Run 2 muonic $\mathcal{R}(D^{0,*})$ MC validation

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Reminder: Updates on run 1 $\mathcal{R}(D^{0,*})$ `.dec` files

Reminder: Updates on form factors (FF) and generator-level cuts

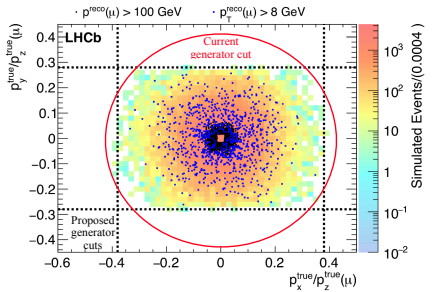
- Updated all signal/normalization FF models to HQET2 with latest CLN parametrization
  - Run 1 MC use HQET, ISGW2, or HQET2 model
  - Plan to reweight to BGL/BCL with HAMMER
- Updated the generator-level cuts
  - Better alignment w/ run 2 triggers
  - Better alignment w/ detector acceptance by switching to rectangular cuts
  - Generator-level cuts should be as tight as possible, but not tighter
- For more info, see:
  - Our initial MC request slides
  - JIRA tickets

Run 1 generator-level cuts:

```
tightCut.Cuts = '[pi+]cc': "in_range( 0.010, GTHETA, 0.400 ) & ( GPT > 700*MeV )",
                '[K-]cc':  "in_range( 0.010, GTHETA, 0.400 ) & ( GPT > 700*MeV )",
                '[mu+]cc': "in_range( 0.010, GTHETA, 0.400 ) & ( GP > 2500*MeV )",
                '[D0]cc':  "( piKP > 15000*MeV ) & ( piKPT > 2300*MeV)"
```

Run 2 generator-level cuts:

```
tightCut.Cuts = '[pi+]cc': "<Rectangular> & ( GTHETA > 0.01 ) & ( GPT > 250*MeV )",
                '[K-]cc':  "<Rectangular> & ( GTHETA > 0.01 ) & ( GPT > 250*MeV )",
                '[mu+]cc': "<Rectangular> & ( GTHETA > 0.01 ) & ( GP > 2950*MeV )",
                '[D0]cc':  "( piKP > 15000*MeV ) & ( piKPT > 2450*MeV )"
```



Reminder: Updates on decay ratios for D^{**} samples

- Reduced 3-body decay ratio of D_0 and D_2 to 5%
- Set $D^{*0}\pi^+/D^{*+}\pi^0$ ratios to 2/1
- Set $D\pi/D^+\pi$ ratios to 1/1

Run 1: 12873030 ($B^- \to D^{**0}\tau\nu$)

```
Decay MyD_0*+
  0.533    MyD0  pi+          PHOTOS PHSP;
  0.0271   MyD*+ pi0 pi0      PHOTOS PHSP;
  0.0542   MyD*+ pi+ pi-      PHOTOS PHSP;
  0.080    MyD*0 pi+ pi0      PHOTOS PHSP;
Decay MyD_0*0
  0.267    MyD0  pi0          PHSP;
  0.040    MyD*0 pi0 pi0      PHOTOS PHSP;
  0.080    MyD*0 pi+ pi-      PHOTOS PHSP;
  0.0542   MyD*+ pi- pi0      PHOTOS PHSP;
Decay MyD_2*+
  0.0587   MyD*+   pi0        PHOTOS TVS_PWAVE  0.0 0.0 1.0 0.0 0.0 0.0;
  0.173    MyD*0   pi+        PHOTOS TVS_PWAVE  0.0 0.0 1.0 0.0 0.0 0.0;
  0.2667   MyD0    pi+        PHOTOS TSS;
  0.0647   MyD_0*0 pi+        PHOTOS PHSP;
  0.0509   MyD_0*+ pi0        PHOTOS PHSP;
  0.0027   MyD*+   pi0 pi0    PHOTOS PHSP;
  0.0054   MyD*+   pi+ pi-    PHOTOS PHSP;
  0.008    MyD*0   pi+ pi0    PHOTOS PHSP;
  0.032    MyD0    pi+ pi0    PHOTOS PHSP;
Decay MyD_2*0
  0.1173   MyD*+   pi-        PHOTOS TVS_PWAVE  0.0 0.0 1.0 0.0 0.0 0.0;
  0.0867   MyD*0   pi0        TVS_PWAVE  0.0 0.0 1.0 0.0 0.0 0.0;
  0.133    MyD0    pi0        TSS;
  0.1019   MyD_0*+ pi-        PHOTOS PHSP;
  0.0323   MyD_0*0 pi0        PHSP;
  0.004    MyD*0   pi0 pi0    PHOTOS PHSP;
  0.008    MyD*0   pi+ pi-    PHOTOS PHSP;
  0.0054   MyD*+   pi- pi0    PHOTOS PHSP;
  0.016    MyD0    pi0 pi0    PHOTOS PHSP;
  0.032    MyD0    pi+ pi-    PHOTOS PHSP;
```

Run 2: 12873460 ($B^- \to D^{**0}\tau\nu$, same as left)

```
Decay MyD_0*+
  0.9500   MyD0  pi+          PHOTOS PHSP;
  0.0248   MyD*0 pi+ pi0      PHOTOS PHSP;
  0.0168   MyD*+ pi+ pi-      PHOTOS PHSP;
  0.0084   MyD*+ pi0 pi0      PHOTOS PHSP;
Decay MyD_0*0
  0.9500   MyD0  pi0          PHOTOS PHSP;
  0.0230   MyD*0 pi+ pi-      PHOTOS PHSP;
  0.0155   MyD*+ pi- pi0      PHOTOS PHSP;
  0.0115   MyD*0 pi0 pi0      PHOTOS PHSP;
Decay MyD_2*+
  0.3800   MyD0    pi+        PHOTOS TSS;
  0.3800   MyD*0   pi+        PHOTOS TVS_PWAVE 0.0 0.0 1.0 0.0 0.0 0.0;
  0.1900   MyD*+   pi0        PHOTOS TVS_PWAVE 0.0 0.0 1.0 0.0 0.0 0.0;
  0.0198   MyD_0*0 pi+        PHOTOS PHSP;
  0.0155   MyD_0*+ pi0        PHOTOS PHSP;
  0.0098   MyD0    pi+ pi0    PHOTOS PHSP;
  0.0024   MyD*0   pi+ pi0    PHOTOS PHSP;
  0.0017   MyD*+   pi+ pi-    PHOTOS PHSP;
  0.0008   MyD*+   pi0 pi0    PHOTOS PHSP;
Decay MyD_2*0
  0.4750   MyD*+   pi-        PHOTOS TVS_PWAVE 0.0 0.0 1.0 0.0 0.0 0.0;
  0.2375   MyD*0   pi0        PHOTOS TVS_PWAVE 0.0 0.0 1.0 0.0 0.0 0.0;
  0.2375   MyD0    pi0        PHOTOS TSS;
  0.0255   MyD_0*+ pi-        PHOTOS PHSP;
  0.0081   MyD_0*0 pi0        PHOTOS PHSP;
  0.0080   MyD0    pi+ pi-    PHOTOS PHSP;
  0.0040   MyD0    pi0 pi0    PHOTOS PHSP;
  0.0020   MyD*0   pi+ pi-    PHOTOS PHSP;
  0.0014   MyD*+   pi- pi0    PHOTOS PHSP;
  0.0010   MyD*0   pi0 pi0    PHOTOS PHSP;
```

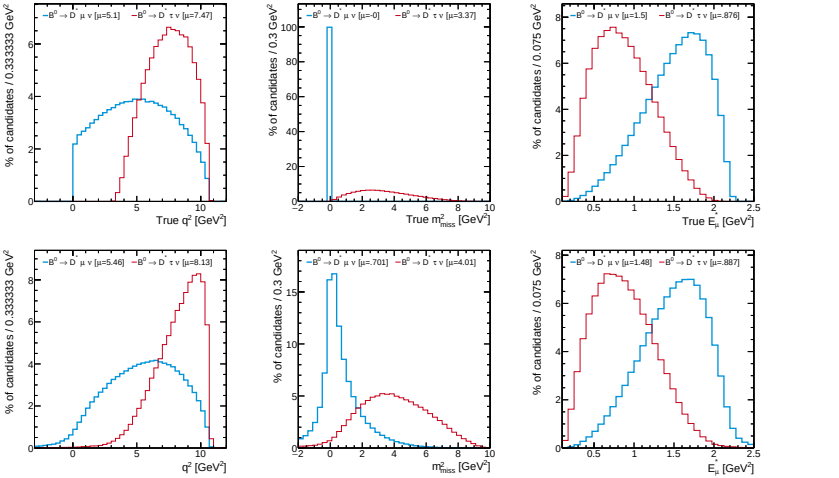
Validation of the new `.dec` files in FullSim

FullSim (FS): Fit variables for $B^0 \to D^{*+}(\mu/\tau)\bar{\nu}$

- The fit variables distributions are consistent w/ our expectations. Same for the next 2 slides

True
q^2, m^2_{miss}, E_l
μ, τ

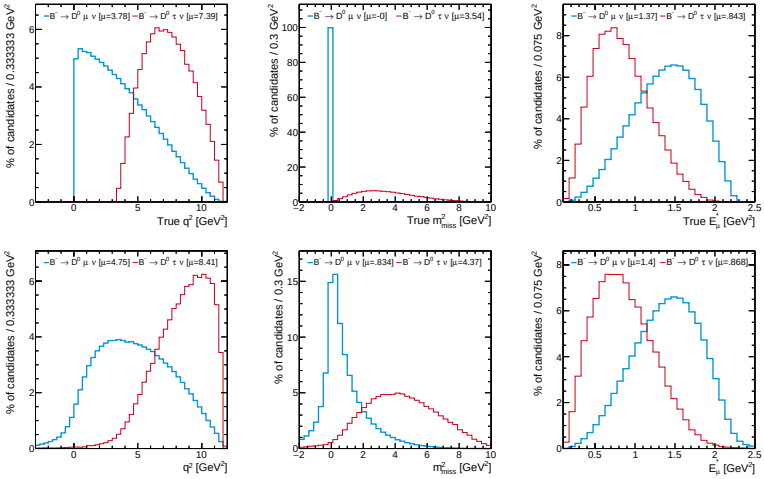
Reconstructed



FS: Fit variables for $B^- \to D^0(\mu/\tau)\bar{\nu}$

True
q^2, m^2_{miss}, E_l
μ, τ

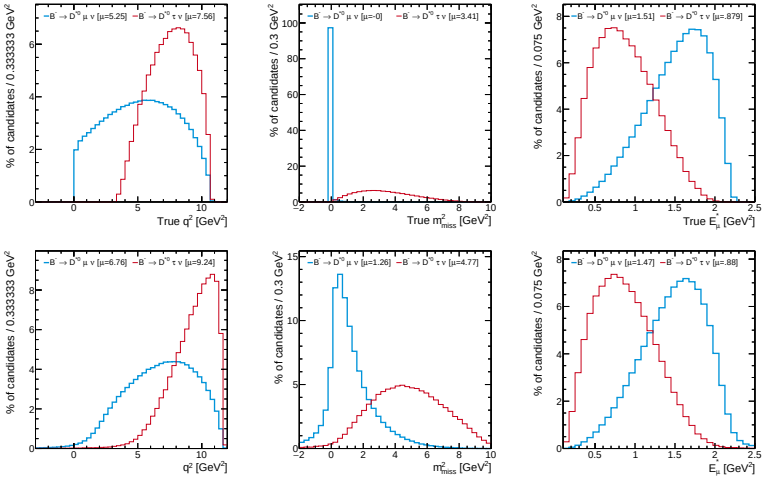
Reconstructed



FS: Fit variables for $B^- \to D^{*0}(\mu/\tau)\bar{\nu}$

True
q^2, m^2_{miss}, E_l
μ, τ

Reconstructed



FS: Selection efficiencies compared to run 1

- We apply run 1 offline cuts to compare w/ run 1 efficiencies. These should not be taken as our final efficiencies
  - "ISO" here means signal sample. See this backup slide for actual cuts
- Checked: Efficiencies respect to events on disk (BKK) are reasonable
  - Comparing to run 1, efficiencies are lower because our generator-level cuts are looser
  - Overall, these efficiencies make sense as similar decay modes have similar efficiencies

					D0 μ reco sample		D*+ μ reco sample	
#	Sample	Name	MC ID	MD events in BKK	Events in ISO sample	ISO/BBK	Events in ISO sample	ISO/BBK
1	D0	B- → D0 μ ν	12573012	1,808,497	145,727	8.1%		
2	D0/D*+	B0 → D*+ μ ν	11574021	1,500,395	52,229	3.5%	79,196	5.3%
3	D0	B- → D*0 μ ν	12773410	2,000,610	155,779	7.8%		
4	D0	B- → D0 τ ν	12573001	117,296	9,512	8.1%		
5	D0/D*+	B0 → D*+ τ ν	11574011	293,257	11,753	4.0%	14,974	5.1%
6	D0	B- → D*0 τ ν	12773400	274,172	21,900	8.0%		
7	D0/D*+	B0 → D**+ μ ν	11874430	1,448,012	31,979	2.2%	10,882	0.8%
8	D0/D*+	B0 → D**+ τ ν	11874440	13,897	392	2.8%	104	0.7%
9	D0/D*+	B- → D**0 μ ν	12873450	1,160,695	57,834	5.0%	4,652	0.4%
10	D0/D*+	B- → D**0 τ ν	12873460	56,126	2,857	5.1%	263	0.5%
11	D0	B- → D**(→D0ππ) μ ν	12675011	212,474	1,572	0.7%		
12	D0	B0 → D**(→D0ππ) μ ν	11674401	176,417	3,620	2.1%		
13	D0/D*+	B- → D**(→D*+ππ) μ ν	12675402	146,287	1,790	1.2%	1,938	1.3%
14	D0/D*+	B0 → D**(→D*+ππ) μ ν	11676012	149,170	900	0.6%	784	0.5%
15	D0	B- → D**(→D*0ππ) μ ν	12875440	209,776	1,593	0.8%		
16	D0	Bs → Ds**(→D0K) μ ν	13874020	141,862	3,172	2.2%		
17	D*+	Bs → D**+μ ν	13674000	72,087			3,886	5.4%
18	D0	B0 → D0(Xc → μ νX')X	11894600	533,760	10,200	1.9%		
19	D0	B0 → D0(Ds → τν)X	11894200	42,460	1,464	3.4%		
20	D0	B+ → D0(Xc → μ νX')X	12893600	586,247	18,252	3.1%		
21	D0	B+ → D0(Ds → τν)X	12893610	126,004	7,669	6.1%		
22	D*+	B0 → D*+ (Xc → μ ν X')X	11894610	589,959			13,746	2.3%
23	D*+	B0 → D*+(Ds → τ ν) X	11894210	57,109			2,483	4.3%
24	D*+	B+ → D*+ (Xc → μ ν X')X	12895400	182,193			2,276	1.2%
25	D*+	B+ → D*+(Ds → τ ν) X	12895000	75,451			1,400	1.9%

FS: Truth-matching efficiency

- Sanity check: we are indeed truth-matching $> 90\%$ of events in each sample for our templates
- For the lower efficiency modes: We don't truth-match 3-body decays so their efficiencies are expected to be lower

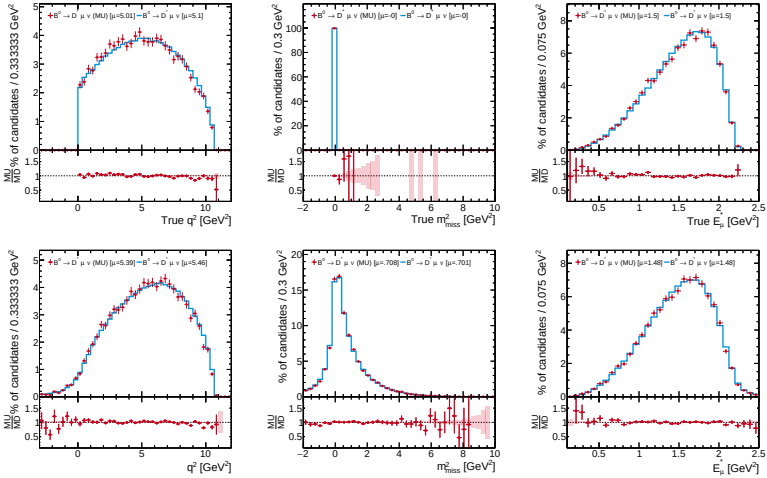
Decay type	Decay ID	Reco	Total events	Truth-matched events	Truth-matching efficiency
B0→D*+munu (tr.only)	11574021	B0	2440479	2226964	91.3%
B0→D*+munu	11574021	B0	980857	895013	91.2%
B0→D*+taunu	11574011	B0	183520	178216	97.1%
B-→D*0munu	12773410	B-	1992613	1871244	93.9%
B-→D*0taunu	12773400	B-	272906	256479	94.0%
B-→D0munu	12573012	B-	1800693	1605923	89.2%
B-→D0taunu	12573001	B-	116712	105968	90.8%
B0→D**+munu	11874430	B0	168606	126352	74.9%
B0→D**+munu	11874430	B-	1437669	1349948	93.9%
B0→D**+taunu	11874440	B0	1664	1216	73.1%
B0→D**+taunu	11874440	B-	13787	13003	94.3%
B-→D**0munu	12873450	B0	250383	215856	86.2%
B-→D**0munu	12873450	B-	1157887	1083894	93.6%
B-→D**0taunu	12873460	B0	11747	10039	85.5%
B-→D**0taunu	12873460	B-	56033	52652	94.0%
B0→DH**+→D*+	11676012	B0	96999	90988	93.8%
B0→DH**+→D*+→D0	11676012	B-	149135	139700	93.7%
B-→DH**0→D*+	12675402	B0	93687	89997	96.1%
B-→DH**0→D*+→D0	12675402	B-	146345	136915	93.6%
B-→DH**0→D0	12675011	B-	212211	198007	93.3%
B0→DH**+→D0	11674401	B-	175335	164888	94.0%
B-→DH**0→D*0→D0	12875440	B-	209693	196118	93.5%
Bs0→Ds**+→D*+	13674000	B0	45961	44736	97.3%
Bs0→Ds**+→D*+→D0	13674000	B-	71917	67590	94.0%
Bs0→Ds**+→(D*+,D*0,D0)	13874020	B-	141347	132995	94.1%
B0→D*+XcX	11894610	B0	376301	359032	95.4%
B-→D*+XcX	12895400	B0	116312	108981	93.7%
B0→D*+DsX	11894210	B0	37892	36137	95.4%
B-→D*+DsX	12895000	B0	48531	45127	93.0%
B0→D0XcX	11894600	B-	527569	489507	92.8%
B-→D0XcX	12893600	B-	578806	534866	92.4%
B0→D0DsX	11894200	B-	42006	38554	91.8%
B-→D0DsX	12893610	B-	125237	115077	91.9%

FS: MU vs MD in $B^0 \to D^{*+}\mu\bar{\nu}$

- Good agreements between MU and MD samples (MU low-stat)

True
q^2, m^2_{miss}, E_l
MagUp
MagDown

Reconstructed



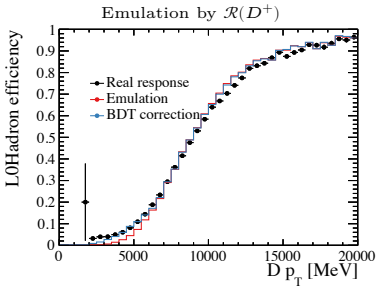
Tracker-only validation

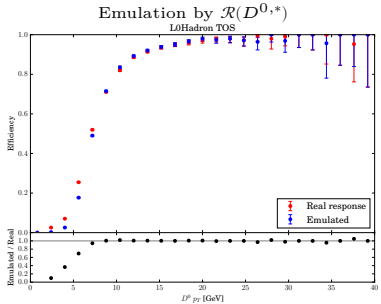
Tracker-only (TO) validation: general strategy

- Check: Triggers used in selection can be emulated
  - Run 2 $\mathcal{R}(D^{0,*})$ requires the following triggers (same as $\mathcal{R}(D^{+})$):
    - L0: B L0Global TIS || D^0 L0Hadron TOS
    - HLT1: D^0 Hlt1TrackMVA TOS || D^0 Hlt1TwoTrackMVA TOS
    - HLT2: B Hlt2XcMuXForTauB2XcMu TOS
  - These triggers are already emulated by $\mathcal{R}(D^{+})$
    - The HLT2 trigger cuts, w/o PID cuts, are applied directly in DaVinci, and we won't compare them here
    - See *LHCb-INT-2019-025* for more info
- Note: Run 1 $\mathcal{R}(D^{0,*})$ additionally required μ L0Global TIS. We dropped this requirement because:
  - This has only minor effect on selection efficiency
  - μ L0Global TIS can't be easily emulated
- Check: Fit variables are similar between FS and TO
- Check: Selection variables similar to FS

TO: Real vs. emulated L0Hadron TOS in $B^0 \to D^{*+}\mu\bar{\nu}$

- This comparison is done w/ FS sample **only** (same for the next 2 slides)
  - "Real response" (Real trigger): The trigger already in the FS sample
  - Emulated: The trigger emulated offline by us
- $\mathcal{R}(D^+)$ emulation has good agreement; we consider their method works for us
  - The **BDT correction** is not implemented by us yet
    - This corrects for higher efficiencies at low P_T, a signal-rich region
  - Better agreements expected after implementing BDT correction





The "Emulated" in the right plot should be compared to "Emulation" in the left

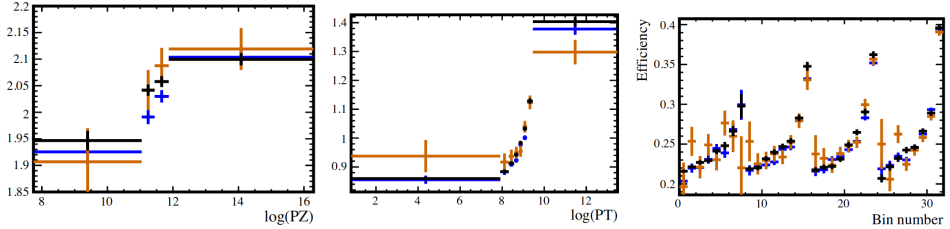
TO: Real vs. emulated L0Global TIS in $B^0 \to D^{*+}\mu\bar{\nu}$

- The L0Global TIS is taken from $B \to J/\psi K$ data sample directly
- This trigger efficiency is assumed to be independent of B decay modes (checked in *LHCb-INT-2019-025*)

$\mathcal{R}(D^+)$ checked that L0Global TIS is independent of B decay modes

$B \to J/\psi K$ $B \to D^+\mu\nu$ $B \to D^+\tau\nu$

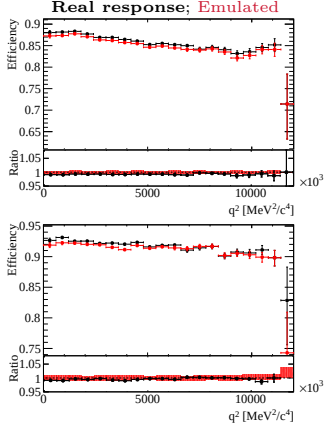
$\log(PZ), \log(PT)$ are logarithm of B momenta; bin number are bins of $\log(PZ) \otimes \log(PT)$



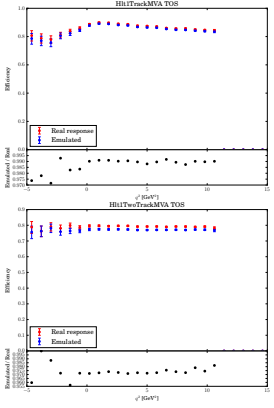
TO: Real vs. emulated HLT1 TOS in $B^0 \to D^{*+}\mu\bar{\nu}$

- Emulated HLT1 triggers agree well in both $\mathcal{R}(D^+)$ and $\mathcal{R}(D^{0,*})$; the emulation method works for us
- The HLT1 triggers cannot be perfectly emulated, due to the online/offline differences of the selection variables (See this backup slide)

$\mathcal{R}(D^+)$: Hlt1TrackMVA (top); Hlt1TwoTrackMVA (bot)

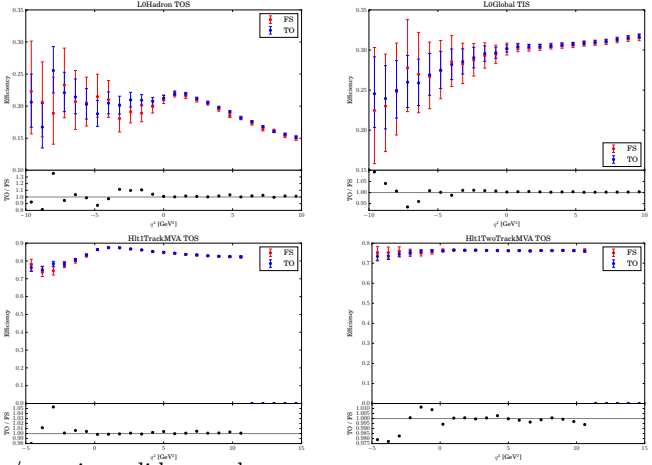


$\mathcal{R}(D^{0,*})$: Hlt1TrackMVA (top); Hlt1TwoTrackMVA (bot)



TO: Emulated triggers between FS and TO in $B^0 \to D^{*+}\mu\bar{\nu}$

- Here we show emulated triggers in FS and TO are very similar:



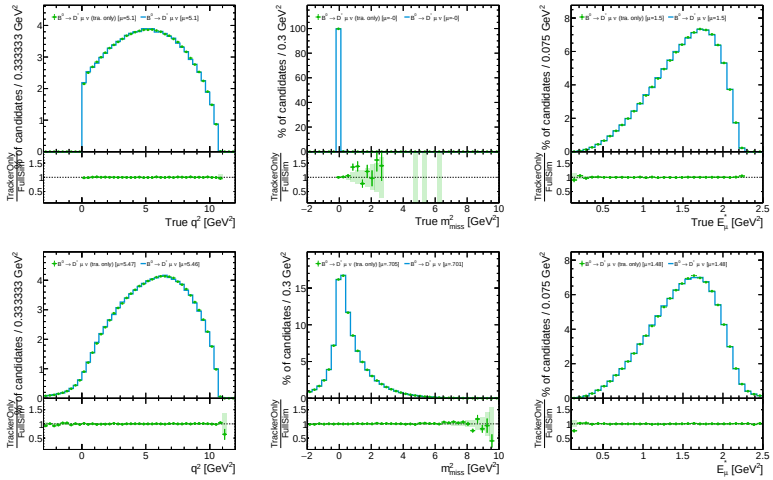
- Thus, together w/ previous slides, we have:
  Real response in FS $\approx$ Emulated in FS = Emulated in TO

TO: Fit variables between FS and TO

- Fit variables have excellent agreements between FS and TO in $B^0 \to D^{*+}\mu\bar{\nu}$

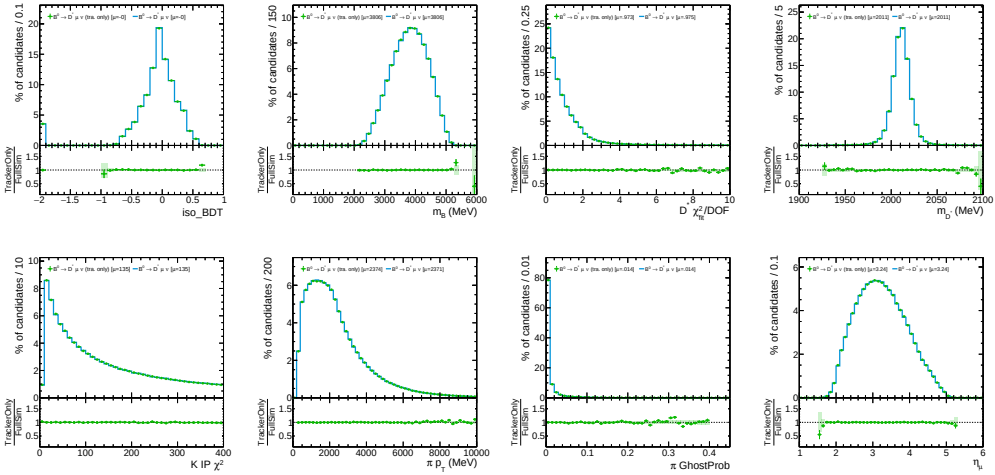
True
q^2, m^2_{miss}, E_l
TO, FS

Reconstructed



TO: Selection variables in FS and TO

- Selection variables also have very good agreements between FS and TO in $B^0 \to D^{*+}\mu\bar{\nu}$



Conclusion

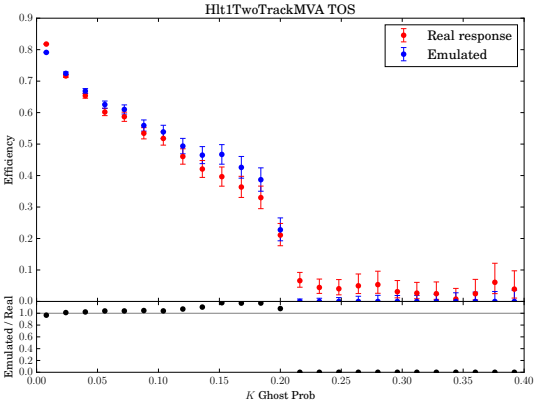
Conclusion and outlook

- Checked new `.dec` files for 25 samples
  - Checked efficiencies and branching fractions
- Checked Tracker-only MC good for $\mathcal{R}(D^{0,*})$
  - Checked trigger emulations and distributions of analysis variables
- Working on estimating numbers for final MC request; results coming soon

Backup

Example: differences between online/offline variables

- For Hlt1TwoTrackMVA TOS, we require K GhostProb < 0.2.
- However, this variable is different between online and offline version



ISO cuts in run 1 $\mathcal{R}(D^{0,*})$

The following cuts are required for $D^0\mu$ combo:

Particle	Variable	Selection
K,π	p_T	$> 0.8\,\text{GeV}/c$
	`Hlt1TrackAllL0` (either track)	TOS
	p_T (TOS track)	$> 1.7\,\text{GeV}/c$
	p	$> 2\,\text{GeV}/c$
	$IP\chi^2$	> 45
	$\sum \lvert p_T \rvert$	$> 1.4\,\text{GeV}/c$
	$DLLK$	$> 4(K), < 2(\pi)$
	`isMuon`	False
	GhostProb	< 0.5
D^0	p_T	$> 2\,\text{GeV}/c$
	`Hlt2CharmHadD02HH_D02KPi`	TOS
	$\chi^2_{\text{fit}}/\text{DOF}$	< 4
	$\ln IP$	> -3.5
	$IP\chi^2$	> 9
	$DIRA$	> 0.9998
	Flight distance χ^2 (PV)	> 250
	$m - \langle m \rangle$	$< 23.4\,\text{MeV}/c^2$

Particle	Variable	Selection
μ	`isMuon`	true
	p	$> 3\,\text{GeV}/c$
	p	$< 100\,\text{GeV}/c$
	η	$1.7 < \eta < 5.$
	$DLLmu$	> 2
	$DLLe$	< 1
	BDTmu	> 0.25
	$\log_{10}(1 - \vec{p}_\mu \cdot \vec{p}_i/(\lvert p_\mu \rvert \lvert p_i \rvert)),\ i = K, \pi$	> -6.5
$\{D^0\mu\}$	$\chi^2_{\text{fit}}/\text{DOF}$	< 6
	d_{XY} (transverse FD)	$< 7\,\text{mm}$
	$DIRA$	> 0.9995
	Mass	$< 5200\,\text{MeV}$
	Mass (μ as π) $-m_{D^0}$	$> 165\,\text{MeV}$
	Max isolation BDT in event	0.15

Additional cuts are required for $D^*\mu$ combo:

Particle	Variable	Selection
π_s	GhostProb	< 0.25
D^{*+}	$\chi^2_{\text{fit}}/\text{DOF}$	< 10
	$\Delta m - \langle \Delta m \rangle$	$< 2\,\text{MeV}/c^2$
μ	`isMuon`	true
	p	$> 3\,\text{GeV}/c$
	p	$< 100\,\text{GeV}/c$
	η	$1.7 < \eta < 5.$
	$DLLmu$	> 2
	$DLLe$	< 1
	BDTmu	> 0.25
	$\log_{10}(1 - \vec{p}_\mu \cdot \vec{p}_i/(\lvert p_\mu \rvert \lvert p_i \rvert)),\ i = K, \pi, \pi_s$	> -6.5
$\{D^0\mu\}$ subcombination	$\chi^2_{\text{fit}}/\text{DOF}$	< 6
	$DIRA$	> 0.9995
$\{D^*\mu\}$	$\chi^2_{\text{fit}}/\text{DOF}$	< 6
	d_{XY} (transverse FD)	$< 7\,\text{mm}$
	$DIRA$	> 0.9995
	Mass	$< 5280\,\text{MeV}$
	Max isolation BDT in event	0.15