Inclusive measurement of $Br(B^+ \to K^+X(3872)/Br(B^+ \to K^+J/\psi)$ and $Br(B^+ \to \pi^+D^{*0}/Br(B^+ \to \pi^+D^0)$

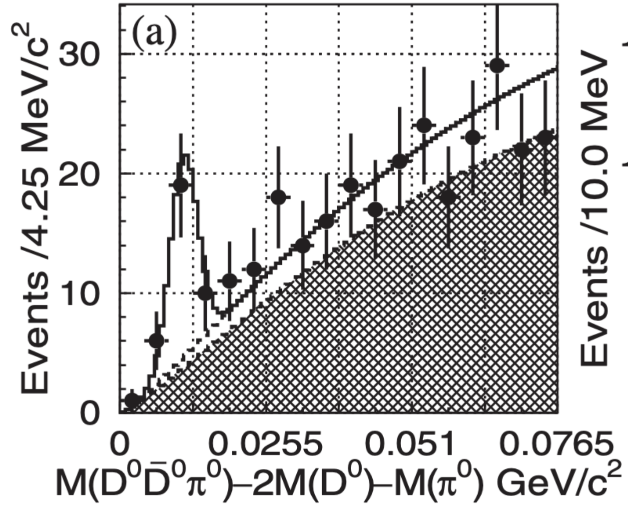
Emilie Bertholet, Sourav Dey, Sara Gandelman, Suxian Li, Hikari Murakami, Gaia Scope, Chengping Shen, Abi Soffer, Maximiliano Topf Wilenski, Sergei Zakharov, Jianshe Zhou

Fudan, Nagoya, Tel Aviv

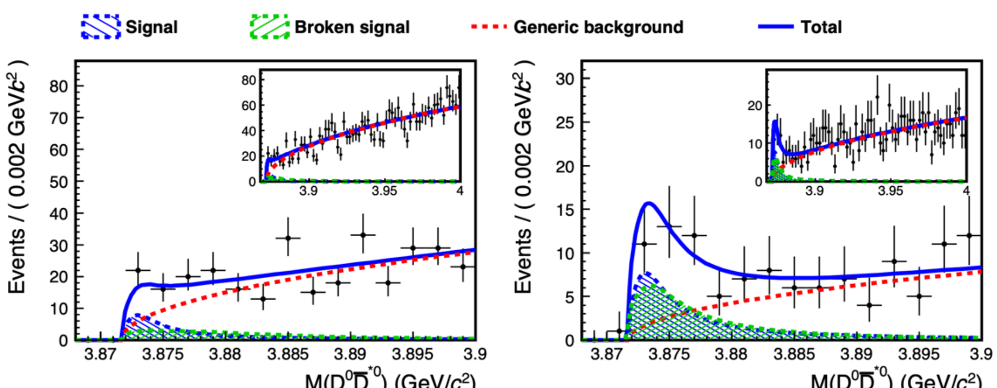
Motivation

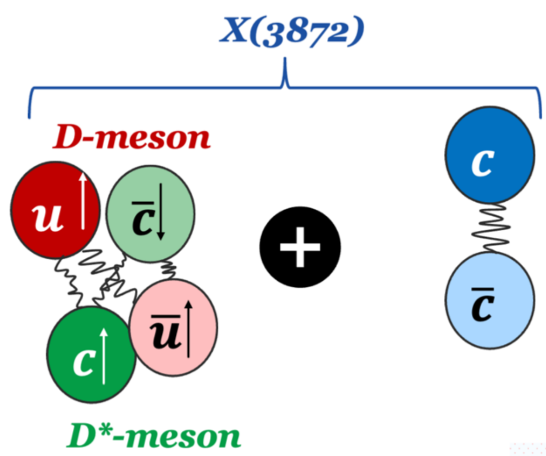
- The X(3872) is understood to be mostly a $D^0\bar{D}^{*0}$ molecule with some $c\bar{c}$ component
- A molecule would decay mostly to $D^0\bar{D}^0\pi^0$, while a $c\bar{c}$ meson has larger BRs to charmonia
- The measured Brs are
  - $Br(X \to J\psi\pi^+\pi^-) = (3.5 \pm 0.9)\%$
  - $Br(X \to D^0\bar{D}^0\pi^0) = (45 \pm 21)\%$
  - $Br(X \to D^0\bar{D}^{*0}) = (34 \pm 12)\%$

Belle, PRL 97, 162002 (2006)



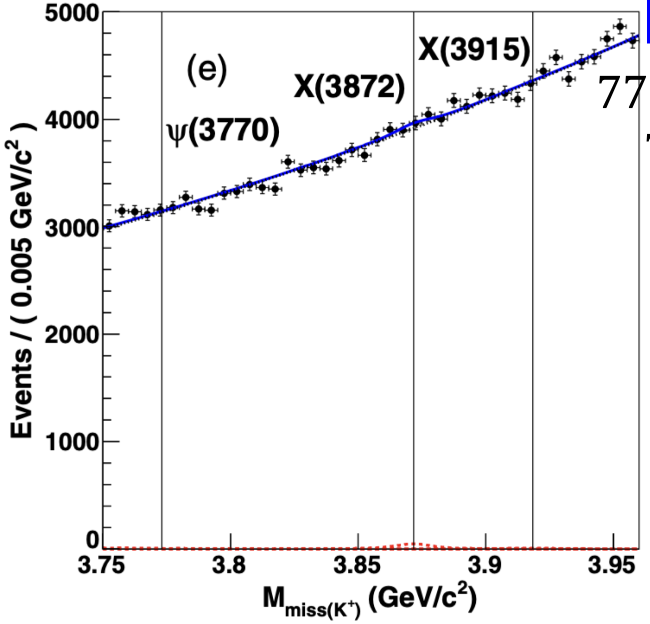
Belle, PRD 107, 112011 (2023)



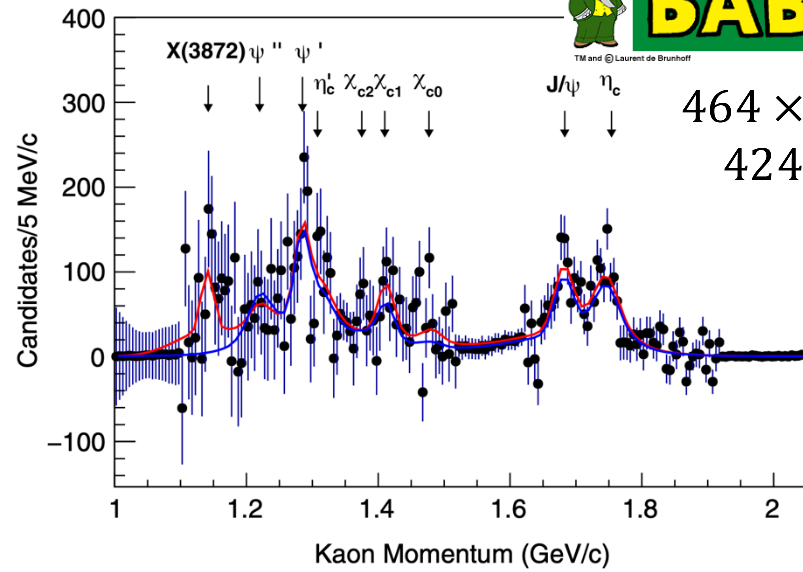


Past results

- Belle: $Br(B^+ \rightarrow K^+X) < 2.6 \times 10^{-4}$ (PRD 97, 012005 (2018))
- BABAR: $Br(B^+ \rightarrow K^+X) = (2.1 \pm 0.6 \pm 0.3) \times 10^{-4}$ (PRL 124, 152001 (2020)):



$772 \times 10^6 B\overline{B}$
$711 fb^{-1}$



$464 \times 10^6 B\overline{B}$
$424 \, fb^{-1}$

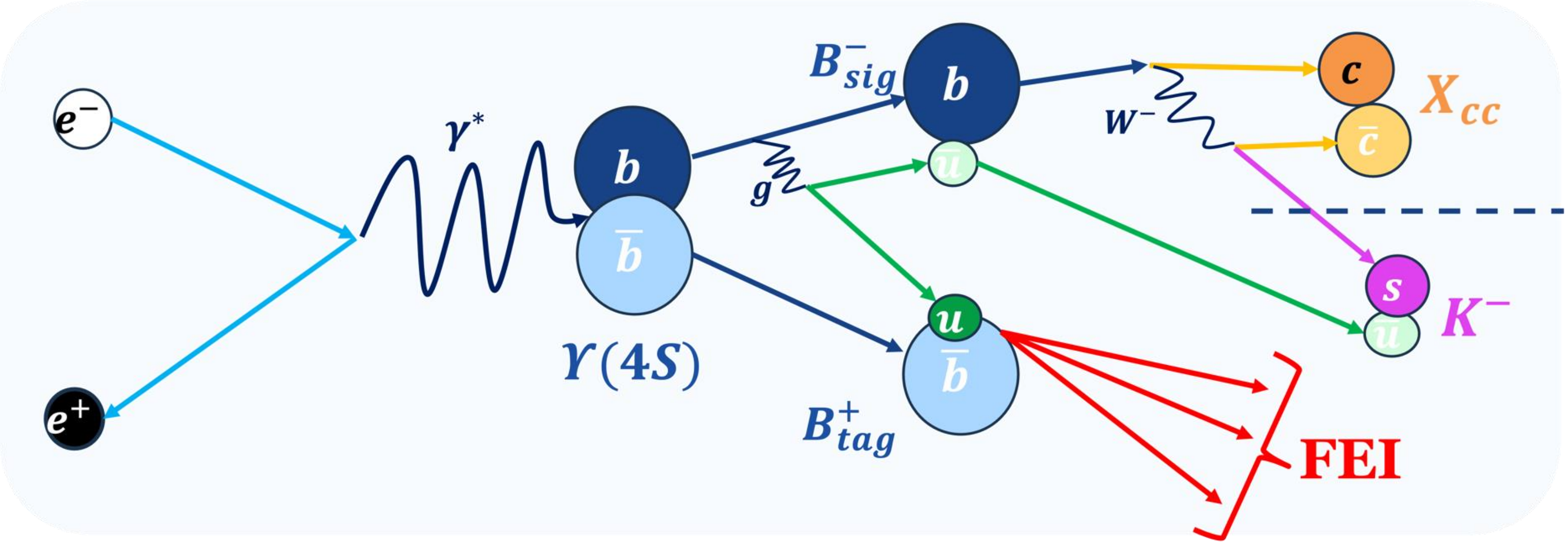
We aim to improve those results using Belle + Belle II $(+362 \, fb^{-1})$ combined dataset and new software: FEI for the tag-side reconstruction (by Belle 2) and DeepSets classifier for continuum suppression (by Ori, Emilie, …)

Inclusive measurement of $Br\left(B^+ \to K^+ X(3872)\right)$

- Only the tag B and kaon are reconstructed – partial reconstruction
- Identify signal in the missing mass spectrum (M Recoil), calculated from 4-momentum conservation (e^+e^- collider ≡ no extra particles):

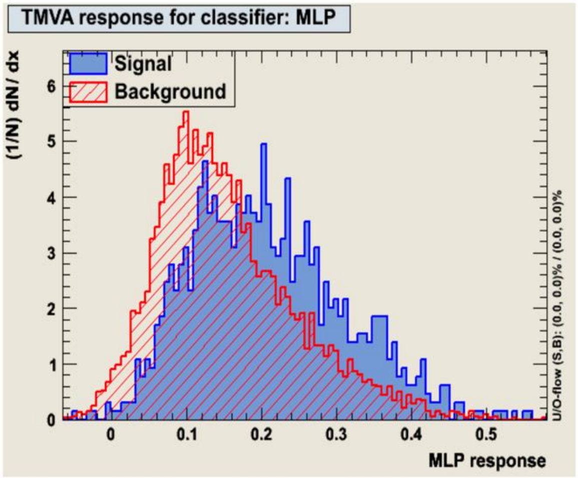
$$M_{recoil} = \sqrt{\left(p^*_{e^+e^-} - p^*_{tag} - p^*_K\right)^2}$$

- Needed for absolute BR measurements.
- Experiments measure $Br(B^+ \to K^+X) \times Br(X \to J/\psi\pi\pi)$ very well. With a measurement of $Br(B^+ \to K^+X)$ we can get $Br(X \to J/\psi\pi\pi)$



Background suppression

- After standard qq suppression, BABAR used TMVA to combine variables that target kaons from charm decays →

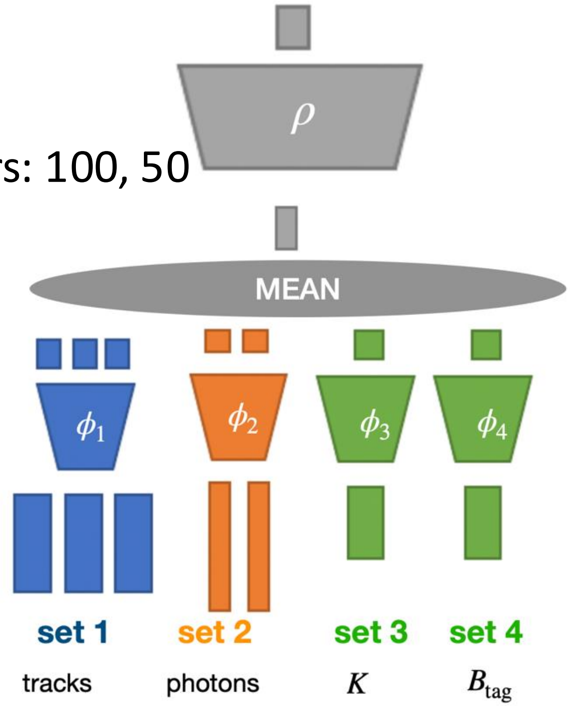


- We figured we might do better with modern ML tools (DeepSets) that use the low-level inputs (in CMS):
  - ROE photons and tracks: p3 (and charge)
  - Tag B: Thrust vector, $\hat{p}$
    - (avoiding $|p| \sim M_{bc}$)
  - Kaon: KID, charge, $\hat{p}$
    - (avoiding $|p| \sim M_{rec}$)
- Event classification:
  - Signal + good tag
  - Background

Hidden layers: 100, 50

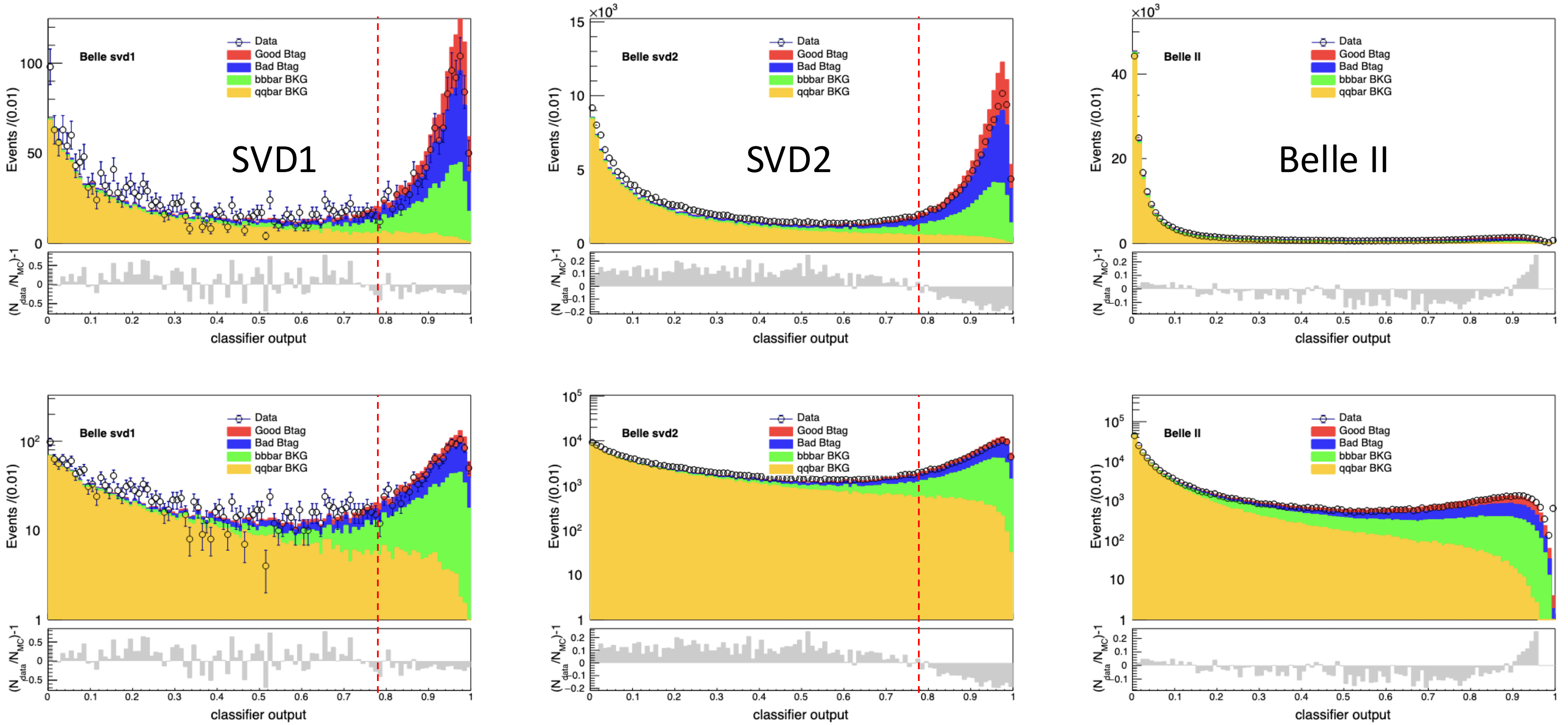
Outputs: 150

Hidden layers: 20, 50, 100



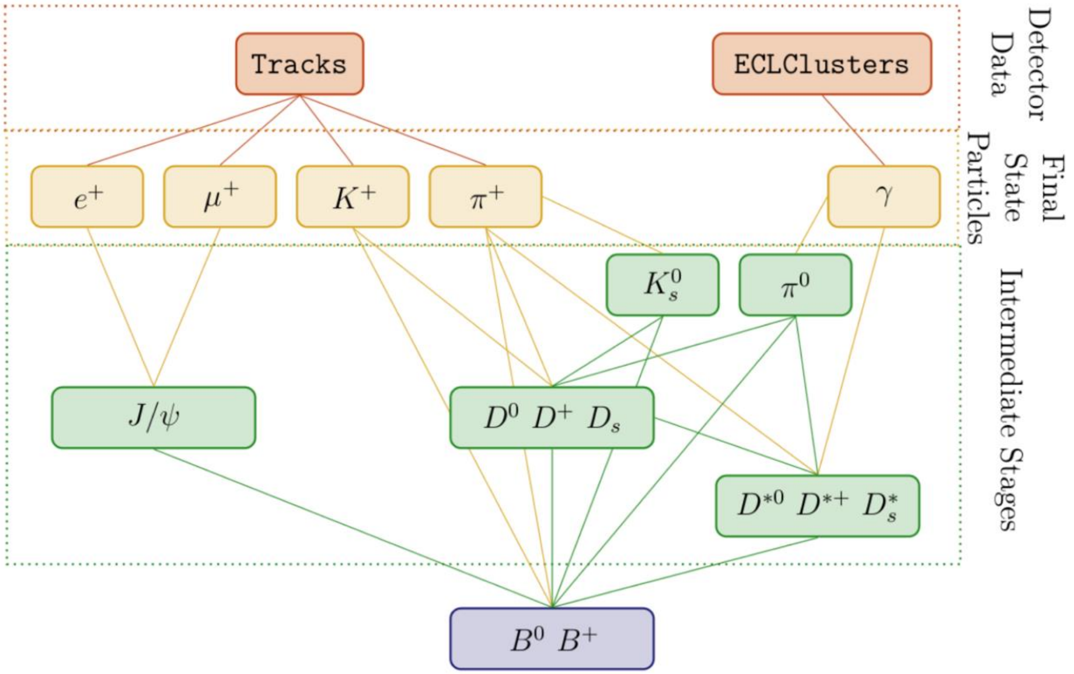
Classifier output shapes

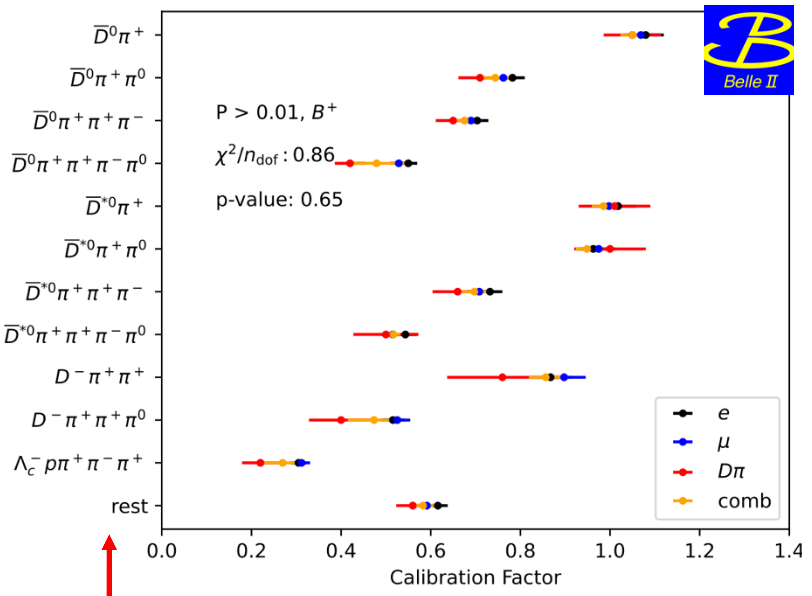
- Different for Belle and Belle II, although the sig-bg separation (ROC curves) are the same
- Easy to pick the classifier cut for Belle (more on that later)



Full Event Interpretation

- Utilizes O(200) decay channels with classifiers trained for each
- Reconstructs O(10000) unique decays chains
- Current efficiency ~0.7%, but this number is being impoved
- Its data-MC efficiency varies based on the B_{tag} reconstruction mode, subsequently it requires calibration, which, in turn, is signal mode dependent

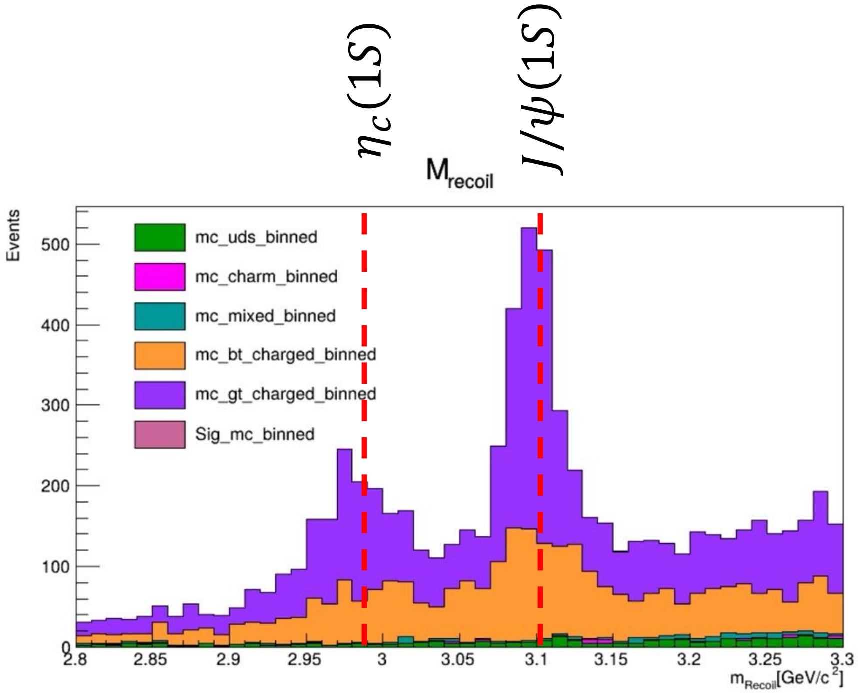


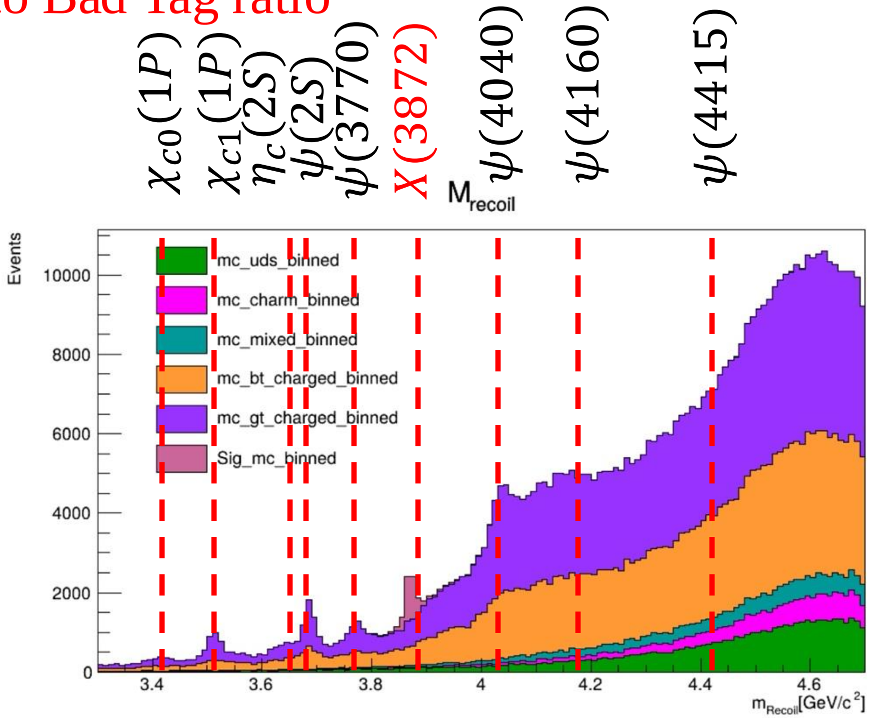


Notice 12 modes!

Signal composition

- The signal is composed from many possible charmonium resonances
- Peaking backgrounds under each signal peak arise from cuts on B_{tag} M_{BC} and ΔE - we call them Bad Tags (opposite to the truth matched Good Tags)
- Analytic fit has too many parameters and gives out high stat error
- Use MC histograms as template p.d.f.s for the fit – but the FEI gives out imperfect MC shape – need to do calibration
- Need information on the Good Tag to Bad Tag ratio





Attempt to use FEI CFs

Before FEI calibration | After FEI calibration

Belle
pion sample

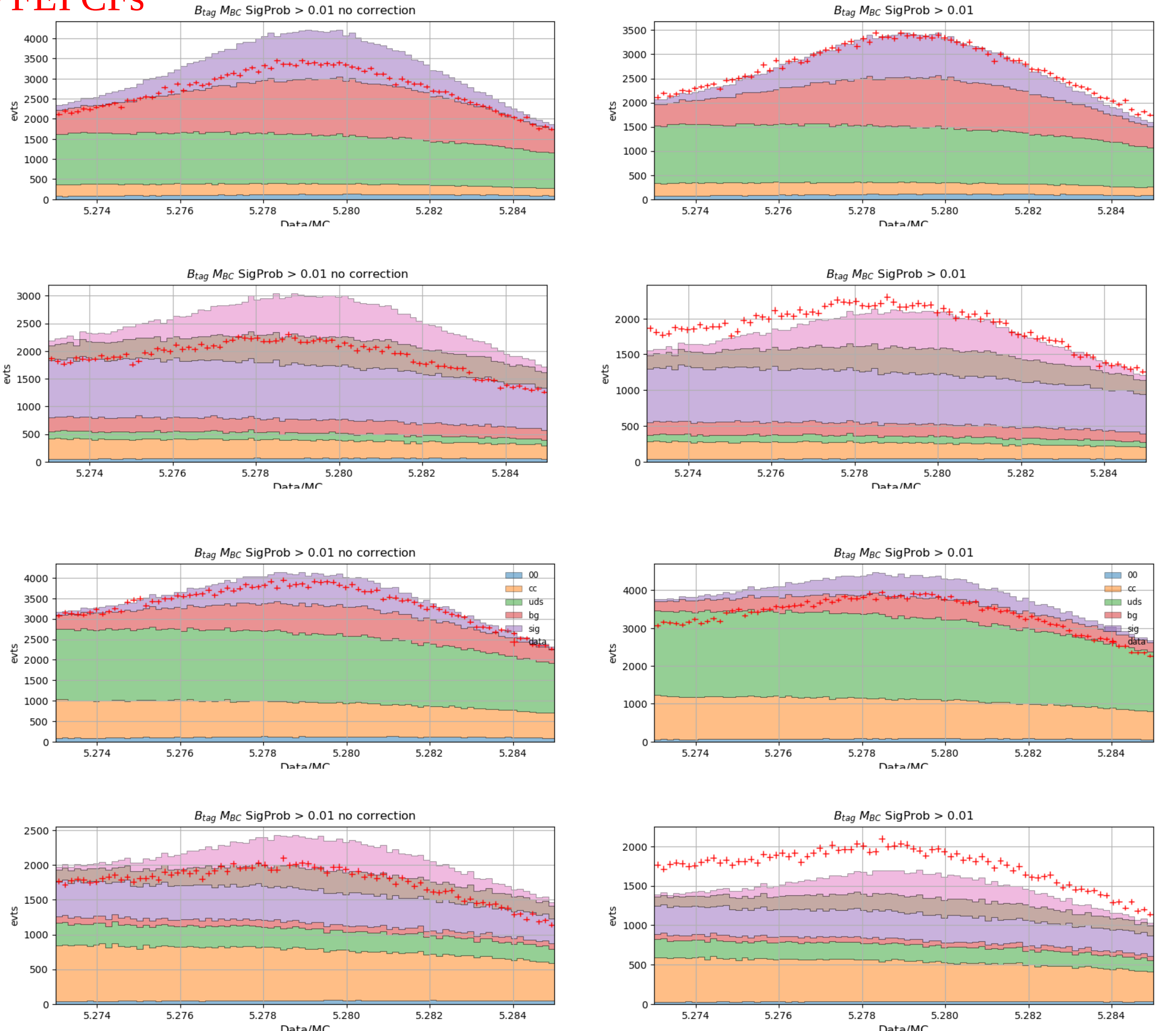
(We don’t apply the qq suppression or best candidate selection used in FEI calibration)

Belle II
pion sample

Belle
Kaon sample

(Different signal selection – different correction factors)

Belle II
Kaon sample



Good Tag fraction correction

- FEI makes an assumption that it is possible to predict data signal yields using MC information with applied calibration after separating the signal by the B_{tag}decay modes – one needs to follow all the cuts for it to be true.
- We make a weaker assumption that by using the same separation we can predict Good Tag - to - Bad Tag ratio in the signal.
- To calculate GTFC we use $B^+ \to D^{(*)0}\pi^+$(the “pion sample”) process, which follows the similar $b \to c$ tree level transition and has less backgrounds, so we can fit it using template p.d.f.s in $1.4 < M_{recoil} < 2.3$
- To validate GTFC we use sideband in $M_{recoil}$of the Kaon sample ($4.2 < M_{recoil} < 4.7$)

Signal fit structure

$$P_{s,t} = G_{s,t} P^{G}_{s,t} - (1 - G_{s,t}) P^{B}_{s,t}$$

Signal resonance ($J/\psi, X(3872)$ ...)

Tag mode ($D\pi, D\pi\pi$ ...)

Good tag fraction (from pion sample)

MC histogram for good tags

MC histogram for bad tags

$B^+ \to D^{(*)0}\pi^+$

- The recoil mass to pion represents charmed meson mass spectrum instead of charmonium mass spectrum
- We use the following MC histograms as a templates (matched with TopoAna package) for the fit, separated into Good Tag and Bad Tag:

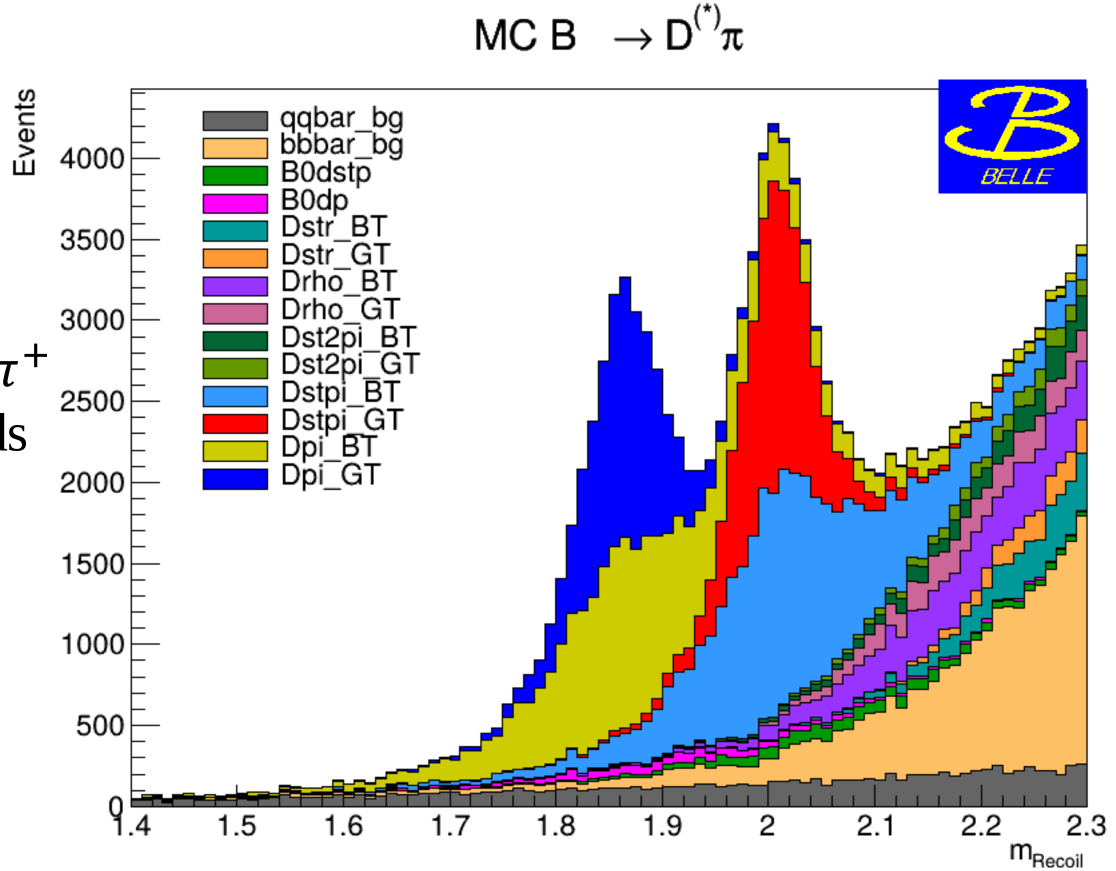
○ $D^{(*)0}\pi^+$

○ $D^{(*)0}\rho^+$

○ $D^{(**)}\pi^+$, composed from $D_1(2420)$, $D_2^{*0}(2460)$, $D_0^{*0}(2300)$, $D_1^0(2430)$

- Wrong signal $B^0 \to D^{(*)-}\pi^+$
- Combinatorial backgrounds

○ $q\bar{q}$ and $b\bar{b}$



$B^+ \rightarrow D^{(*)0}\pi^+$

- The # of $D^{*0}\pi^-$ events is parameterized with the branching-fraction ratio:

$$\frac{N(B^- \rightarrow D^{*0}\pi^-)}{N(B^- \rightarrow D^0\pi^-)} \equiv N^{D^{*0}\pi^-/D^0\pi^-} = \mathcal{B}^{D^{*0}\pi^-/D^0\pi^-} \cdot \frac{\epsilon_{D^{*0}\pi^-,t}}{\epsilon_{D^0\pi^-,t}}$$

Physics result (blinded) $\dfrac{Br(B^- \rightarrow D^{*0}\pi^-)}{Br(B^- \rightarrow D^0\pi^-)}$

BaBar (2006): 1.14 ± 0.07 ± 0.04
arXiv:hep-ex/0609033

- $D^0\rho^-, D^{*0}\rho^-$ yields are constrained to the $D^0\pi^-$ yield using PDG BRs and uncertainties $\oplus$ MC stat err
- $D^+\pi^-, D^{*+}\pi^-$ are similarly constrained, but with a larger (50%) uncertainty to account for unknown FEI $B^+ \rightarrow B^0$ wrong signal (their yield is very small)
- $D^{**0}\pi^-$ is similarly constrained, with a 50% uncertainty, to allow for incompleteness/inaccuracy of the modes and BRs in MC

Handling of the good-tag fractions

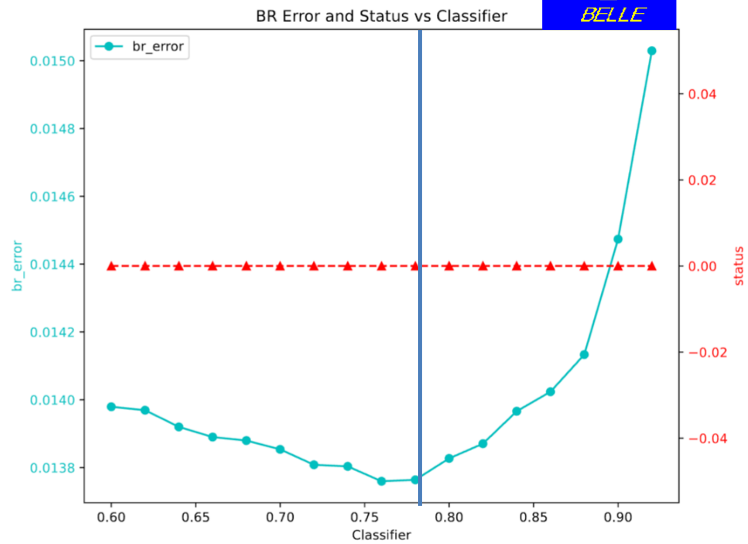
- We use a single data/MC correction factor (per tag mode)

For $D^0\pi^-$: $$G_{D^0\pi^-,t} = G^{\mathrm{MC}}_{D^0\pi^-,t}\, G^{\mathrm{data/MC}}_t$$

To be used in kaon sample fit

For $D^{*0}\pi^-, D^0\rho^-, D^{*0}\rho^-, D^{**0}\pi^-$: $$G_{s,t} = G_{D^0\pi^-,t}\, G^{s/D^0\pi^-}_t$$

The good-tag ratio relative to $D^0\pi^-$: constrained to MC, allowed to float to within 5%



Note:

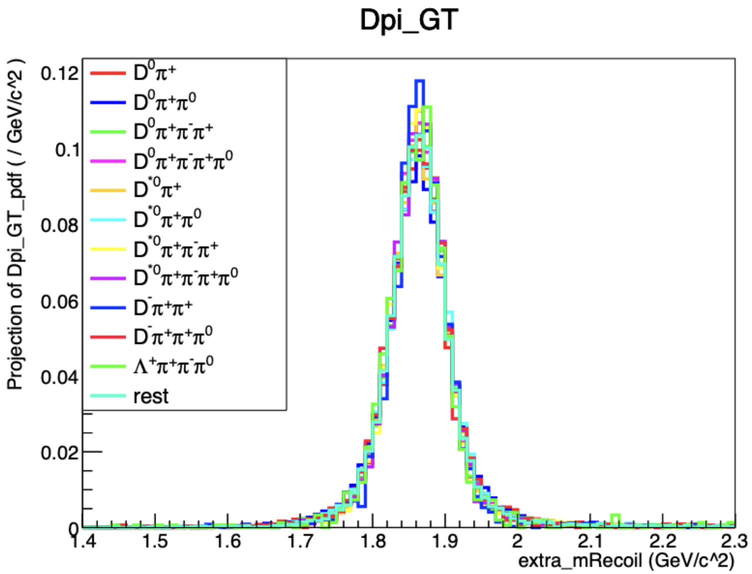
- ○ We fit simultaneously the 12 tag modes, and extract branching-fraction ratios (rather than absolute BRs)
- ○ We fine-tune the classifier cut for the best Br ratio uncertainty on Monte Carlo sim fit

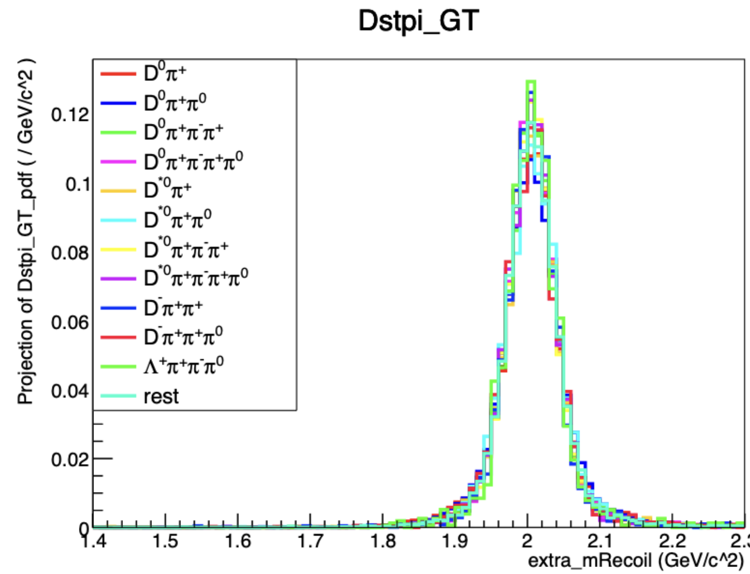
Good-tag fractions relative to $D^0\pi^-$ in MC

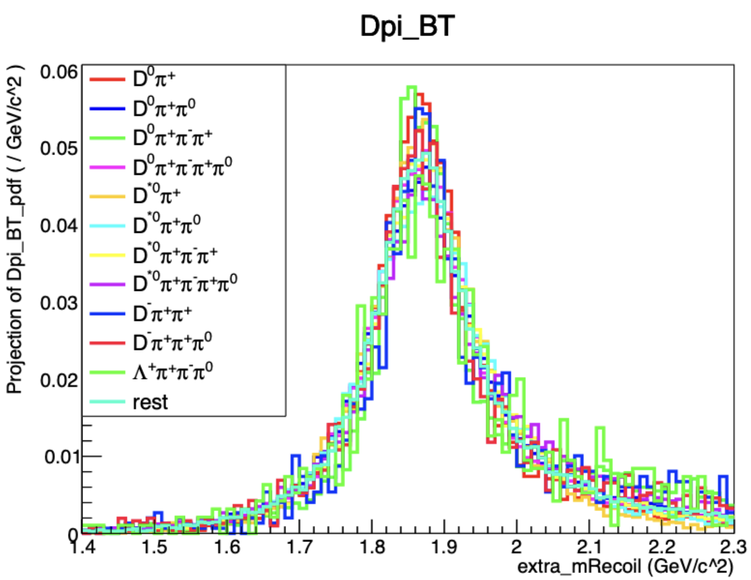
The values that $G_t^{s/D^0\pi^-}$ is constrained to

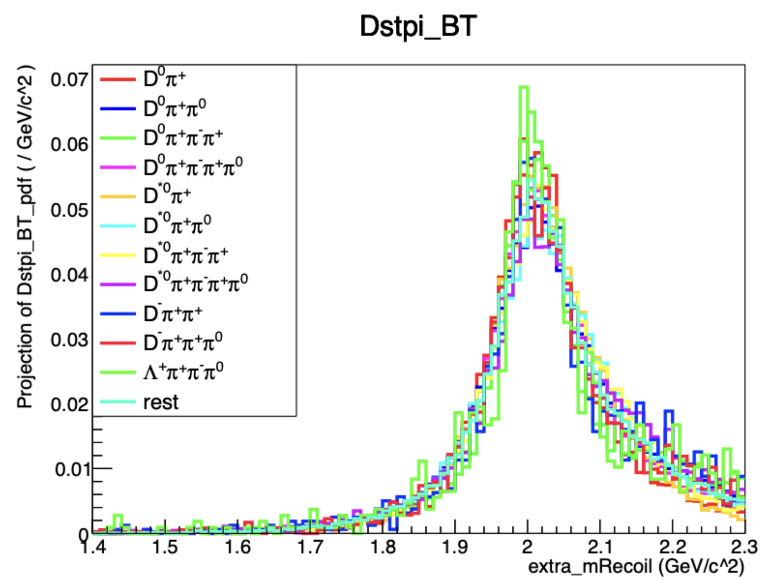
Mode	RG $D^*\pi$	RG $D^{**}\pi$	RG $D\rho$	RG $D^*\rho$
$D^0\pi^+$	0.99 ± 0.050	0.97 ± 0.048	0.96 ± 0.048	0.95 ± 0.047
$D^0\pi^+\pi^0$	0.97 ± 0.048	0.93 ± 0.046	0.90 ± 0.045	0.87 ± 0.044
$D^0\pi^+\pi^-\pi^+$	1.00 ± 0.050	0.90 ± 0.045	1.01 ± 0.051	1.02 ± 0.051
$D^0\pi^+\pi^-\pi^+\pi^0$	0.97 ± 0.049	0.94 ± 0.047	0.89 ± 0.044	0.86 ± 0.043
$D^{*0}\pi^+$	0.95 ± 0.047	0.92 ± 0.046	0.90 ± 0.045	0.84 ± 0.042
$D^{*0}\pi^+\pi^0$	0.90 ± 0.045	0.86 ± 0.043	0.83 ± 0.042	0.75 ± 0.038
$D^{*0}\pi^+\pi^-\pi^+$	0.94 ± 0.047	0.90 ± 0.045	0.90 ± 0.045	0.85 ± 0.042
$D^{*0}\pi^+\pi^-\pi^+\pi^0$	0.95 ± 0.047	0.94 ± 0.047	0.87 ± 0.043	0.82 ± 0.041
$D^-\pi^+\pi^+$	1.01 ± 0.051	0.96 ± 0.048	1.00 ± 0.050	0.97 ± 0.048
$D^-\pi^+\pi^+\pi^0$	0.95 ± 0.048	0.90 ± 0.045	0.96 ± 0.048	0.94 ± 0.047
$\Lambda^+\pi^+\pi^-\pi^0$	0.96 ± 0.048	0.81 ± 0.041	0.96 ± 0.048	0.90 ± 0.045
rest	0.95 ± 0.048	0.89 ± 0.045	0.90 ± 0.045	0.87 ± 0.043

The Mrec shapes have small tag-mode dependence (which we account for)

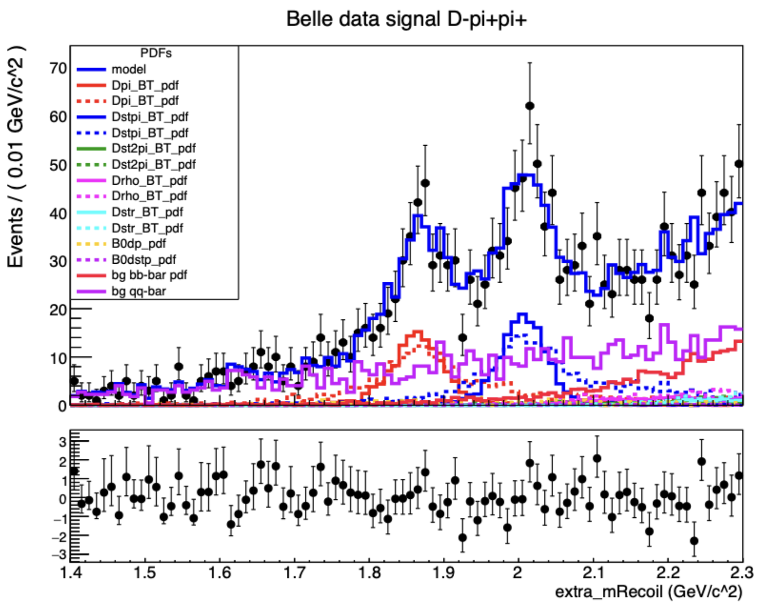


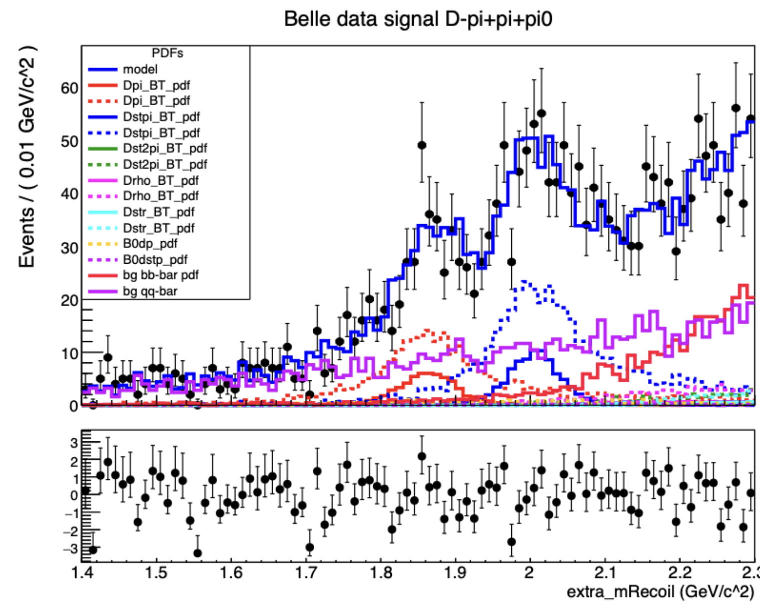


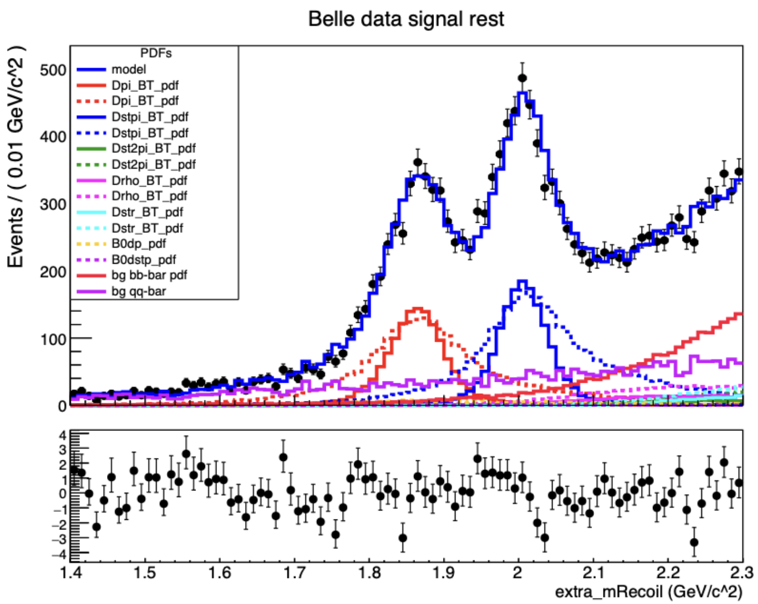


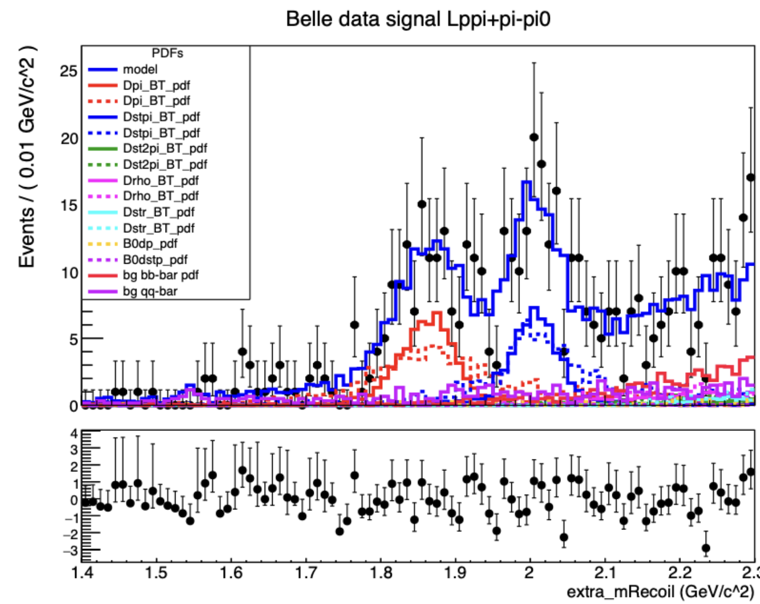


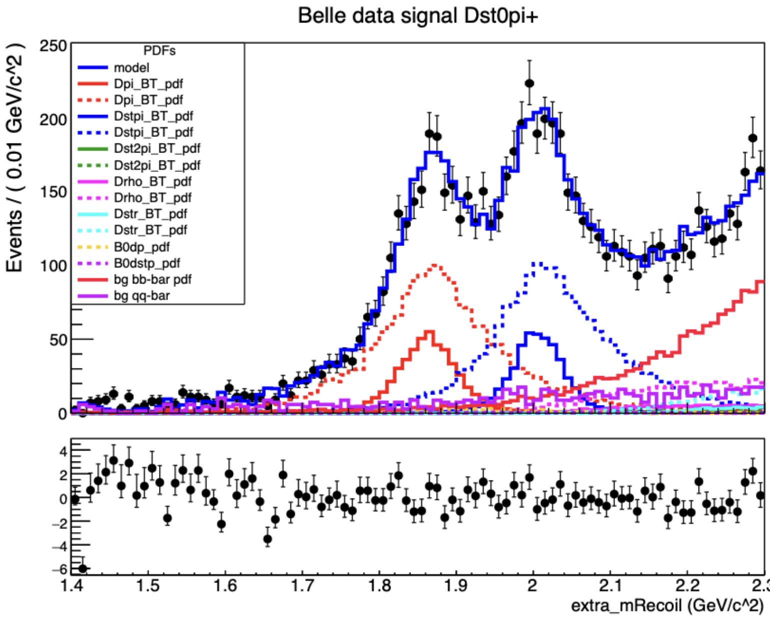
Single-tag-mode fit plots

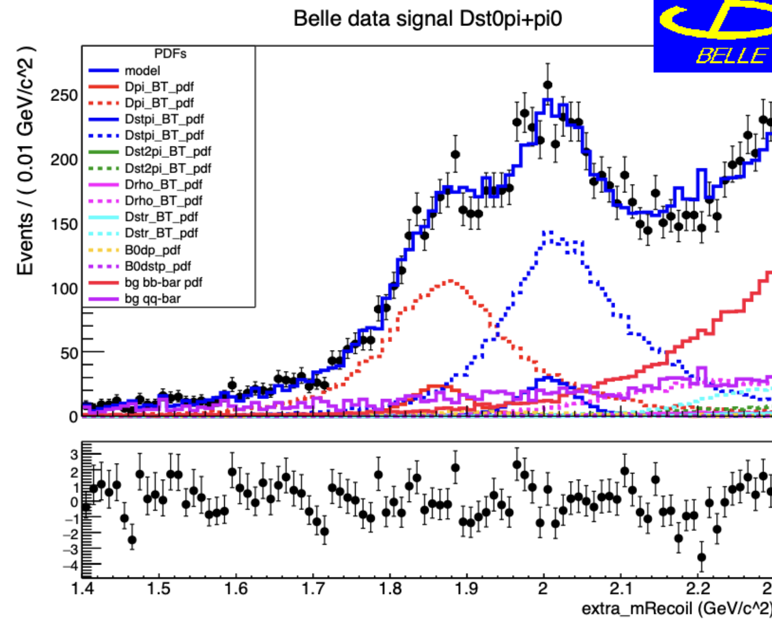


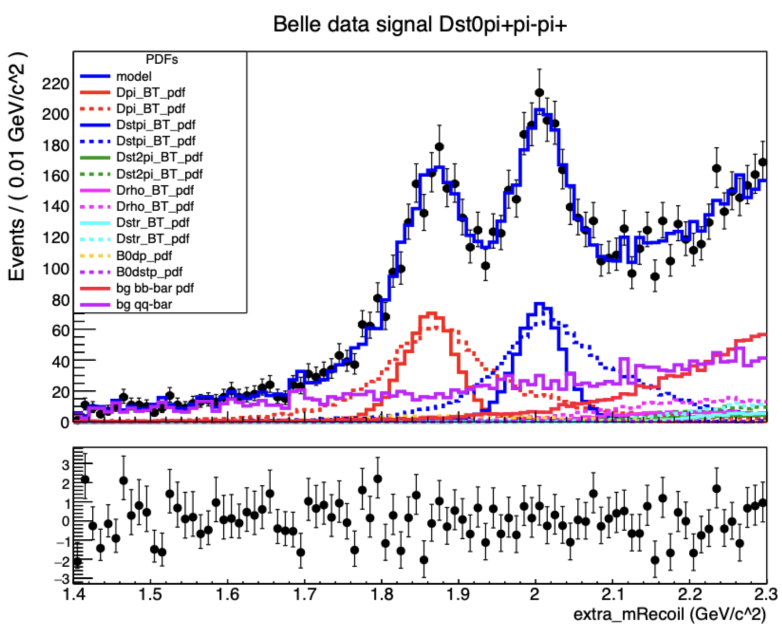


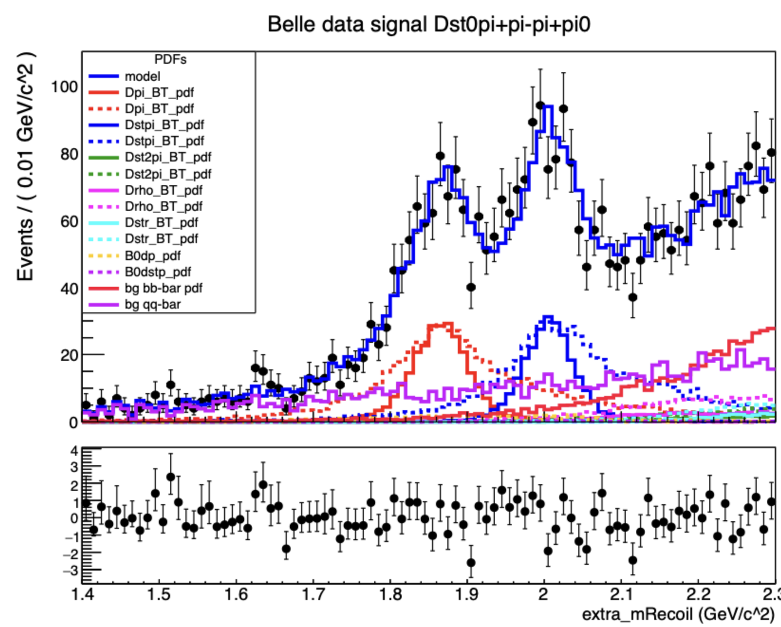


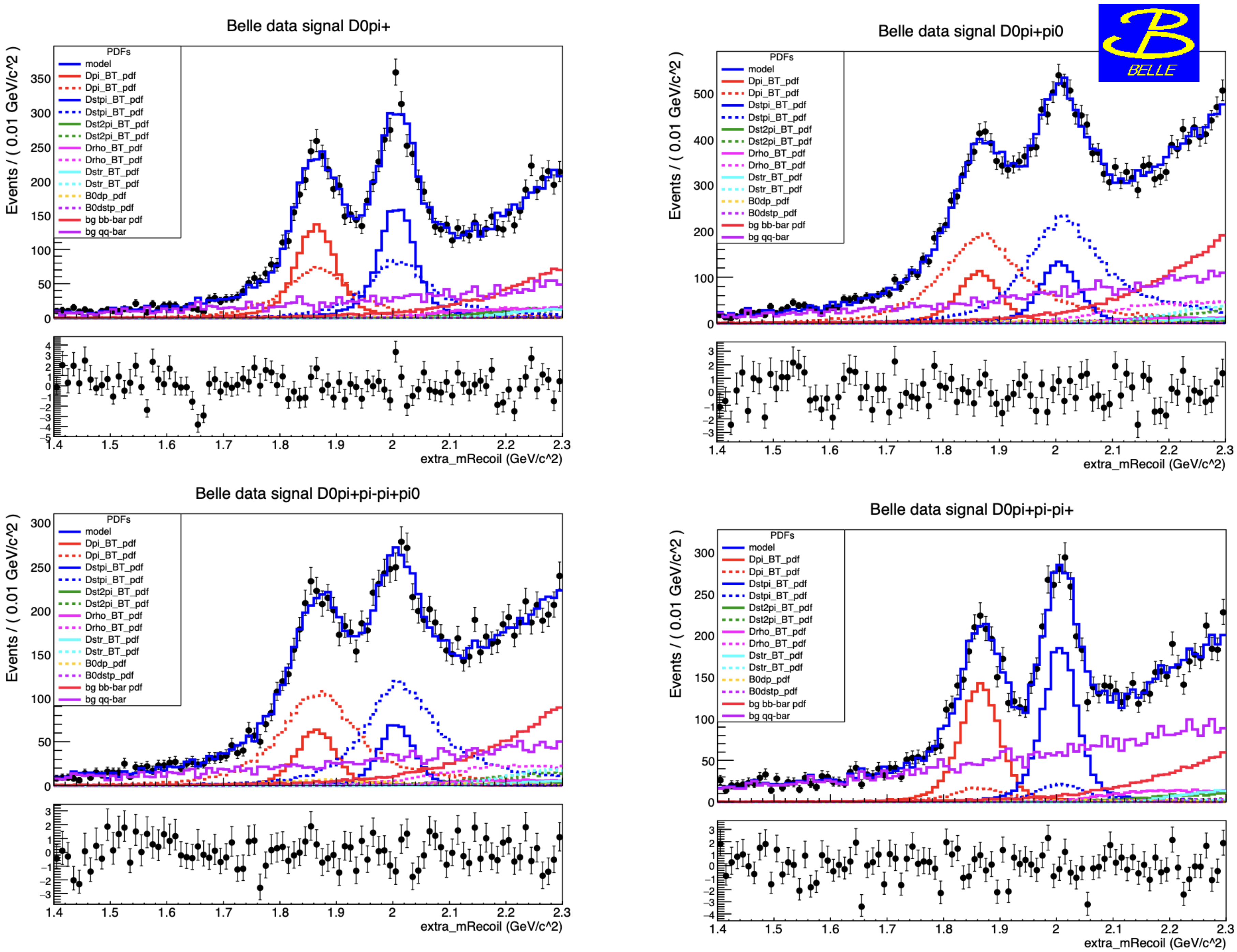



Belle data signal Dst0pi+
PDFs
model
Dpi_BT_pdf
Dpi_BT_pdf
Dstpi_BT_pdf
Dstpi_BT_pdf
Dst2pi_BT_pdf
Dst2pi_BT_pdf
Drho_BT_pdf
Drho_BT_pdf
Dstr_BT_pdf
Dstr_BT_pdf
B0dp_pdf
B0dstp_pdf
bg bb-bar pdf
bg qq-bar
Events / (0.01 GeV/c^2)
extra_mRecoil (GeV/c^2)

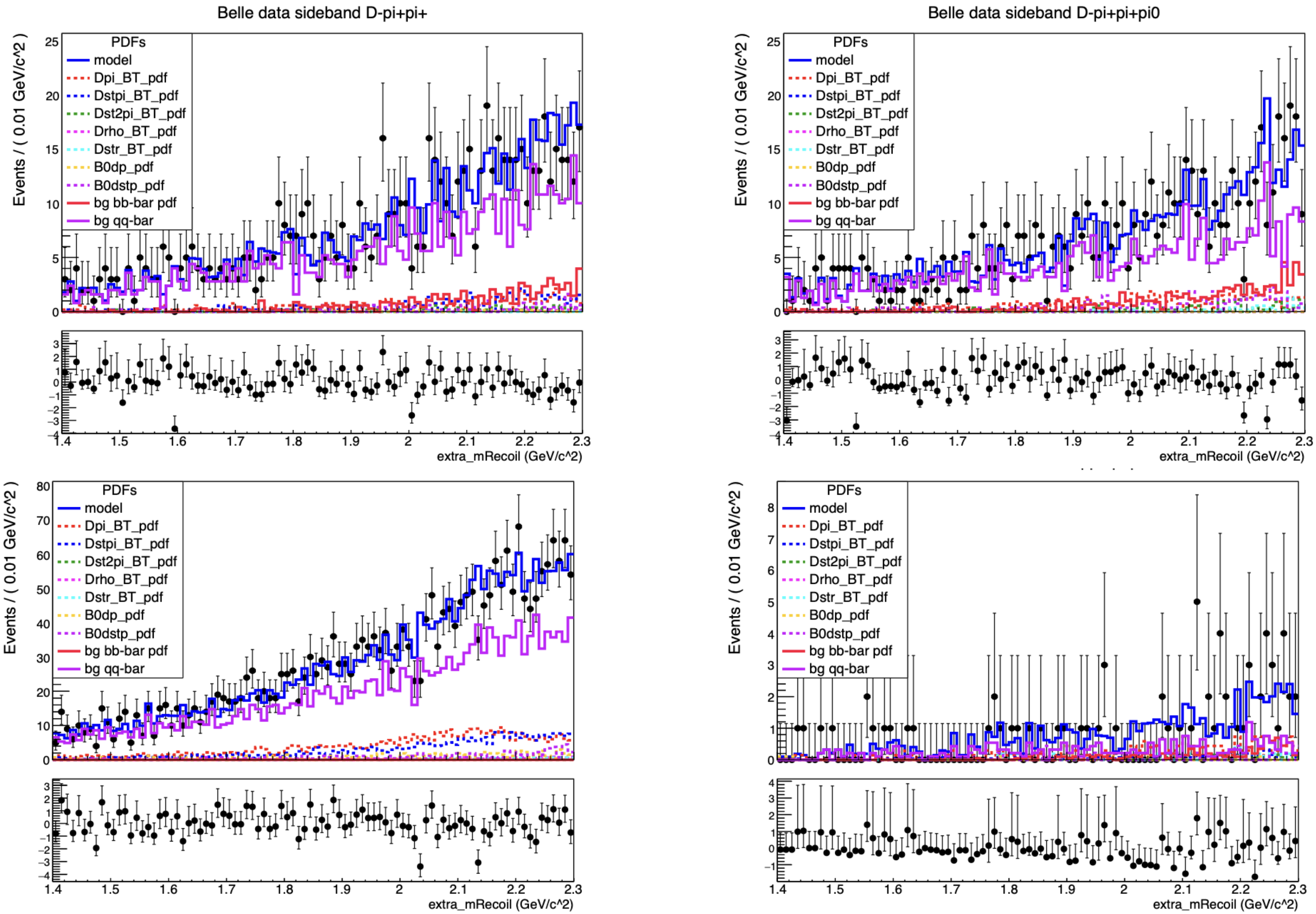

Belle data signal Dst0pi+pi0
PDFs
model
Dpi_BT_pdf
Dpi_BT_pdf
Dstpi_BT_pdf
Dstpi_BT_pdf
Dst2pi_BT_pdf
Dst2pi_BT_pdf
Drho_BT_pdf
Drho_BT_pdf
Dstr_BT_pdf
Dstr_BT_pdf
B0dp_pdf
B0dstp_pdf
bg bb-bar pdf
bg qq-bar
Events / (0.01 GeV/c^2)
extra_mRecoil (GeV/c^2)

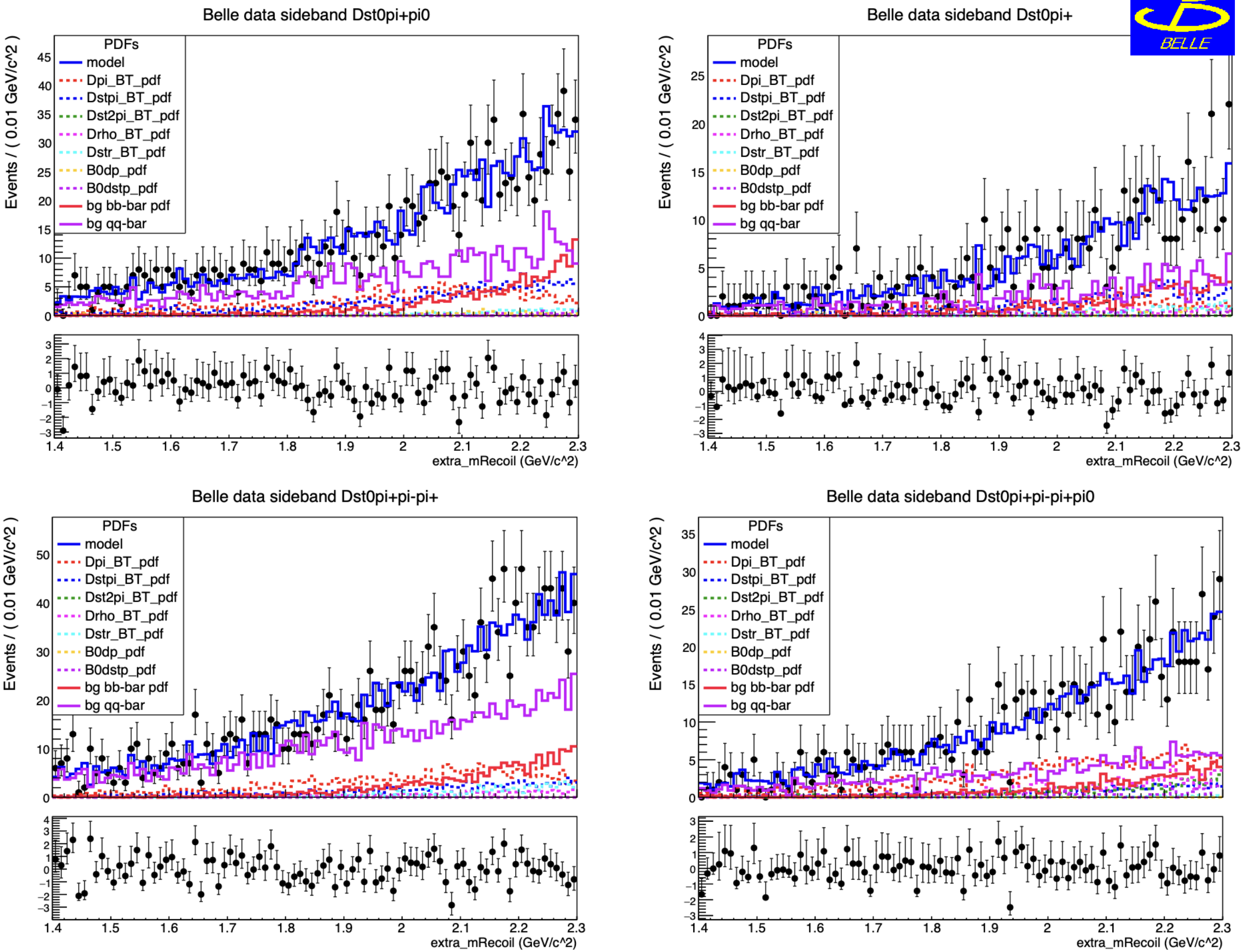

Belle data signal Dst0pi+pi-pi+
PDFs
model
Dpi_BT_pdf
Dpi_BT_pdf
Dstpi_BT_pdf
Dstpi_BT_pdf
Dst2pi_BT_pdf
Dst2pi_BT_pdf
Drho_BT_pdf
Drho_BT_pdf
Dstr_BT_pdf
Dstr_BT_pdf
B0dp_pdf
B0dstp_pdf
bg bb-bar pdf
bg qq-bar
Events / (0.01 GeV/c^2)
extra_mRecoil (GeV/c^2)


Belle data signal Dst0pi+pi-pi+pi0
PDFs
model
Dpi_BT_pdf
Dpi_BT_pdf
Dstpi_BT_pdf
Dstpi_BT_pdf
Dst2pi_BT_pdf
Dst2pi_BT_pdf
Drho_BT_pdf
Drho_BT_pdf
Dstr_BT_pdf
Dstr_BT_pdf
B0dp_pdf
B0dstp_pdf
bg bb-bar pdf
bg qq-bar
Events / (0.01 GeV/c^2)
extra_mRecoil (GeV/c^2)

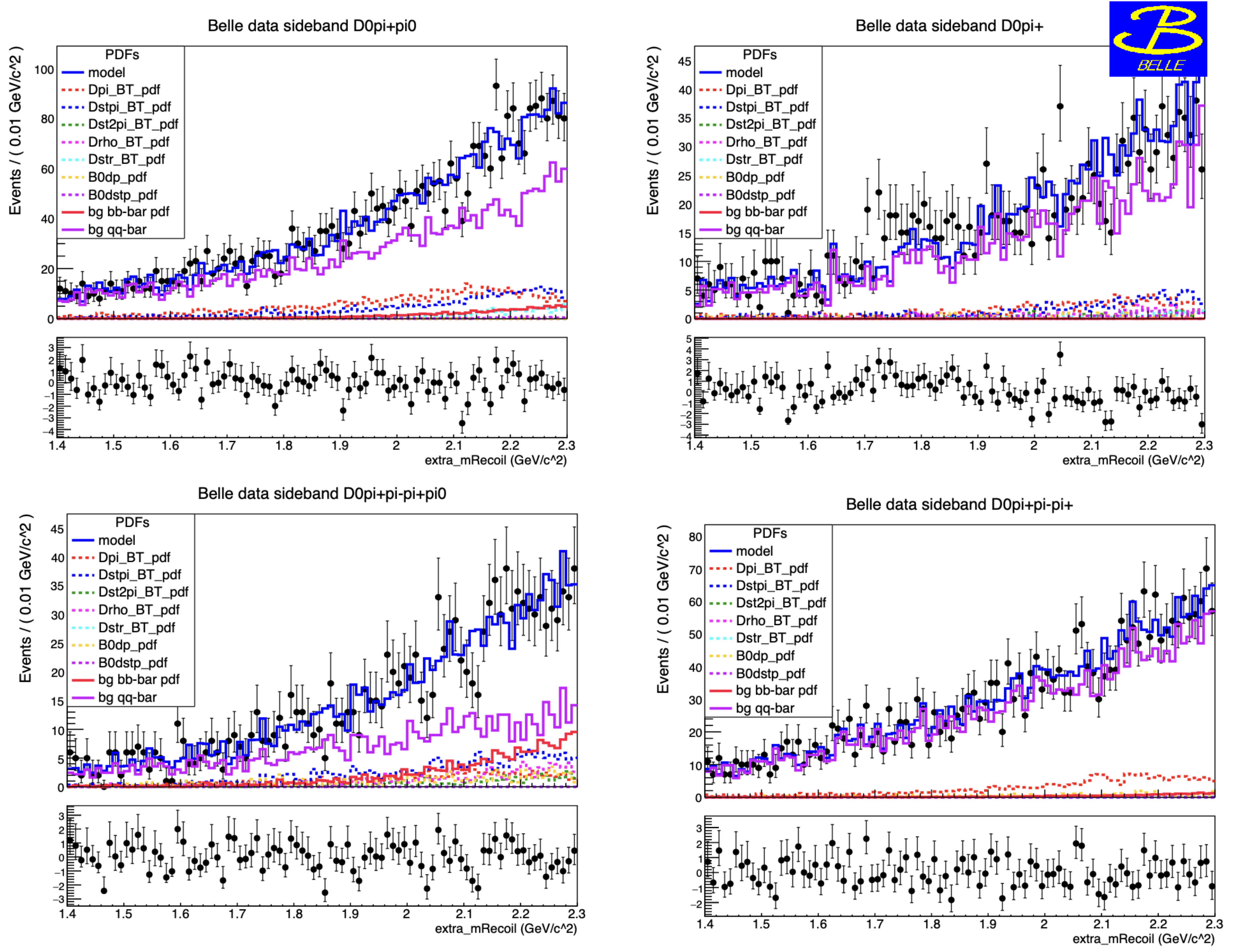

Belle data signal D0pi+
Belle data signal D0pi+pi0
Belle data signal D0pi+pi-pi+pi0
Belle data signal D0pi+pi-pi+
BELLE
PDFs
model
Dpi_BT_pdf
Dpi_BT_pdf
Dstpi_BT_pdf
Dstpi_BT_pdf
Dst2pi_BT_pdf
Dst2pi_BT_pdf
Drho_BT_pdf
Drho_BT_pdf
Dstr_BT_pdf
Dstr_BT_pdf
B0dp_pdf
B0dstp_pdf
bg bb-bar pdf
bg qq-bar
Events / (0.01 GeV/c^2)
extra_mRecoil (GeV/c^2)

M_{bc}^{tag} Sideband fits





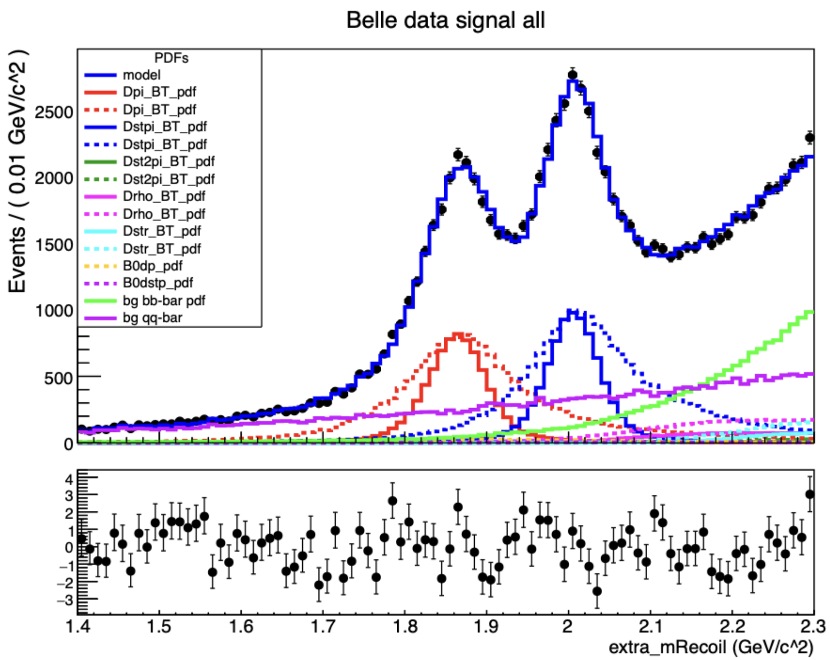
Belle data sideband Dst0pi+pi0
Belle data sideband Dst0pi+
Belle data sideband Dst0pi+pi-pi+
Belle data sideband Dst0pi+pi-pi+pi0
PDFs
model
Dpi_BT_pdf
Dstpi_BT_pdf
Dst2pi_BT_pdf
Drho_BT_pdf
Dstr_BT_pdf
B0dp_pdf
B0dstp_pdf
bg bb-bar pdf
bg qq-bar
Events / (0.01 GeV/c^2)
extra_mRecoil (GeV/c^2)
BELLE

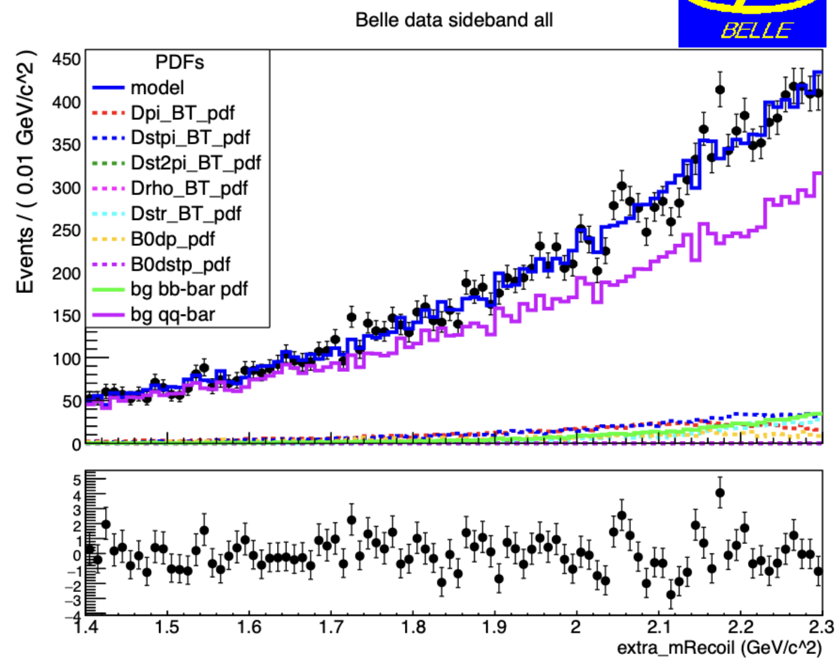


Belle data sideband D0pi+pi0
Belle data sideband D0pi+
Belle data sideband D0pi+pi-pi+pi0
Belle data sideband D0pi+pi-pi+
PDFs
model
Dpi_BT_pdf
Dstpi_BT_pdf
Dst2pi_BT_pdf
Drho_BT_pdf
Dstr_BT_pdf
B0dp_pdf
B0dstp_pdf
bg bb-bar pdf
bg qq-bar
Events / (0.01 GeV/c^2)
extra_mRecoil (GeV/c^2)
BELLE

All tag modes together

- This is just to show what a fit to everything looks like (it ignores tag-mode differences so we don't use the results of this fit)





From the simultaneous fit we can observe the uncertainty of the $\frac{Br(B \to D^{*}\pi)}{Br(B \to D\pi)}$ (the ratio itself is blinded) to be 1.6%, which is consistent with the uncertainty from the MC simultaneous fit we did for the classifier cut optimisation. For reference, Babar had 7% statistical uncertainty.

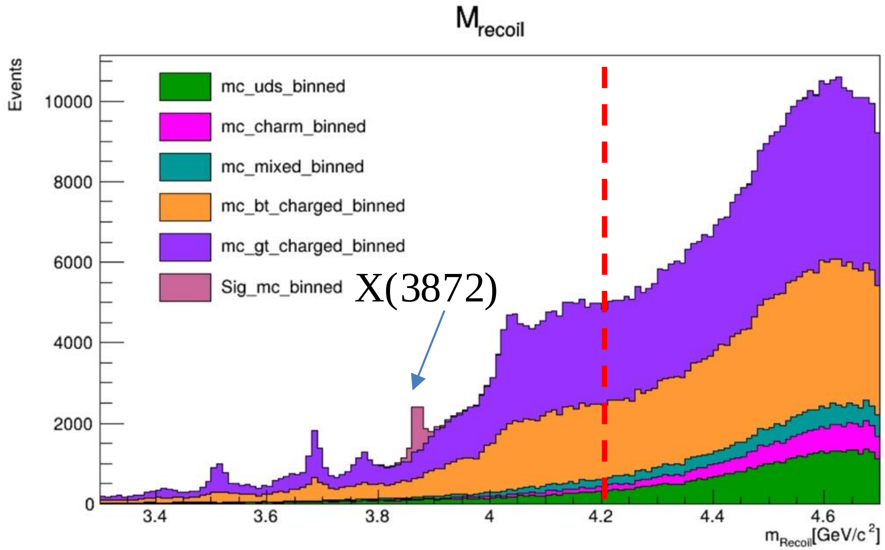
A fit to 1 stream of Belle MC is good

(all tag modes together)

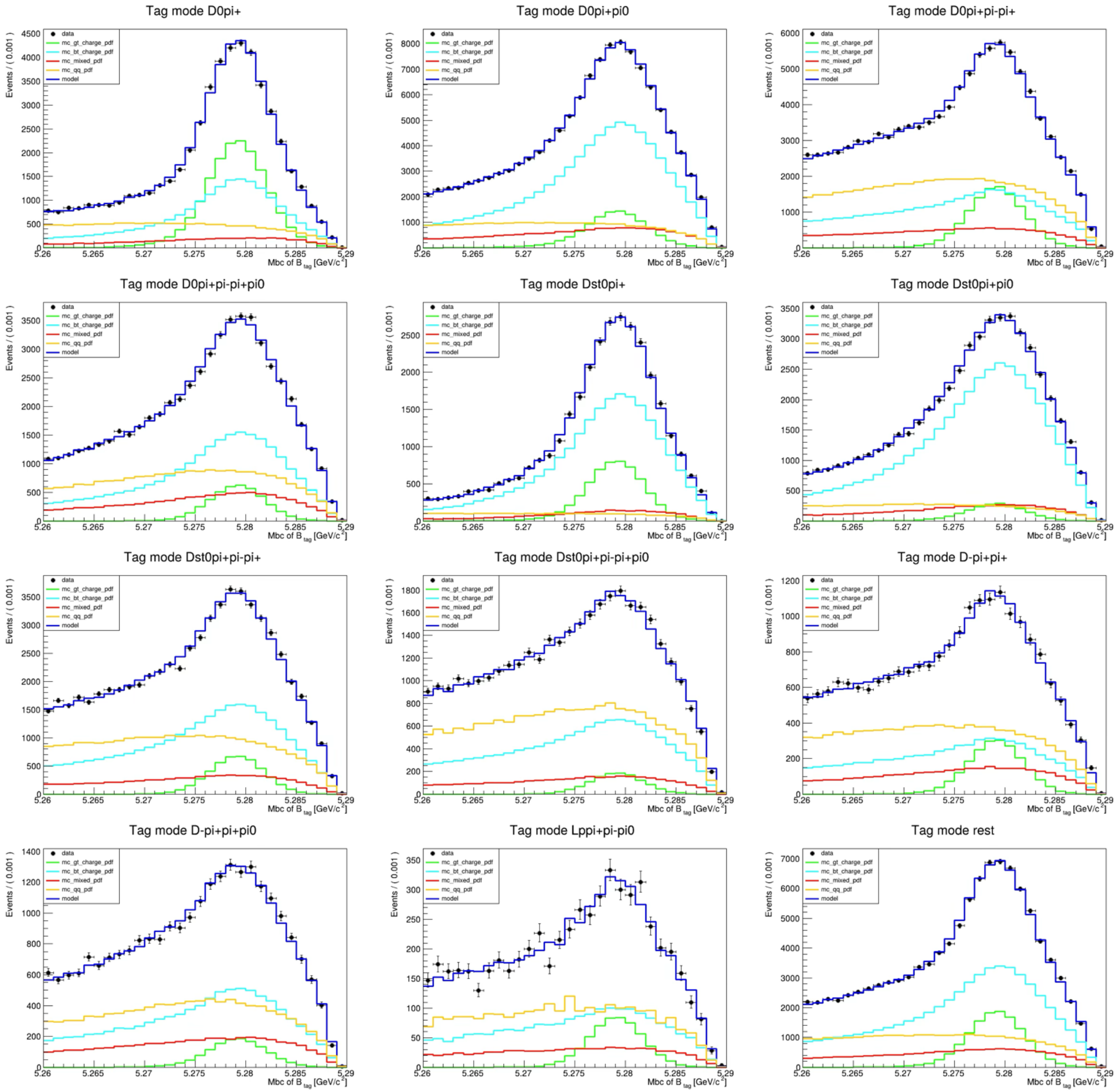
Parameter	**Initial Value**	**Final Value**	**Relative Diff**
$ND\pi$	38062	37767 ± 631	-0.468
N_{bg}	31782	36065 ± 2523	1.698
$RGD\pi$	1.000	1.032 ± 0.039	0.810
$RG\rho$	0.909	0.921 ± 0.090	0.129
$RGD^{**}\pi$	0.919	0.916 ± 0.081	-0.039
$RGD^{*}\pi$	0.959	0.963 ± 0.041	0.084
$RGD^{*}\rho$	0.876	0.850 ± 0.123	-0.216
$RNB^0D\pi$	0.051	0.052 ± 0.023	0.049
$RNB^0D^{*}\pi$	0.062	0.065 ± 0.027	0.101
$RND\rho$	0.339	0.348 ± 0.019	0.460
$RND^{**}\pi$	0.124	0.063 ± 0.054	-1.130
$RND^{*}\pi$	1.074	1.060 ± 0.023	-0.609
$RND^{*}\rho$	0.156	0.114 ± 0.024	-1.783

GTFC validation using kaon sideband ($4.2 < M_{recoil} < 4.7$)

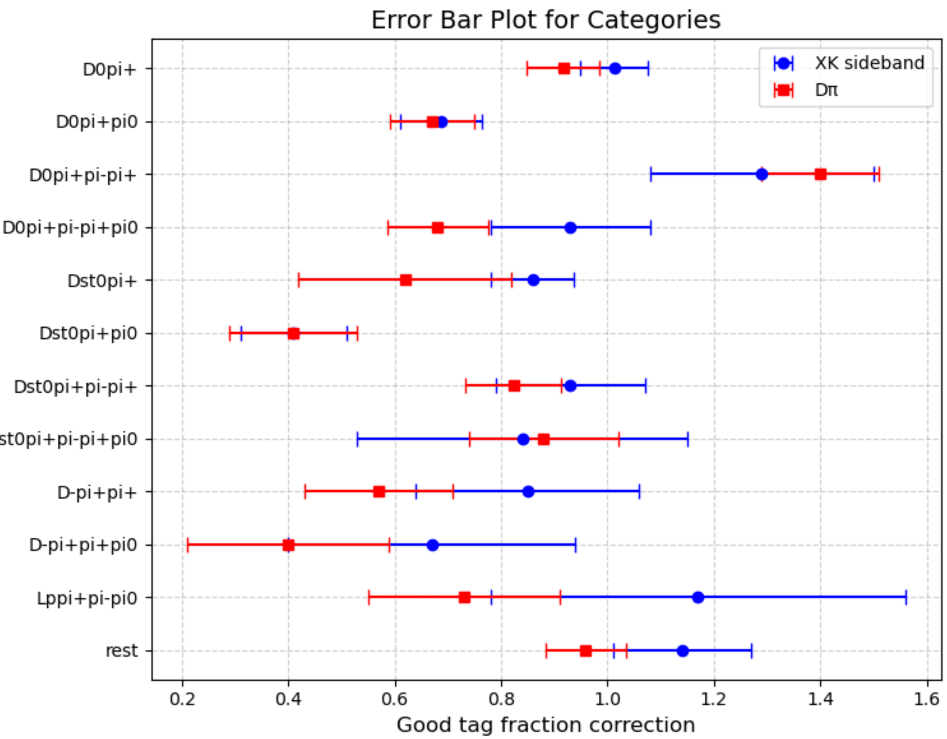
- The high mass region in the kaon sample has large amount of events, so we use this sideband to fit the B_{tag} M_{BC} distribution
- The fit function again uses MC templates, but now no separation on signal modes, only by the MC sample and Good Tag / Bad Tag for the charged sample
- Charged BT yield to Mixed yield ratio is constrained to MC with 50% uncertainty
- The X(3872) is plotted using signal MC only for reference



Sideband fits per tag mode



GTFC validation results



Kaon sideband → $GTFC_k$ Pion signal → $GTFC_\pi$

modes	$GTFC_k$	$GTFC_\pi$	$N\sigma$
D0pi+	1.013 ± 0.064	0.917 ± 0.068	1.024
D0pi+pi0	0.687 ± 0.076	0.671 ± 0.079	0.14
D0pi+pi-pi+	1.29 ± 0.21	1.40 ± 0.11	-0.46
D0pi+pi-pi+pi0	0.93 ± 0.15	0.681 ± 0.095	1.39
Dst0pi+	0.859 ± 0.079	0.62 ± 0.20	1.14
Dst0pi+pi0	0.41 ± 0.10	0.41 ± 0.12	0.0028
Dst0pi+pi-pi+	0.93 ± 0.14	0.823 ± 0.089	0.62
Dst0pi+pi-pi+pi0	0.84 ± 0.31	0.88 ± 0.14	-0.12
D-pi+pi+	0.85 ± 0.21	0.57 ± 0.14	1.094
D-pi+pi+pi0	0.67 ± 0.27	0.40 ± 0.19	0.84
Lppi+pi-pi0	1.17 ± 0.39	0.73 ± 0.18	1.041
rest	1.14 ± 0.13	0.959 ± 0.075	1.18

The GTFC are mostly within 1 sigma agreement, but to account for the differences, for the Kaon signal fit we will use the combined uncertainty for the GTFC constraint.

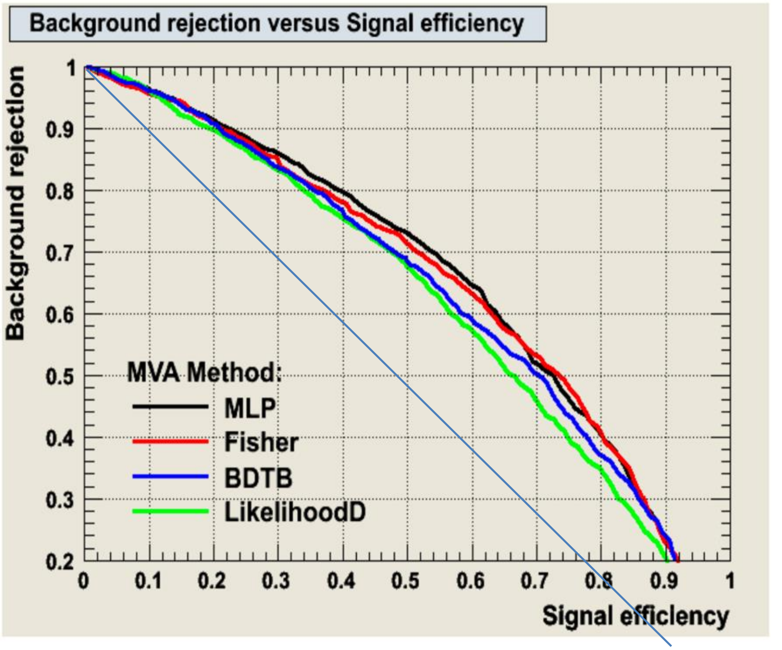
To do list

- Perform the pion-sample fit for Belle II, obtain final good-tag-fraction corrections and Br ratio for $D^{*0}\pi^{-}/D^{0}\pi^{-}$
- Complete the $B \rightarrow X_{cc}K$ fit using the same methodology, and constraining the GTFCs to the pion sample results
- Systematic uncertainties that aren't nuisance parameters:
  - MC statistics
  - Classifier-efficiency dependence on kaon/pion momentum and X decay mode

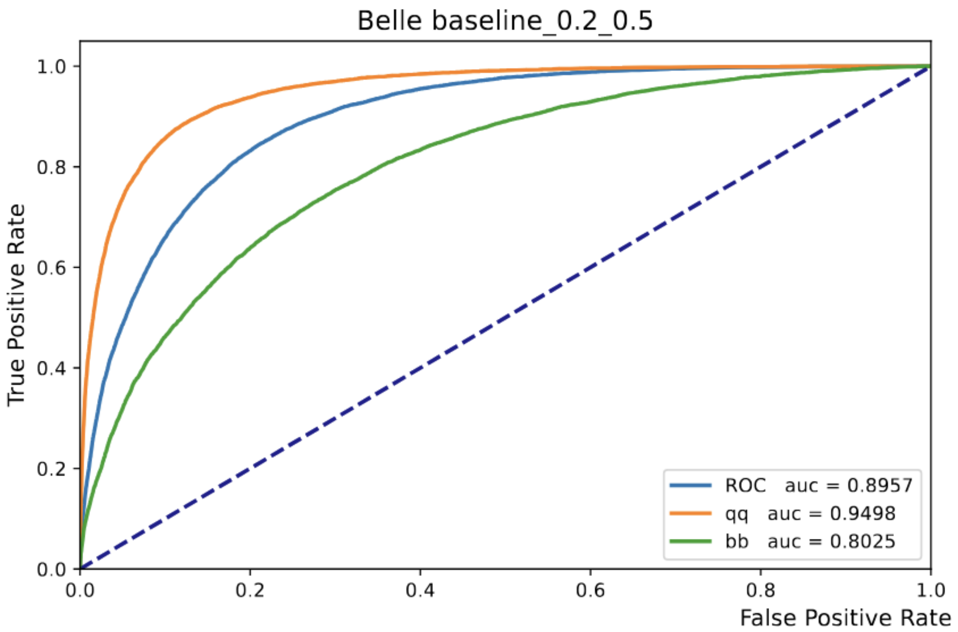
Backup slides

ROC curves of MVA clasisfier

- BABAR’s:

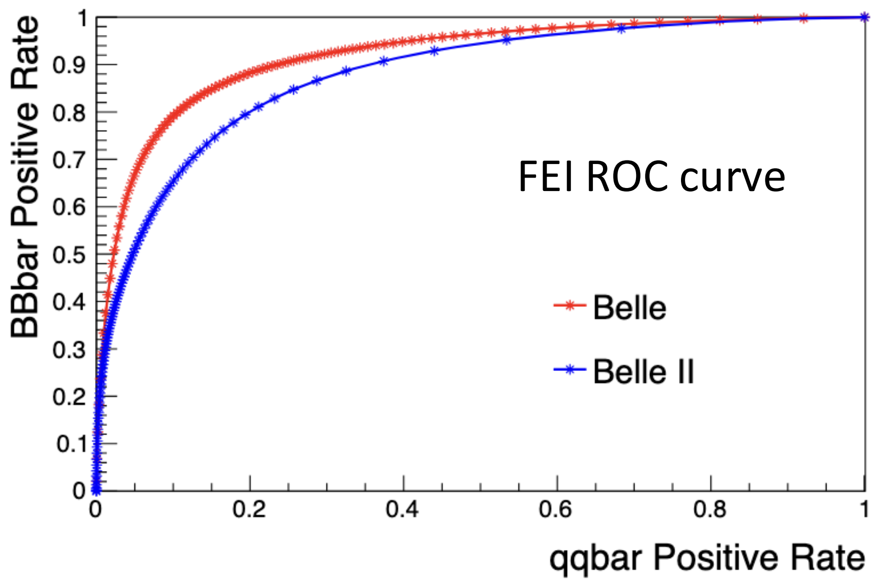


- Ours:

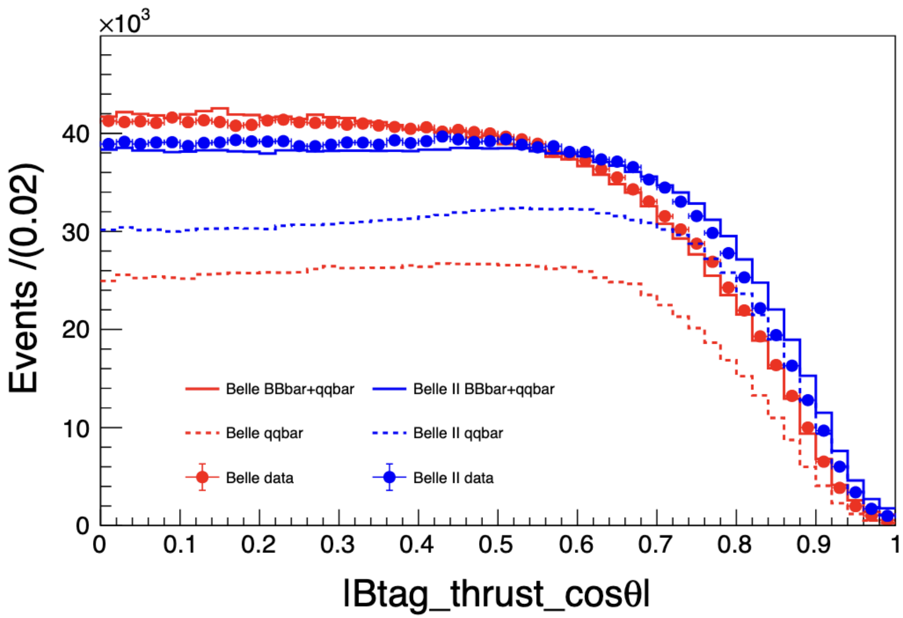


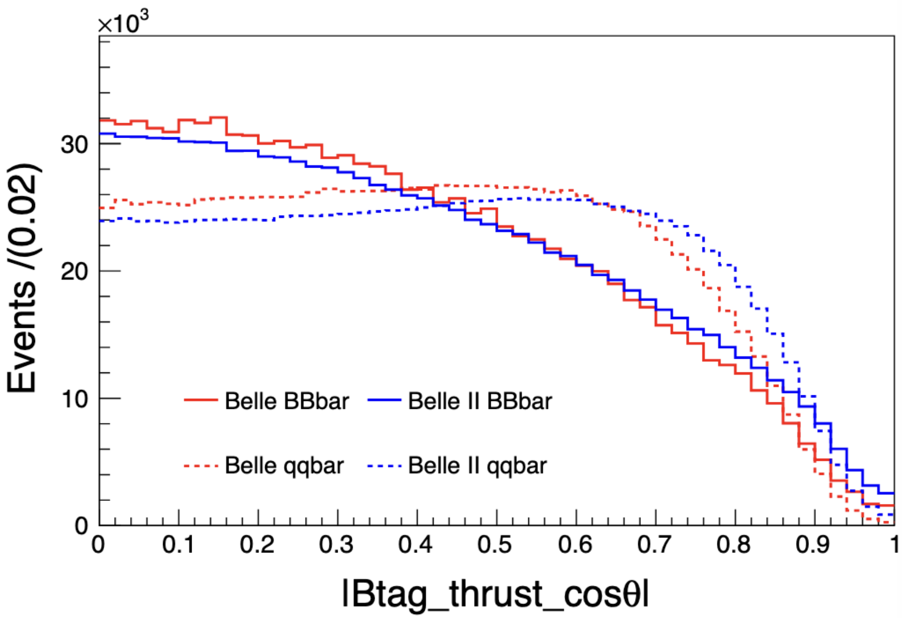
We have early studies showing that the classifier output doesn’t depend on recoil mass, but they need to be redone.

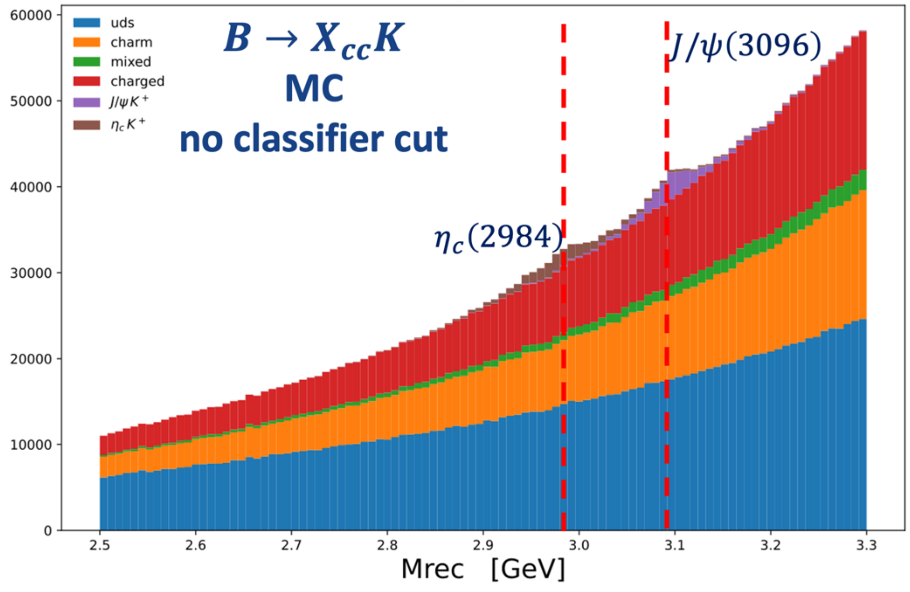
Probably due to more efficient qq suppression of FEI for Belle

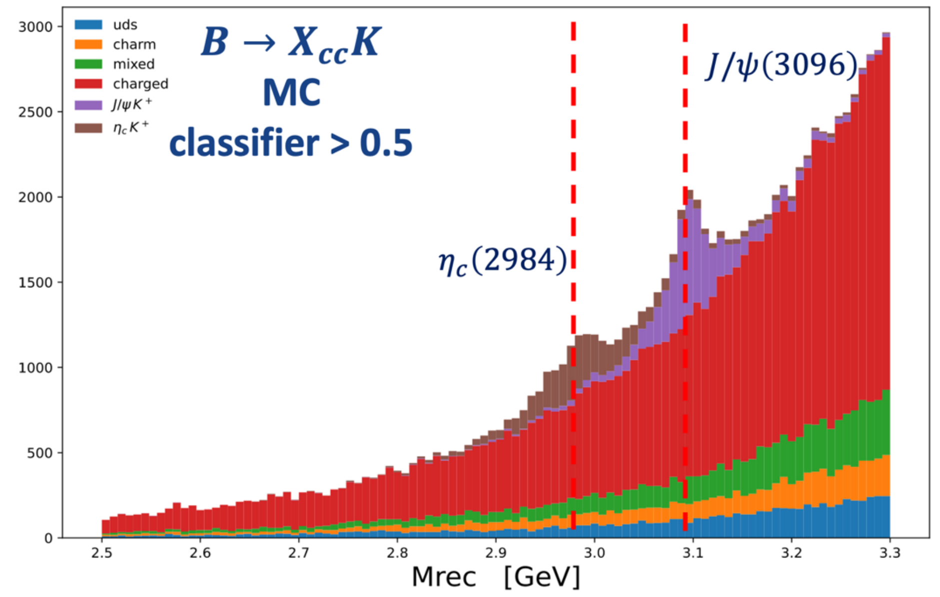


Belle II events are more continuum-like

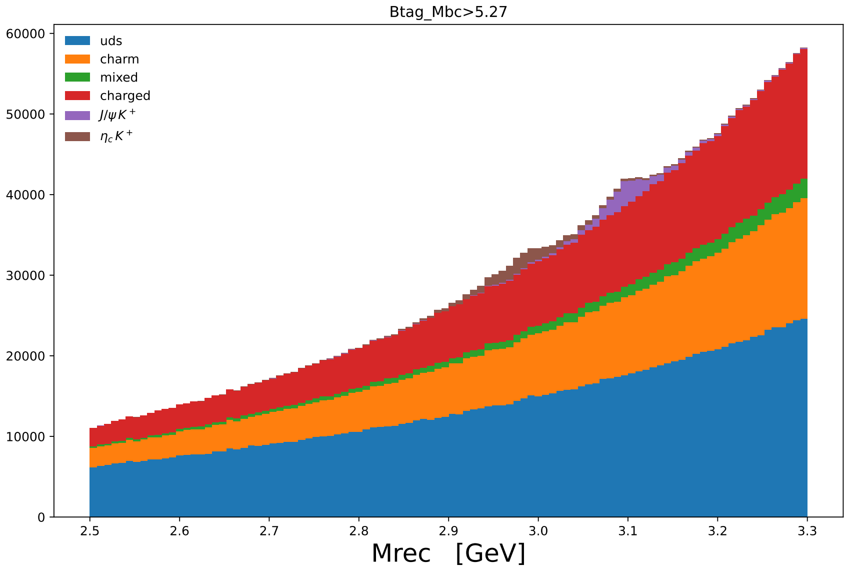


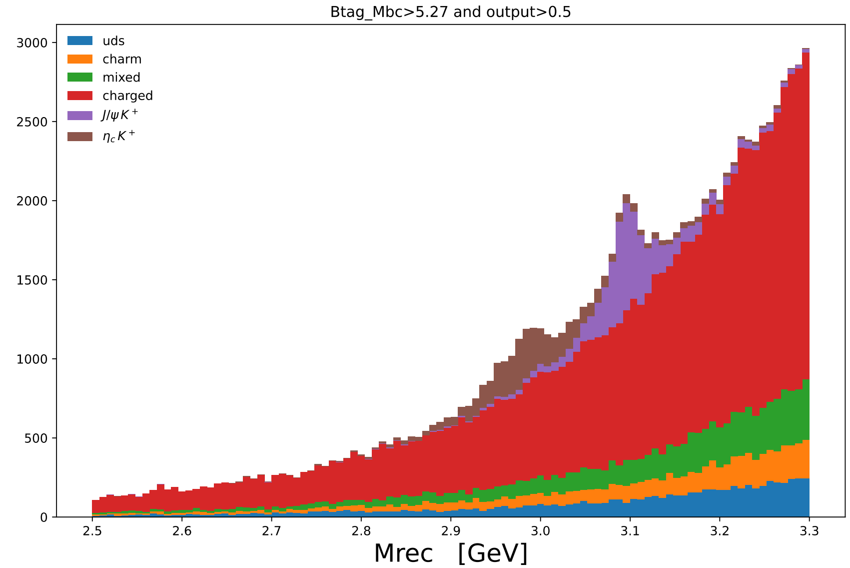


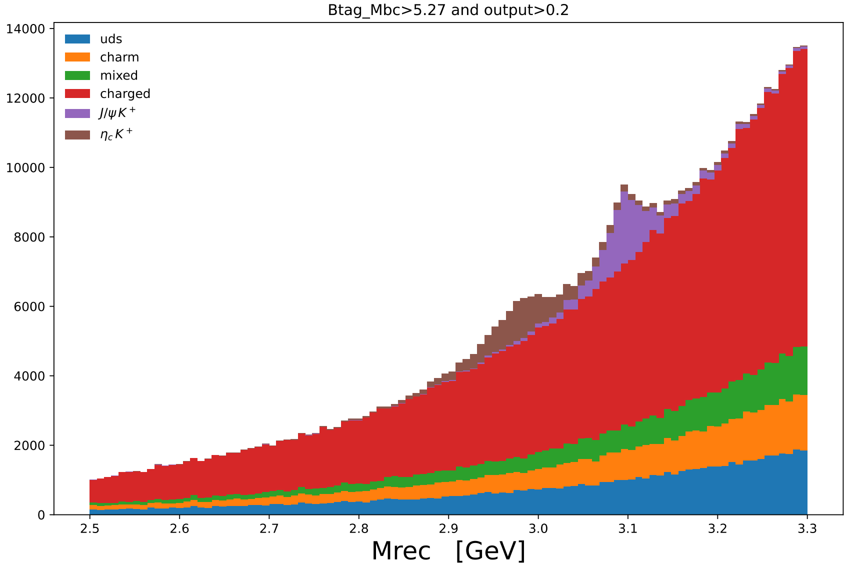

$B \to X_{cc}K$
MC
no classifier cut
$\eta_c(2984)$
$J/\psi(3096)$
uds
charm
mixed
charged
$J/\psi K^+$
$\eta_c K^+$
Mrec [GeV]

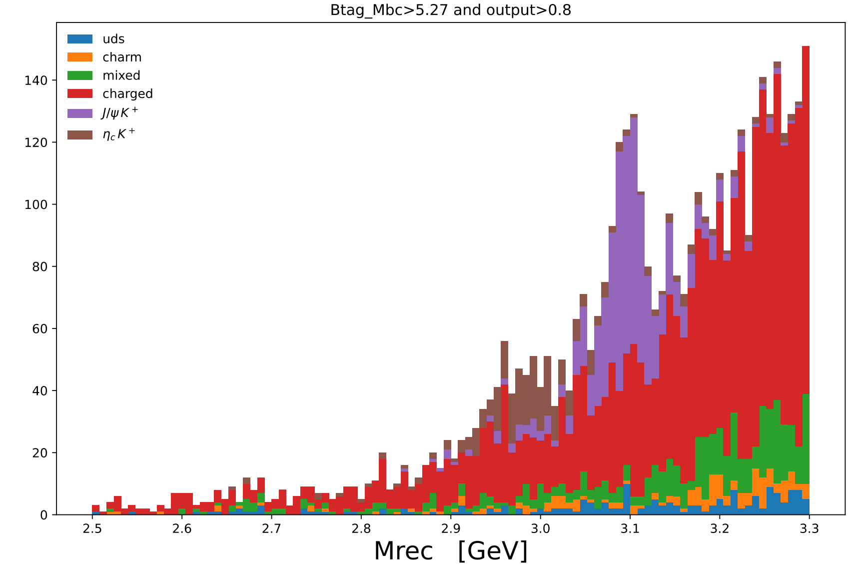

$B \to X_{cc}K$
MC
classifier > 0.5
$\eta_c(2984)$
$J/\psi(3096)$
uds
charm
mixed
charged
$J/\psi K^+$
$\eta_c K^+$
Mrec [GeV]

Recoil mass spectra (Low mass region)

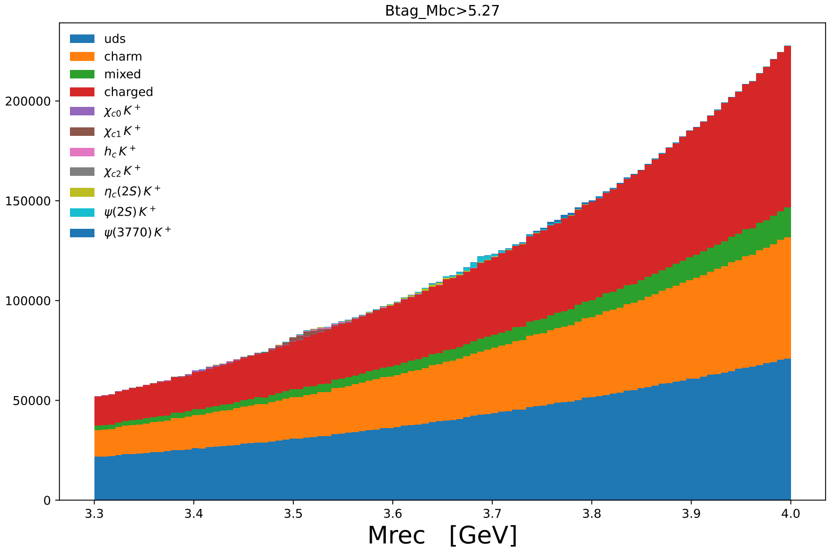


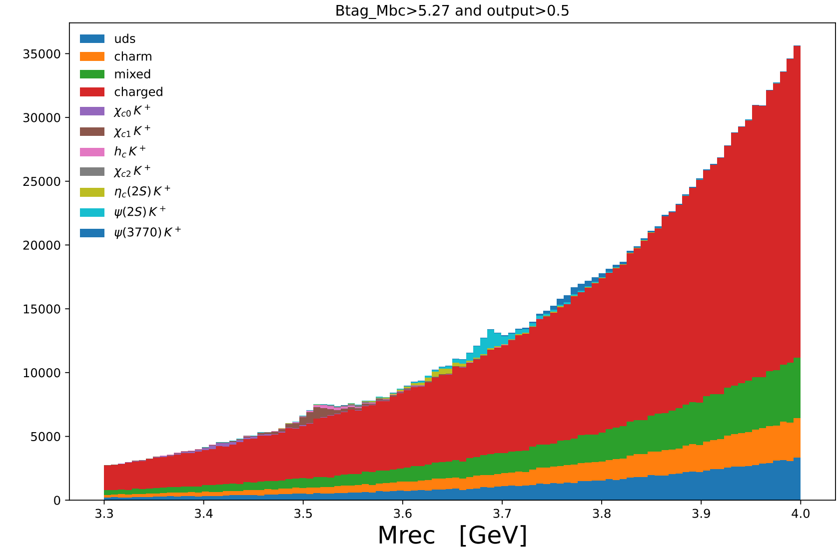


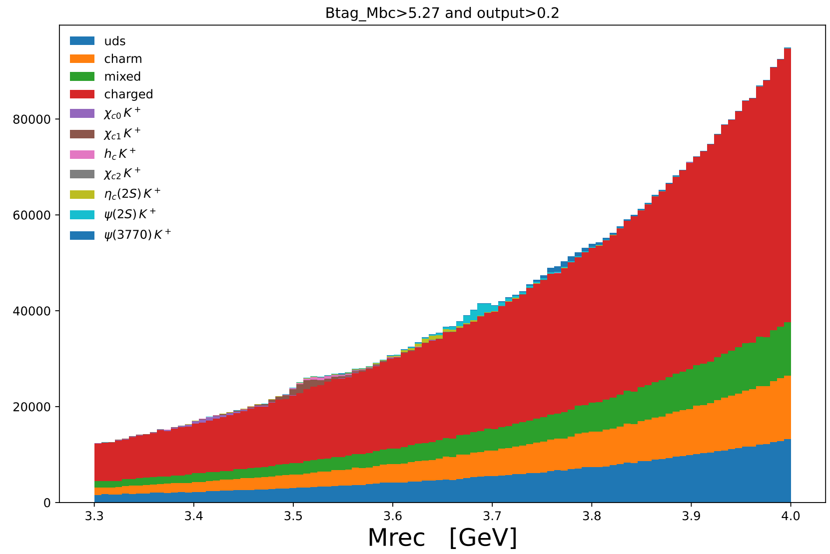


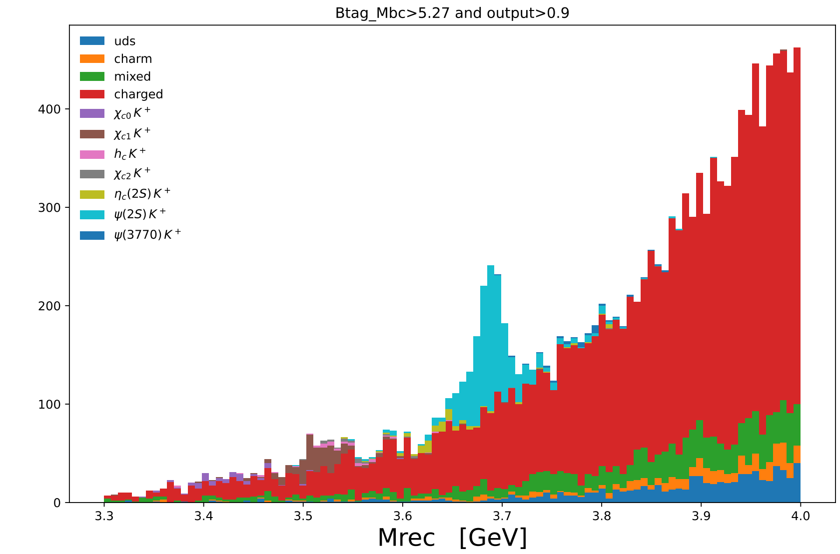


Recoil mass spectra (High mass region)









Cuts

- $M_{BC}(B_{tag}) > 5.27\ GeV$
- $-0.15 < \Delta E < 0.1\ GeV$
- Kaon has high momentum and correct PID
- FEI SigProb > 0.01 as a recommended FEI cut
- FEI skim cuts on ROE also recommended
- classifier cut > 0.78 – used instead FEI recommended continuum suppression
- good tracks and photons for the DeepSets classifier

Cuts

Items	Event selections
pi+:FEI_cleaned	$d_0 < 0.5\,\mathrm{cm}$ $\lvert z_0 \rvert < 2\,\mathrm{cm}$ $p_T > 0.1\,\mathrm{GeV}$
gamma:FEI_cleaned	$0.296706 < \theta < 2.61799$ $E > 0.1\,\mathrm{GeV}$

FEI skims pre-cuts	`pi+:FEI_cleaned`
	`gamma:FEI_cleaned`
	$n_{\mathrm{cleaned\,tracks}} \geq 3$
	$n_{\mathrm{cleaned\,ECL\,clusters}} \geq 3$
	E_{vis} in the CMS frame $> 4\,\mathrm{GeV}$
	$2\,\mathrm{GeV} < E_{\mathrm{cleaned\,tracks\,and\,clustersinECL}} < 7\,\mathrm{GeV}$
	JZ: what's the meaning?

FEI hadronic skim Tag cuts	$M_{\mathrm{bc}} > 5.24\,\mathrm{GeV}$ $\lvert\Delta E\rvert < 0.2\,\mathrm{GeV}$ `sigProb` > 0.001 (omitted for $B^+_{\mathrm{tag}} \to D^- \pi^+ \pi^+$)

goodTrack cut	θ in CDC acceptance `nCDCHits>20` $\mathrm{d}r < 0.5$ $\lvert \mathrm{d}z \rvert < 2$

prompt kaon candidates	picked from `stdK` "all" list
	`goodTrack`
	`kaonID>0.7`

B_{tag} **candidates**	picked from `B+:fei` list `sigProb` > 0.01
ROE tracks	picked from `stdPi` "all" list `goodTrack`

ROE photons	$E > 0.06\,\mathrm{GeV}$
	`abs(clusterTiming) < 20`
	`clusterNHits>1.5`
	`clusterE1E9>0.5`
	$0.2967 < \theta_{\mathrm{cluster}} < 2.6180$
	$E^{\mathrm{ECL}}_{\mathrm{forward}} > 0.200\,\mathrm{GeV}$
	$E^{\mathrm{ECL}}_{\mathrm{barrel}} > 0.100\,\mathrm{GeV}$
	$E^{\mathrm{ECL}}_{\mathrm{backward}} > 0.180\,\mathrm{GeV}$

Fitting Mrec

Component	Known BR (10^{-4})	At least 3 sigma in BABAR analysis
$B^- \to \eta_c K^-$	11.0 ± 0.7	✓
$B^- \to J/\psi K^-$	10.20 ± 0.19	✓
$B^- \to \chi_{c0} K^-$	1.51 ± 0.14	
$B^- \to \chi_{c1} K^-$	4.72 ± 0.22	
$B^- \to h_c K^-$	0.37 ± 0.13	
$B^- \to \chi_{c2} K^-$	0.11 ± 0.04	
$B^- \to \eta_c(2S) K^-$	4.4 ± 1.0	
$B^- \to \psi(2S) K^-$	6.24 ± 0.12	✓
$B^- \to \psi(3770) K^-$	4.3 ± 1.1	
$B^- \to X(3872) K^-$	2.3 ± 0.6	✓
Combinatorial $B\bar{B}$ background		
$q\bar{q}$		

Fitting Mrec

- The more we studied this, we realized that getting a clear signal while controlling systematic uncertainties isn't trivial. We checked many options…
- Analytic functions → too many parameters, large statistical uncertainty
- MC histograms → FEI simulation is known to be wrong
- Finally, we decided to simultaneously fit the 12 tag modes, where for each resonance we use the PDF

$$P_{s,t} = G_{s,t}\, P^{G}_{s,t} - (1 - G_{s,t}) P^{B}_{s,t}$$

Signal resonance
($J/\psi, X(3872)$ ...)

Tag mode
($D\pi, D\pi\pi$ ...)
(fit simultaneously 12 modes)

Good tag fraction
(from pion sample)

MC histogram for good tags

MC histogram for bad tags

Pion sample fit

- Reconstruct tag_B + pion instead of a kaon
- Fit the following components:

1. $B^- \to D^0 \pi^-$
2. $B^- \to D^{*0} \pi^-$
3. $B^- \to D^0 \rho^-$
4. $B^- \to D^{*0} \rho^-$
5. $B^- \to D^{**0} \pi^-$, where D^{**0} refers to the two narrow states $D_1^0(2420)$, $D_2^*(2460)$, and the two broad states $D_0^{*0}(2300)$, $D_1^0(2430)$.
6. $\bar{B}^0 \to D^+ \pi^-$
7. $\bar{B}^0 \to D^{*+} \pi^-$
8. Combinatorial $B\bar{B}$ background
9. $q\bar{q}$

- From MC studies, we realized external constraints are needed in this fit

The yield constraints relative to $D^0\pi^-$

Today showing only Belle results

Mode	RN $D\rho$	RN $D^*\rho$	RN $D^-\pi^+$	RN $D^{*-}\pi^+$	RN $D^{**}\pi$
$D^0\pi^+$	0.24 ± 0.017	0.10 ± 0.018	0.02 ± 0.010	0.00 ± 0.001	0.13 ± 0.066
$D^0\pi^+\pi^0$	0.26 ± 0.017	0.11 ± 0.019	0.04 ± 0.018	0.00 ± 0.002	0.13 ± 0.064
$D^0\pi^+\pi^-\pi^+$	0.23 ± 0.016	0.09 ± 0.017	0.05 ± 0.026	0.01 ± 0.003	0.12 ± 0.062
$D^0\pi^+\pi^-\pi^+\pi^0$	0.25 ± 0.017	0.10 ± 0.018	0.08 ± 0.041	0.01 ± 0.005	0.12 ± 0.059
$D^{*0}\pi^+$	0.25 ± 0.019	0.10 ± 0.019	0.03 ± 0.016	0.00 ± 0.002	0.13 ± 0.064
$D^{*0}\pi^+\pi^0$	0.27 ± 0.019	0.11 ± 0.020	0.03 ± 0.016	0.00 ± 0.002	0.13 ± 0.064
$D^{*0}\pi^+\pi^-\pi^+$	0.25 ± 0.017	0.10 ± 0.019	0.06 ± 0.030	0.01 ± 0.003	0.12 ± 0.062
$D^{*0}\pi^+\pi^-\pi^+\pi^0$	0.25 ± 0.019	0.10 ± 0.019	0.06 ± 0.032	0.01 ± 0.004	0.12 ± 0.059
$D^-\pi^+\pi^+$	0.24 ± 0.025	0.09 ± 0.019	0.09 ± 0.044	0.02 ± 0.008	0.13 ± 0.067
$D^-\pi^+\pi^+\pi^0$	0.24 ± 0.023	0.10 ± 0.021	0.12 ± 0.059	0.02 ± 0.009	0.13 ± 0.063
$\Lambda^+\pi^+\pi^-\pi^0$	0.26 ± 0.033	0.09 ± 0.022	0.05 ± 0.024	0.01 ± 0.005	0.13 ± 0.066
rest	0.25 ± 0.017	0.10 ± 0.018	0.05 ± 0.023	0.01 ± 0.003	0.12 ± 0.059

Based on this, it might make sense to use a tag-mode-independent constraint

The good-tag fraction data/MC correction

Mode	MC Yield	MC GT fraction	Fit Yield	Data-MC GT correction
$D^0\pi^+$	2839 ± 18	0.57 ± 0.004	2613 ± 72	0.92 ± 0.077
$D^0\pi^+\pi^0$	7116 ± 29	0.31 ± 0.001	5211 ± 143	0.75 ± 0.097
$D^0\pi^+\pi^-\pi^+$	3242 ± 20	0.61 ± 0.004	1640 ± 94	1.31 ± 0.166
$D^0\pi^+\pi^-\pi^+\pi^0$	5236 ± 25	0.32 ± 0.002	2759 ± 110	0.70 ± 0.111
$D^{*0}\pi^+$	2322 ± 17	0.34 ± 0.002	2390 ± 77	0.62 ± 0.106
$D^{*0}\pi^+\pi^0$	3873 ± 22	0.24 ± 0.001	2630 ± 96	0.36 ± 0.135
$D^{*0}\pi^+\pi^-\pi^+$	3790 ± 21	0.41 ± 0.002	1906 ± 83	0.81 ± 0.105
$D^{*0}\pi^+\pi^-\pi^+\pi^0$	1962 ± 15	0.38 ± 0.003	903 ± 65	0.78 ± 0.177
$D^-\pi^+\pi^+$	612 ± 8	0.70 ± 0.010	366 ± 38	0.46 ± 0.151
$D^-\pi^+\pi^+\pi^0$	763 ± 9	0.50 ± 0.006	343 ± 40	0.37 ± 0.227
$\Lambda^+\pi^+\pi^-\pi^0$	306 ± 6	0.61 ± 0.012	161 ± 18	0.59 ± 0.186
rest	5994 ± 27	0.35 ± 0.002	4008 ± 120	1.02 ± 0.098

Use these values in the kaon-sample fit

To do list

- Perform the pion-sample fit simultaneously for all tag modes and for Belle + Belle II, obtain final good-tag-fraction corrections and Br ratio for $D^{*0}\pi^-/D^0\pi^-$
  - We expect the uncertainty on BR ratio to be competitive with the PDG average
- We are validating the good-tag-fraction procedure with fully reconstructed $B^- \to J/\psi\, K^-$
  - The events are very clean, so GTF ~ 0. We plan to increase it by using sidebands.
  - We might also use Mrec regions outside of resonances in the kaon sample
- Optimize the classifier-output cut and conduct the kaon-sample fit
  - The PDF has the same structure as that for the pion-sample fit, but specific coding is still needed.
- Systematic uncertainties that aren't nuisance parameters:
  - MC statistics
  - Classifier-efficiency dependence on kaon/pion momentum and X decay mode