0: 16, B+: 14	BLR
$B \to D_0^*[\to D\pi\pi]\ell\nu$	$8 \cdot 10^6$	B0: 16, B+: 14	BLR
$B \to D_1'[\to D^*\pi\pi]\ell\nu$	$8 \cdot 10^6$	B0: 3.2, B+: 2.8	BLR
$B \to D_0^*[\to D^*\pi\pi]\ell\nu$	$8 \cdot 10^6$	B0: 3.2, B+: 2.8	BLR
$B \to D_0^*[\to D\eta]\ell\nu$	$8 \cdot 10^6$	B0: 1.8, B+: 1.8	BLR
$B \to D_1'[\to D^*\eta]\ell\nu$	$8 \cdot 10^6$	B0: 1.8, B+: 1.8	BLR

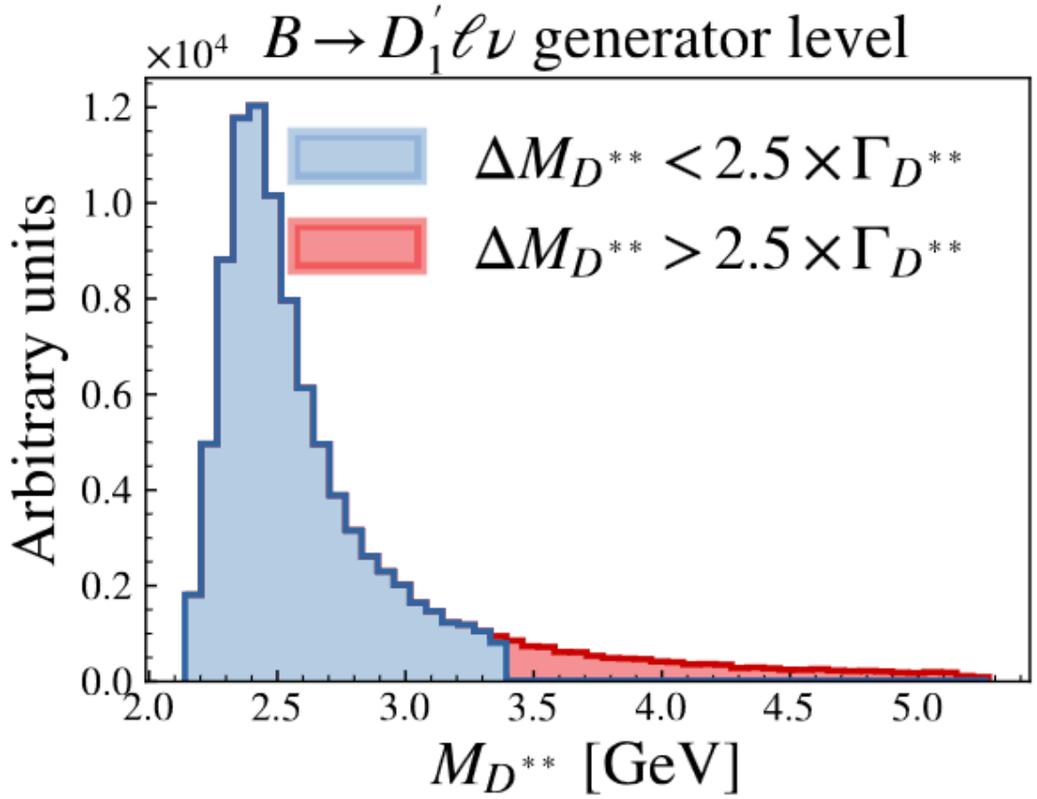
- $\mathcal{B}(B \to D^{(*)}\pi\ell\nu)$ set to 0; BR saturated by production via D^{**} BR.

D^{**} resonances

- Issue is spotted with the modelling D_0^* and $D_1^{'}$ resonances.
  First observation of this issue by Henrik.

- Due to their large width, some events are generated with D^{**} mass larger than the nominal one leading to an unphysical enhancement in the $w \sim 1$ region.





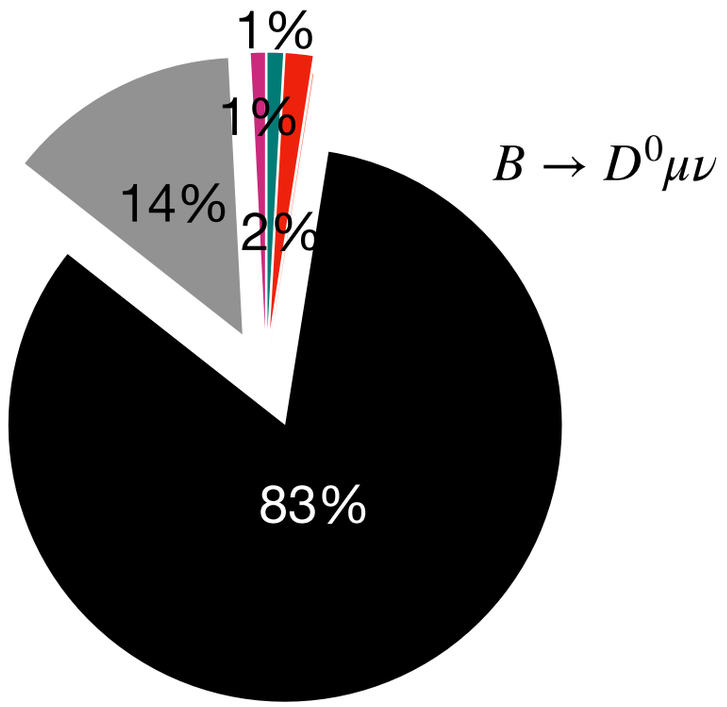
Events that exceed 3 times the width of D_0^* and 2.5 times of $D_1^{'}$ are rejected.

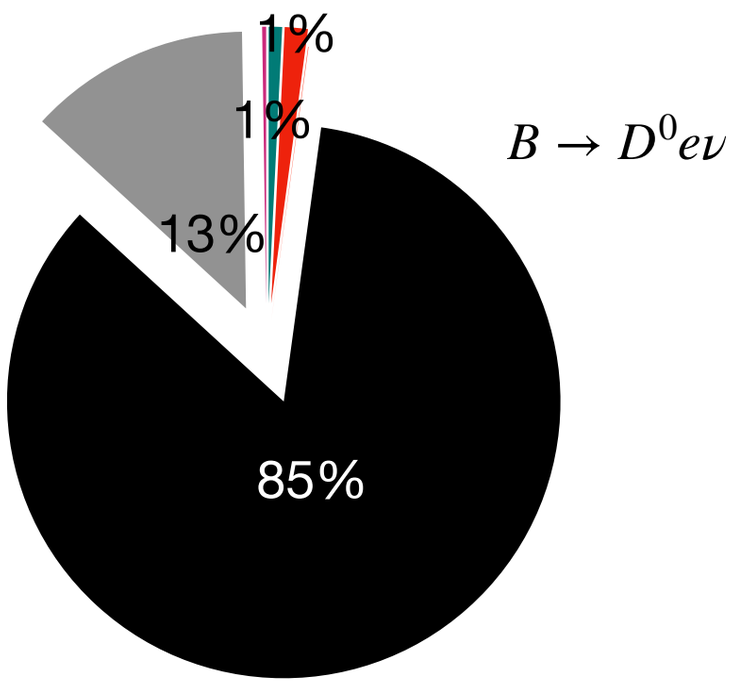
$X\ell\nu$ composition

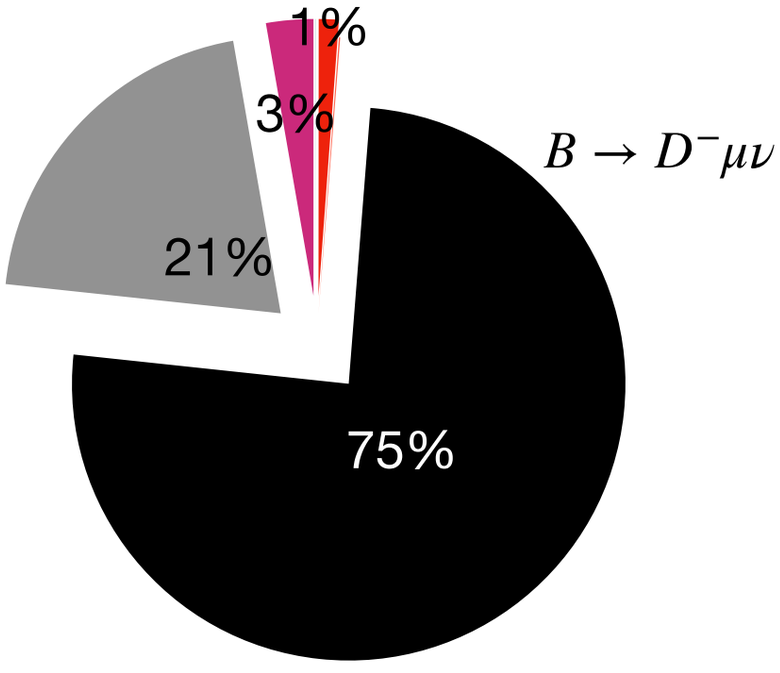
Studied the $X\ell\nu$ component after the BR and gap modes corrections.

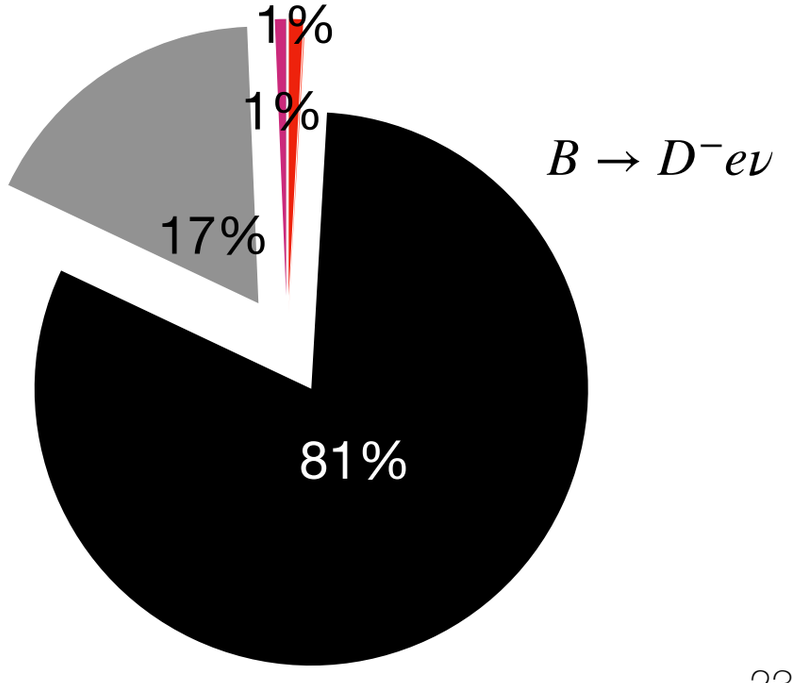
Divided the $X\ell\nu$ component in different sub-components:

1. $D\tau\nu$
2. $D^*\tau\nu$
3. $D^{**}\tau\nu$
4. Gap modes
5. $D^{(*)}\ell\nu$
6. $D^{**}\ell\nu$



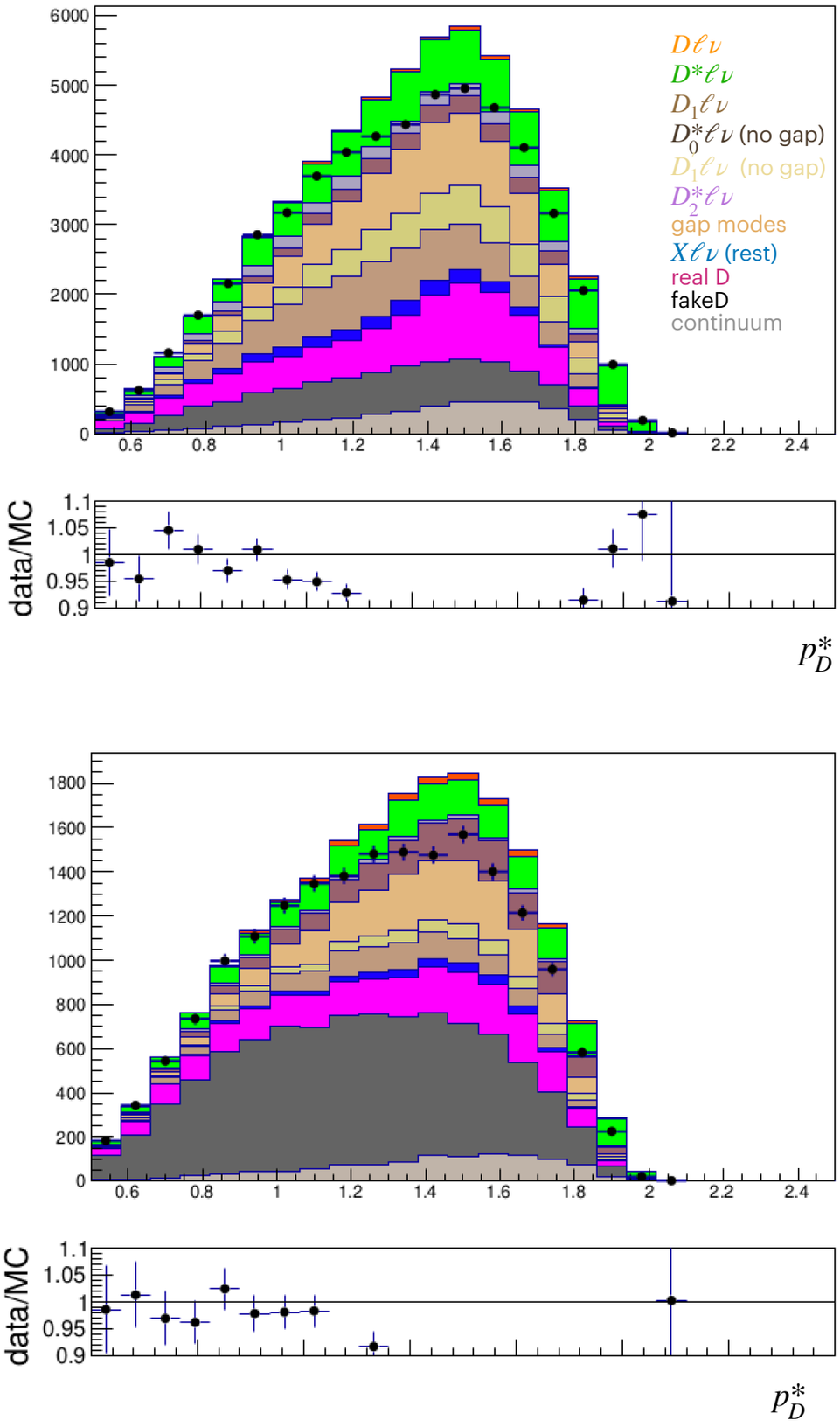


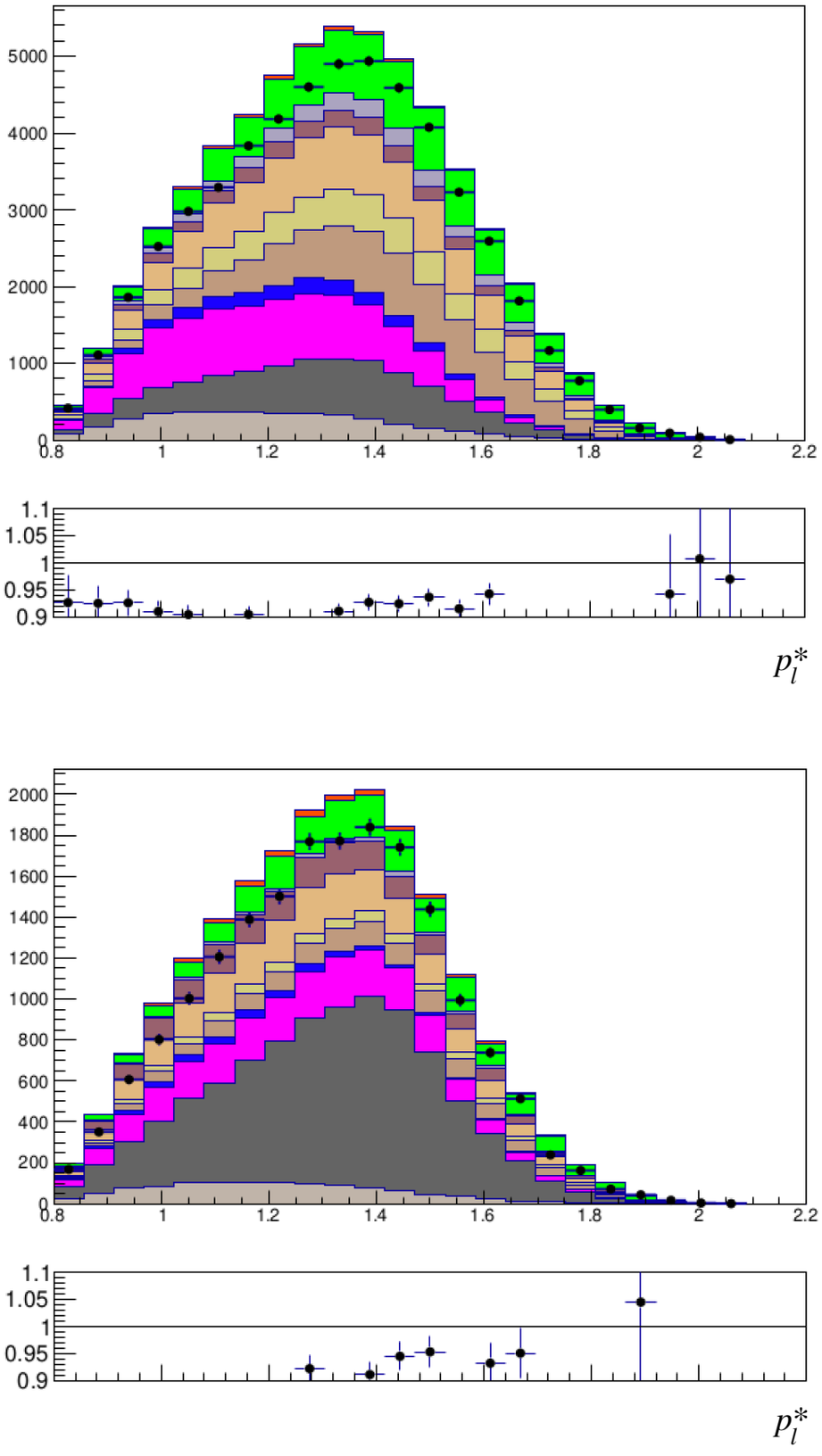




Projections (pre-fit)

$D^0 e\nu$





$D^- e\nu$