Measurements of $B \to D^{**}\ell\nu_\ell$ decays at Belle

Frank Meier

Lake Louise Winter Institute 2022
20 - 25 February 2022

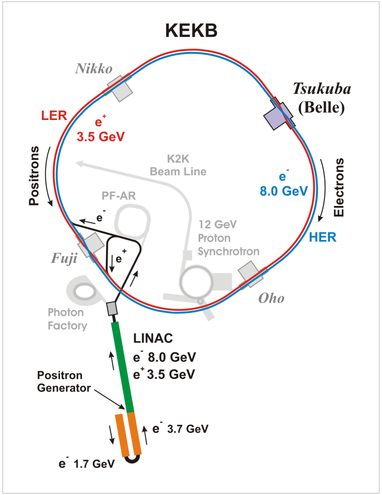
Research supported by U.S. Department of Energy Office of Science

Introduction

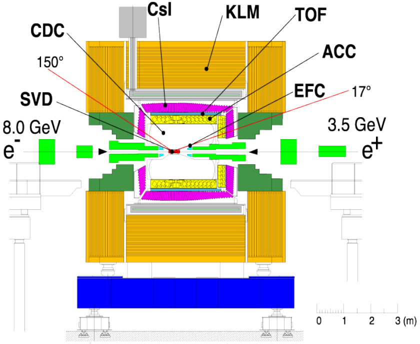
- inclusive: BR($B^+ \to X_c \ell \nu_\ell$) = (10.8 ± 0.4) % / BR($B^0 \to X_c \ell \nu_\ell$) = (10.1 ± 0.4) % (PRD 75, 032001)
- sum of BR($B \to D^{(*)} \ell \nu_\ell$) and BR($B \to D^{(*)} \pi \ell \nu_\ell$) = 9.05 % / 8.35 %
- gap of ~1.75 % between inclusive and exclusive branching fraction measurements of $B \to X_c \ell \nu_\ell$
- statistical fluctuation?
  - $B \to D \ell \nu_\ell$ and $B \to D^* \ell \nu_\ell$ known at 3 - 4 % level
  - $B \to D \pi \ell \nu_\ell$ and $B \to D^* \pi \ell \nu_\ell$ only known at 7 - 9 % / 12 - 14 % level for charged / neutral modes
- missing exclusive decay modes?
  - $B \to D^{(*)} \pi \pi \ell \nu_\ell$ observed by BaBar (Phys. Rev. Lett. 116, 041801 (2016))
    - BR($B^+ \to \overline{D}^0 \pi^+ \pi^- \ell^+ \nu_\ell$) = $(0.161 \pm 0.030\,(\text{stat}) \pm 0.018\,(\text{syst}) \pm 0.008)$ %
    - BR($B^+ \to \overline{D}^{*0} \pi^+ \pi^- \ell^+ \nu_\ell$) = $(0.080 \pm 0.040\,(\text{stat}) \pm 0.023\,(\text{syst}) \pm 0.003)$ %
    - BR($B^0 \to D^- \pi^+ \pi^- \ell^+ \nu_\ell$) = $(0.127 \pm 0.039\,(\text{stat}) \pm 0.026\,(\text{syst}) \pm 0.007)$ %
    - BR($B^0 \to D^{*-} \pi^+ \pi^- \ell^+ \nu_\ell$) = $(0.138 \pm 0.039\,(\text{stat}) \pm 0.030\,(\text{syst}) \pm 0.003)$ %
  - $B \to D^{(*)} \eta \ell \nu_\ell$ not yet measured at all

- $B \to D^{(*)} \pi \ell \nu_\ell$ and $B \to D^{(*)} \pi \pi \ell \nu_\ell$ important background contributions in measurements of $R(D)$ / $R(D^*)$

Experimental Setup



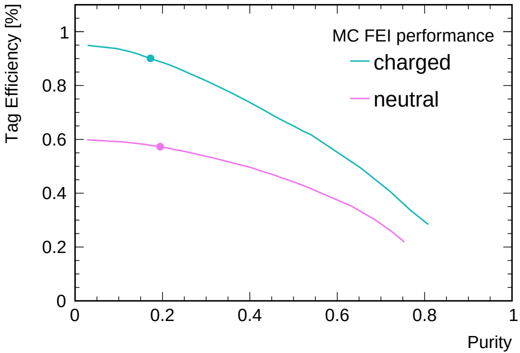
- asymmetric collision of e^+e^-
- center-of-mass energy mostly at $\Upsilon(4S)$ resonance
- $\Upsilon(4S) \to B^+B^-$ (~51.5 %), $\Upsilon(4S) \to B^0\overline{B}^0$ (~48.5 %)
- Belle collected ~772M $B\overline{B}$ pairs over the course of 10 years

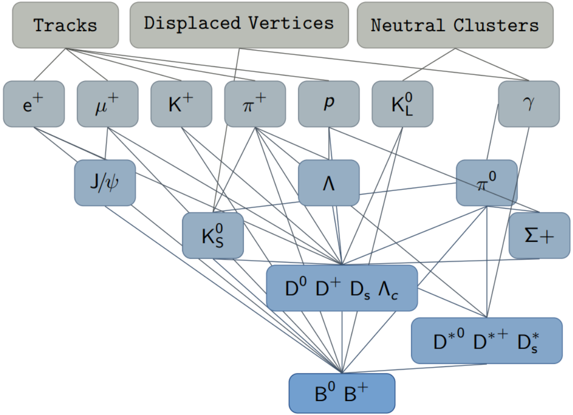


Full Event Interpretation

Comput. Softw. Big Sci. 3 (2019)

- fully reconstruct one of the B mesons (tag-side) in many exclusive modes
- hadronic and semileptonic version:
  trade-off between efficiency and purity
- train BDT for each stage
  $\Rightarrow$ signal probability





Analysis in a nut shell

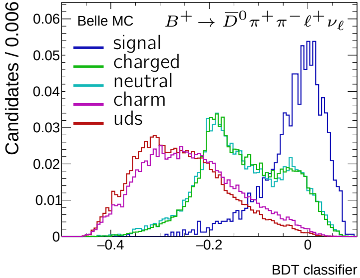
Duke UNIVERSITY

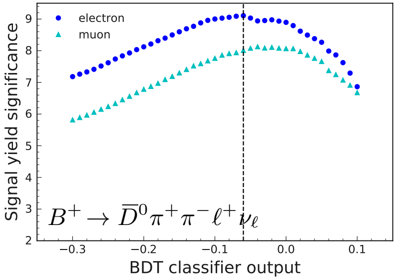
- read in and convert data from Belle to Belle II format using B2BII   Comput. Softw. Big Sci. 2 (2018)
- run hadronic Full Event Interpretation with Belle training
  - B_{tag} selection: $|\Delta E| < 180$ MeV, $M_{\text{bc}} > 5.27$ GeV/c^2, signal probability > 0.005
- final state particle selection ($e^\pm$, $\mu^\pm$, $K^\pm$, $\pi^\pm$, π^0, and K_S^0)
- reconstruct D from final state particles and D^* by adding slow pion
  - $D^+ \to K^-\pi^+\pi^+$, $D^+ \to K_S^0\pi^+$, $D^+ \to K_S^0\pi^+\pi^0$, $D^+ \to K^-K^+\pi^+$, $D^+ \to K_S^0\pi^+\pi^-\pi^+$, $D^+ \to K_S^0K^+$, $D^+ \to \pi^+\pi^0$
  - $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^+\pi^-$, $D^0 \to K^-\pi^+\pi^0$, $D^0 \to K_S^0\pi^+\pi^-$, $D^0 \to K^-K^+$, $D^0 \to K_S^0\pi^+\pi^-\pi^0$, $D^0 \to \pi^+\pi^-$

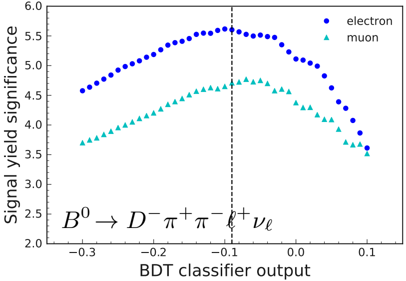
  new D modes wrt PRD 98, 012005
- combine $D^{(*)}$ with 0, 1, and 2 bachelor pions + 1 lepton to form 24 different B_{sig} modes
- reconstruct $\Upsilon(4S)$ from B_{tag} + B_{sig} (B^+B^-, $B^0\overline{B}^0$, B^0B^0)
- check that there are no additional tracks in the rest of the event
- best $\Upsilon(4S)$ candidate selection based on tag-side signal probability and preference of D^* over D modes
- measure branching fractions of $B \to D^{(*)}\pi\ell\nu_\ell$ and $B \to D^{(*)}\pi\pi\ell\nu_\ell$ relative to $B \to D^*\ell\nu_\ell$

BDT to suppress continuum background in $D\pi\pi$ modes

- training samples:
  - background: off-resonance data
  - signal: $B^+ \to \overline{D_1^0}\ell^+\nu_\ell$ with $\overline{D_1^0} \to \overline{D}^0\pi^+\pi^-$
    $B^0 \to D_1^-\ell^+\nu_\ell$ with $D_1^- \to D^-\pi^+\pi^-$
- 25 training variables describing tag-side quantities, event shape, and rest of the event, like unaccounted energy in the ECL or Fox-Wolfram moments
- scan BDT output classifier to find optimal relative signal significance

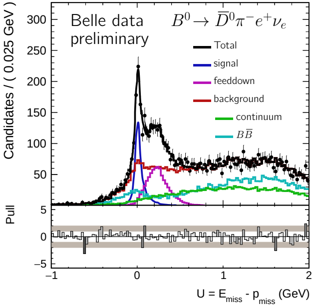






Fit model

- fit dimension: $U = E_{\text{miss}} - p_{\text{miss}}$ with $E_{\text{miss}} = E_{e^+e^-} - E_{\text{tag}} - E_{D^{**}} - E_l$
  - better sensitivity than fitting missing mass squared $M_\nu^2 = E_{\text{miss}}^2 - p_{\text{miss}}^2$
- simultaneous fit with 16 categories: B^+ and B^0, D and D^*, π and $\pi\pi$, e and μ
- fit components:
  - signal: MC with decay via D_1 $(D\pi\pi)$ or D'_1 $(D^*\pi\pi)$ resonance
  - feeddown of $D^*\pi\pi$ in $D\pi\pi$ (π^0 missed in reconstruction of $D^* \to D\pi^0$)
  - off-resonance data to describe continuum events
  - $B\overline{B}$ background (charged + neutral samples merged)
  - $B \to D^{**}\ell\nu_\ell$ background
    - signal-to-background (crossfeed) efficiency ratio fixed to MC value
    - yield related to signal component within simultaneous fit
- PDF constructed as histograms with 120 bins in [−1 ; 2]
  - MC weighted to correct known data-MC differences in PID, tracking efficiency, π^0 and K_S^0 efficiency, charm branching fractions, and tagging mode composition



Relative systematic uncertainties

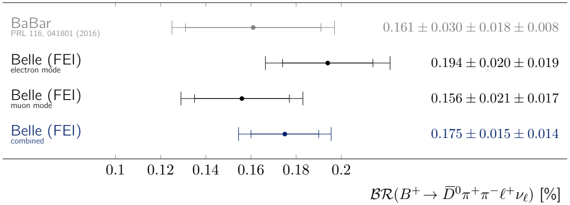
- largest systematic uncertainty from fit modeling
  - composition of signal model
  - shape uncertainties due to limited MC statistics
- BDT signal efficiency differs between data and MC (systematic determined using $B \to D^* \ell \nu_\ell$)
- uncertainty on branching fraction of normalization mode $\Rightarrow$ systematic of 1.9 % (B^0) and 3.9 % (B^+)
- uncertainty on branching fraction of charm modes (0.7 - 1.4 %)
- small systematic uncertainties from PID, tracking, and selection efficiencies because of partial cancellation in ratio with normalization mode

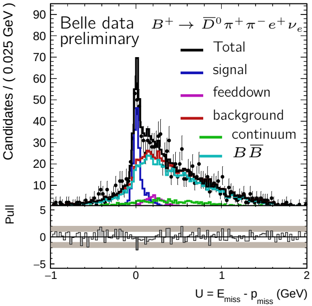
Total systematic uncertainties in %

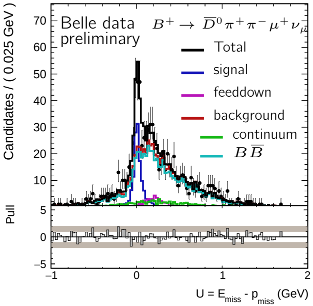
	$D\pi\ell\nu_\ell$	$D^*\pi\ell\nu_\ell$	$D\pi\pi\ell\nu_\ell$	$D^*\pi\pi\ell\nu_\ell$
B^0	2.6	2.6	8.9	22.4
B^+	4.5	4.8	7.8	12.0

Results for $B^+ \to \overline{D}^0\pi^+\pi^-\ell^+\nu_\ell$ (preliminary)

- $N_{\text{sig}}(B^+ \to \overline{D}^0\pi^+\pi^- e^+\nu_e) = 197 \pm 20$
- $N_{\text{sig}}(B^+ \to \overline{D}^0\pi^+\pi^- \mu^+\nu_\mu) = 131 \pm 18$
- BaBar found 171 ± 30 $B^+ \to \overline{D}^0\pi^+\pi^-\ell^+\nu_\ell$





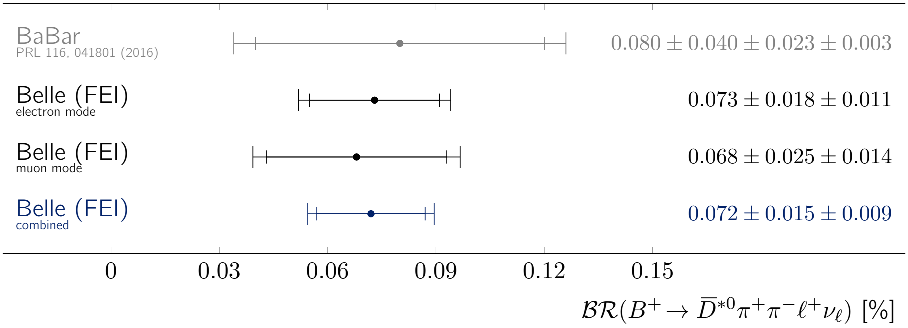


- good agreement of combined value with BaBar measurement
- statistical uncertainty reduced by factor 2

Results for $B^+ \to \overline{D}^{*0}\pi^+\pi^-\ell^+\nu_\ell$ (preliminary)

- $N_{\text{sig}}(B^+ \to \overline{D}^{*0}\pi^+\pi^- e^+\nu_e) = 57 \pm 14$
- $N_{\text{sig}}(B^+ \to \overline{D}^{*0}\pi^+\pi^- \mu^+\nu_\mu) = 39 \pm 14$

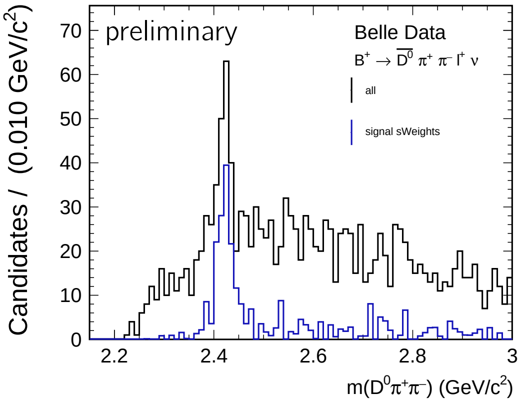
- BaBar found 74 ± 36 $B^+ \to \overline{D}^{*0}\pi^+\pi^-\ell^+\nu_\ell$ signal candidates



- excellent agreement between electron and muon mode and with result by BaBar
- total uncertainty 2.5 times lower

Resonance model of $B^+ \to \overline{D}^{(*)0}\pi^+\pi^-\ell^+\nu_\ell$

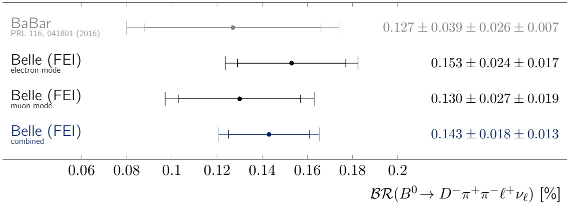
- use sPlot technique to calculate sWeights from fit of $E_{\text{miss}} - p_{\text{miss}}$ distribution
- plot background-subtracted invariant $m(D^0\pi^+\pi^-)$ mass distribution (statistics too low for $D^{*0}\pi^+\pi^-$)

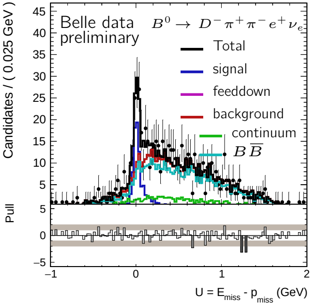


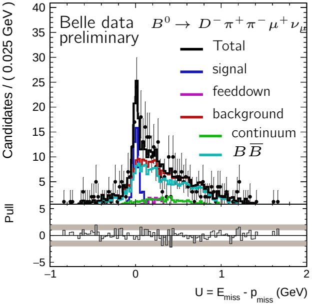
- decay via narrow D_1^0 resonance ($m(D_1^0)_{\text{PDG}} = (2422.1 \pm 0.6)$ MeV/c^2) can be confirmed

Results for $B^0 \to D^-\pi^+\pi^-\ell^+\nu_\ell$ (preliminary)

- $N_{\text{sig}}(B^0 \to D^-\pi^+\pi^-e^+\nu_e) = 88 \pm 14$
- $N_{\text{sig}}(B^0 \to D^-\pi^+\pi^-\mu^+\nu_\mu) = 58 \pm 12$
- BaBar found 56 ± 17 $B^0 \to D^-\pi^+\pi^-\ell^+\nu_\ell$



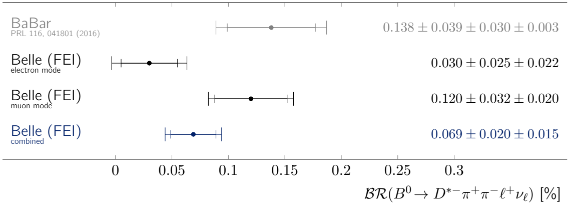


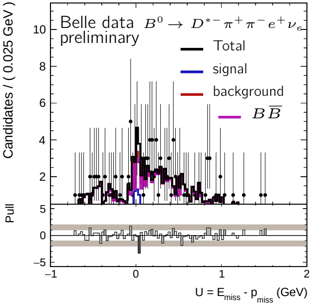


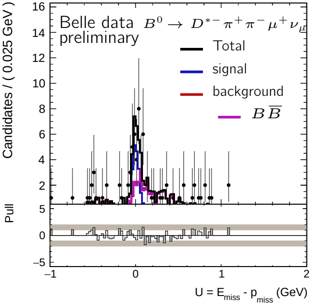
- total branching fraction compatible with BaBar value
- statistical uncertainty again reduced by factor 2

Results for $B^0 \to D^{*-}\pi^+\pi^-\ell^+\nu_\ell$ (preliminary)

- $N_{\text{sig}}(B^0 \to D^{*-}\pi^+\pi^-e^+\nu_e) = 11 \pm 9$
- $N_{\text{sig}}(B^0 \to D^{*-}\pi^+\pi^-\mu^+\nu_\mu) = 37 \pm 10$
- BaBar found 65 ± 18 $B^0 \to D^{*-}\pi^+\pi^-\ell^+\nu_\ell$



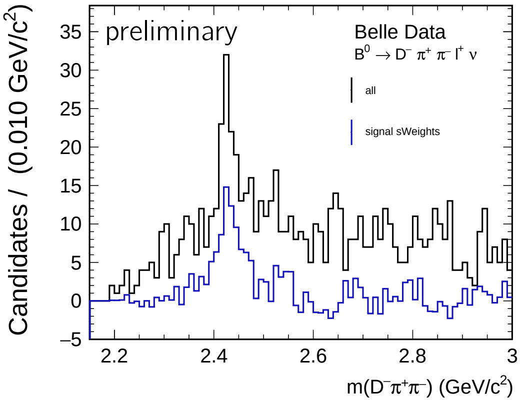




- very few signal candidates found in electron mode
- combined value 1.25σ below BaBar's result

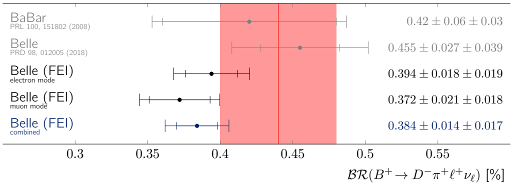
Resonance model of $B^0 \to D^{(*)-}\pi^+\pi^-\ell^+\nu_\ell$

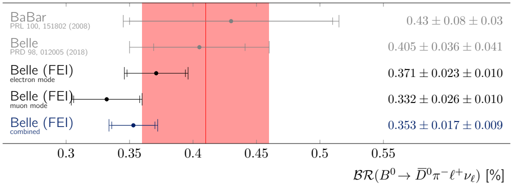
- use sPlot technique to calculate sWeights from fit of $E_{\text{miss}} - p_{\text{miss}}$ distribution
- plot background-subtracted invariant $m(D^-\pi^+\pi^-)$ mass distribution (statistics too low for $D^{*-}\pi^+\pi^-$)

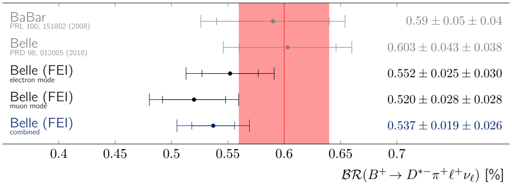


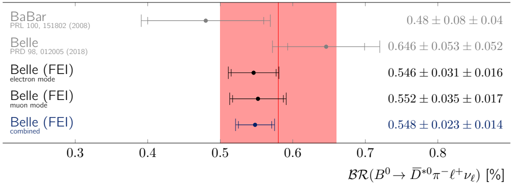
- clear peak at D_1^+ resonance ($m(D_1^+)_{\text{PDG}} = (2422.1 \pm 0.6)$ MeV$/c^2$), but broader than for B^+ case

Results for $B \to D^{(*)}\pi\ell\nu_\ell$ (preliminary)









- all branching fractions a little bit lower than the previous world average and at least twice as precise

Conclusion

- world's best measurements of $B \to D^{**}\ell\nu_\ell$ branching fractions
- improvement of at least factor 2 over any other measurement, mainly thanks to new tagging algorithm
- all results of combined branching fractions compatible with previous world averages

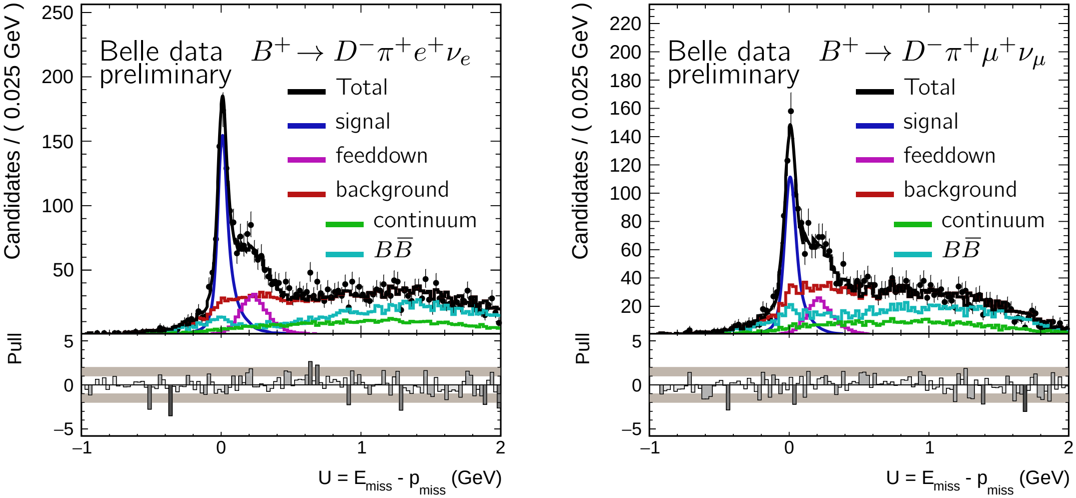
$$\mathcal{B}(B^0 \to \overline{D}^0\pi^-\ell^+\nu_\ell) = 0.353 \pm 0.017\,(\text{stat}) \pm 0.009\,(\text{syst})\,\%$$
$$\mathcal{B}(B^+ \to D^-\pi^+\ell^+\nu_\ell) = 0.384 \pm 0.014\,(\text{stat}) \pm 0.017\,(\text{syst})\,\%$$
$$\mathcal{B}(B^0 \to \overline{D}^{*0}\pi^-\ell^+\nu_\ell) = 0.548 \pm 0.023\,(\text{stat}) \pm 0.014\,(\text{syst})\,\%$$
$$\mathcal{B}(B^+ \to D^{*-}\pi^+\ell^+\nu_\ell) = 0.537 \pm 0.019\,(\text{stat}) \pm 0.026\,(\text{syst})\,\%$$

$$\mathcal{B}(B^0 \to D^-\pi^+\pi^-\ell^+\nu_\ell) = 0.143 \pm 0.018\,(\text{stat}) \pm 0.013\,(\text{syst})\,\%$$
$$\mathcal{B}(B^+ \to \overline{D}^0\pi^+\pi^-\ell^+\nu_\ell) = 0.175 \pm 0.015\,(\text{stat}) \pm 0.014\,(\text{syst})\,\%$$
$$\mathcal{B}(B^0 \to D^{*-}\pi^+\pi^-\ell^+\nu_\ell) = 0.069 \pm 0.020\,(\text{stat}) \pm 0.015\,(\text{syst})\,\%$$
$$\mathcal{B}(B^+ \to \overline{D}^{*0}\pi^+\pi^-\ell^+\nu_\ell) = 0.072 \pm 0.015\,(\text{stat}) \pm 0.009\,(\text{syst})\,\%$$

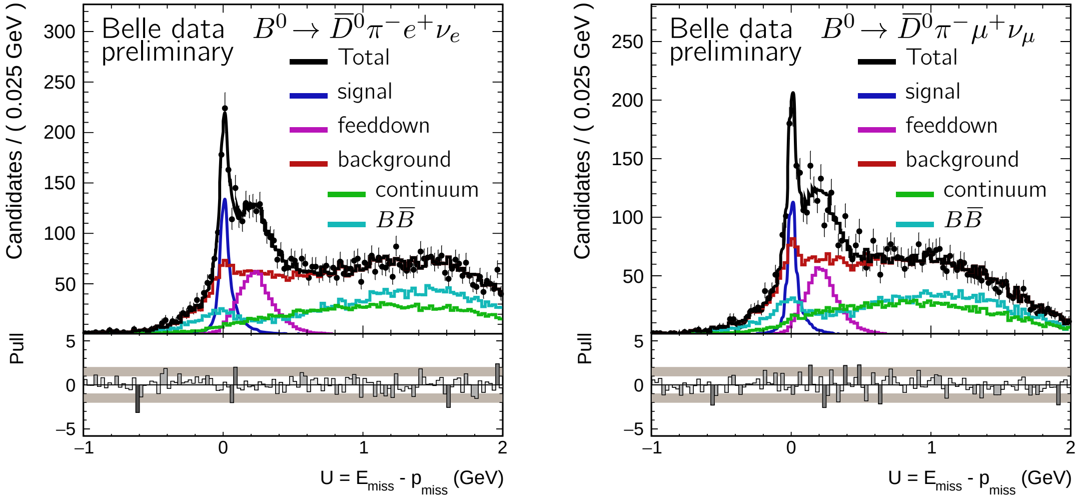
- study of D^{**} mass spectrum using sPlot technique
- paper to be submitted to journal soon

Backup

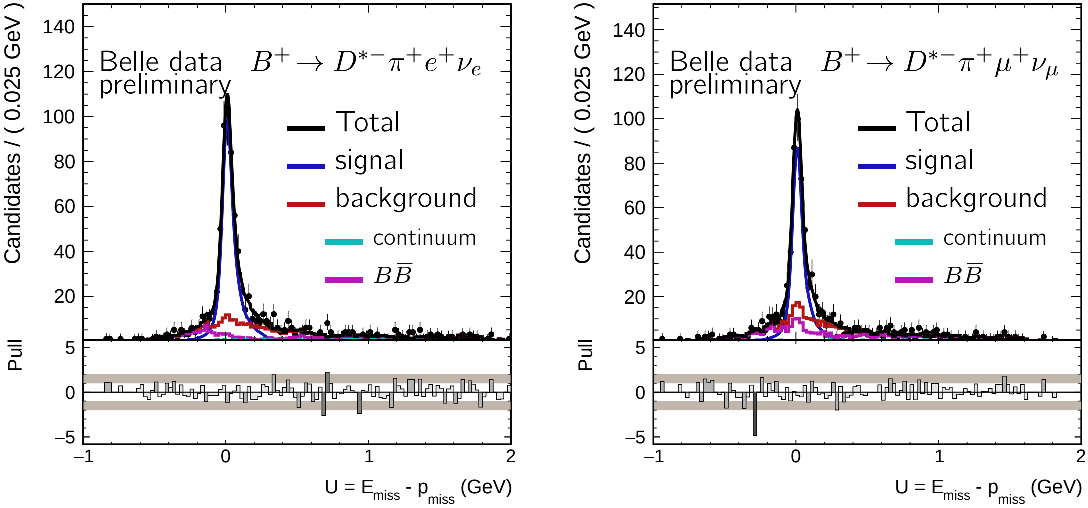
$B^+ \to D^- \pi^+ \ell^+ \nu_\ell$



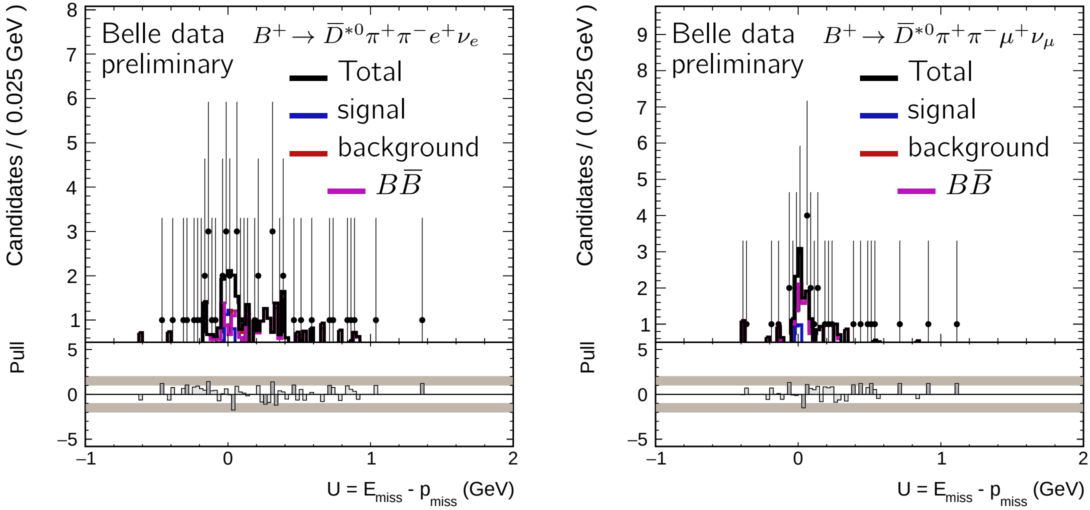
$B^0 \to \overline{D}^0\pi^-\ell^+\nu_\ell$



$B^+ \to D^{*-}\pi^+\ell^+\nu_\ell$



Fit of $B^+ \to \overline{D}^{*0}\pi^+\pi^-\ell^+\nu_\ell$



PDG averages of exclusive $B \to X_c \ell \nu_\ell$ branching fractions

- BR($B^+ \to \overline{D}^0 \ell^+ \nu_\ell$) = $(2.35 \pm 0.09)\,\%$ ($\sigma = 3.8\,\%$)
- BR($B^+ \to \overline{D}^{*0} \ell^+ \nu_\ell$) = $(5.66 \pm 0.22)\,\%$ ($\sigma = 3.9\,\%$)
- BR($B^+ \to D^- \pi^+ \ell^+ \nu_\ell$) = $(0.44 \pm 0.04)\,\%$ ($\sigma = 9.1\,\%$)
- BR($B^+ \to D^{*-} \pi^+ \ell^+ \nu_\ell$) = $(0.60 \pm 0.04)\,\%$ ($\sigma = 6.7\,\%$)

- BR($B^0 \to D^- \ell^+ \nu$) = $(2.31 \pm 0.10)\,\%$ ($\sigma = 4.3\,\%$)
- BR($B^0 \to D^{*-} \ell^+ \nu_\ell$) = $(5.05 \pm 0.14)\,\%$ ($\sigma = 2.8\,\%$)
- BR($B^0 \to \overline{D}^0 \pi^- \ell^+ \nu_\ell$) = $(0.41 \pm 0.05)\,\%$ ($\sigma = 12.2\,\%$)
- BR($B^0 \to \overline{D}^{*0} \pi^- \ell^+ \nu_\ell$) = $(0.58 \pm 0.08)\,\%$ ($\sigma = 13.8\,\%$)

Comparison with BaBar

- sources of largest systematic uncertainties in BaBar publication
  - decay model: $D^{**} \to D\pi\pi$ vs $D^{**\prime} \to D^{**}\pi$ followed by $D^{**} \to D\pi$
  - limited size of MC samples to model fit PDF
  - modeling of MVA input variables

sPlot technique

- sPlot: a statistical tool to unfold data distributions (Nucl.Instrum.Meth. A 555 (2005))
- method to statistically subtract background contributions
- perform extended maximum likelihood fit of discriminating variable
- calculate weights based on the yields and the pdf values
- apply weights to spectator variables $\Rightarrow$ signal-only distribution
    - no correlation allowed between discriminating and spectator variable

Final state particle selection

- good photons: $E_\gamma > 0.075/0.05/0.1$ GeV (FWD / BRL / BWD)
- $\mu^\pm$, $e^\pm$: **dr** < 0.5 cm, $|$**dz**$| < 2$ cm, $p > 0.3$ GeV/c
- $\mu^\pm$: **muIDBelle** > 0.9, **eIDBelle** < 0.8, $25^\circ < \theta < 145^\circ$
- $e^\pm$: **muIDBelle** < 0.9, **eIDBelle** > 0.8, **inCDCAcceptance**
  - Bremsstrahlung correction using closest good photon in 5° cone
- K, p, π: **dr** < 2 cm, $|$**dz**$| < 5$ cm, **muIDBelle** < 0.9, **eIDBelle** < 0.8
- $K^\pm$: **atcPIDBelle(3,2)** > 0.6
- $\pi^\pm$: **atcPIDBelle(3,2)** < 0.4, **atcPIDBelle(4,3)** < 0.2 or **atcPIDBelle(4,2)** < 0.2
- K_S^0: **K_S0:mdst** with **goodBelleKshort** and $0.482 < m_{\pi^+\pi^-} < 0.514$ GeV/c^2
- π^0: **pi0:mdst** with $0.12 < m_{\gamma\gamma} < 0.15$ GeV/c^2 and good photons

Reconstruction of D mesons

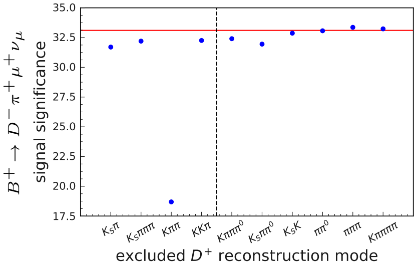
1. $D^0 \to K^- \pi^+$
2. $D^0 \to K^- \pi^+ \pi^0$
3. $D^0 \to K^- \pi^+ \pi^+ \pi^-$
4. $D^0 \to K_S^0 \pi^+ \pi^-$
5. $D^0 \to K^- K^+$
6. $D^0 \to K_S^0 \pi^0$
7. $D^0 \to K_S^0 \pi^+ \pi^- \pi^0$
8. $D^0 \to \pi^+ \pi^-$
9. $D^0 \to K^- \pi^+ \pi^- \pi^+ \pi^0$
10. $D^0 \to \pi^+ \pi^- \pi^0$

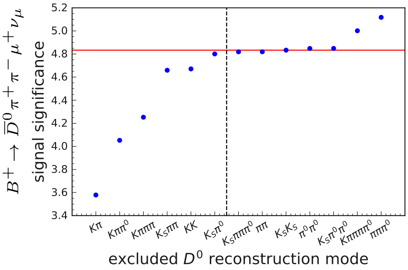
1. $D^+ \to K_S^0 \pi^+$
2. $D^+ \to K_S^0 \pi^+ \pi^- \pi^+$
3. $D^+ \to K^- \pi^+ \pi^+$
4. $D^+ \to K^- K^+ \pi^+$
5. $D^+ \to K^- \pi^+ \pi^+ \pi^0$
6. $D^+ \to K_S^0 \pi^+ \pi^0$
7. $D^+ \to K_S^0 K^+$
8. $D^+ \to \pi^+ \pi^0$
9. $D^+ \to \pi^+ \pi^- \pi^+$

- perform TreeFit with mass constraints on D, K_S^0, and π^0 (no TreeFit for $D^0 \to K_S^0 \pi^0$)
- mass window: ± 15 MeV/c^2 for modes with at least one charged track and no π^0, ± 25 MeV/c^2 otherwise
- usefulness of D modes studied

Usefulness of D reconstruction modes for $B \to D^* \ell \nu_\ell$

- exclude D reconstruction modes individually
- perform signal extraction using six streams
- plot average signal significance defined as signal yield divided by (statistical) fit uncertainty





- identify modes that boost signal significance and those that reduce sensitivity
- previously used D modes almost always useful

Reconstruction of D^* and B modes

- $D^{*0} \to D^0\pi^0$
  - $0.1389 < m_{D^{*0}} - m_{D^0} < 0.1455$ GeV/c^2
- $D^{*\pm} \to D^0\pi^\pm$, $D^{*\pm} \to D^\pm\pi^0$
  - $|m_{D\pi} - m_{D^{*\pm}}(\text{PDG})| < 3$ MeV/c^2
- perform TreeFit with mass constraints on D^*, D, K_S^0, π^0
- $B^0 \to D^-\ell^+\nu$, $B^0 \to D^{*-}\ell^+\nu_\ell$, $B^+ \to \overline{D}^0\ell^+\nu_\ell$, $B^+ \to \overline{D}^{*0}\ell^+\nu_\ell$
- $B^0 \to \overline{D}^0\pi^-\ell^+\nu_\ell$, $B^0 \to \overline{D}^{*0}\pi^-\ell^+\nu_\ell$, $B^+ \to D^-\pi^+\ell^+\nu_\ell$, $B^+ \to D^{*-}\pi^+\ell^+\nu_\ell$
  - $2.05 < m_{D\pi} < 3$ GeV/c^2
- $B^0 \to D^-\pi^+\pi^-\ell^+\nu_\ell$, $B^0 \to D^{*-}\pi^+\pi^-\ell^+\nu_\ell$, $B^+ \to \overline{D}^0\pi^+\pi^-\ell^+\nu_\ell$, $B^+ \to \overline{D}^{*0}\pi^+\pi^-\ell^+\nu_\ell$
- ROE mask for no additional track in the event: `dr` < 2 cm, $|$`dz`$| < 5$ cm
- criteria for best $\Upsilon(4S)$ candidate selection
  - best B_{tag} signal probability, then B_{sig} with D^* preferred, then B_{sig} with lower $|m_D - m_D(\text{PDG})|$

Vetoes to suppress peaking background

- require $p_{\text{miss}} > 200$ MeV/c to suppress purely hadronic decays
- some $B^+ \to D^{*-}\pi^+\ell^+\nu_\ell$ with $D^{*-} \to \overline{D}^0\pi^-$ fail D^* selection (either mass window or vertex fit) and are instead reconstructed as $B^+ \to \overline{D}^0\pi^+\pi^-\ell^+\nu_\ell$
- veto this background contribution by requiring $m(\overline{D}^0\pi^-) > 2.05$ GeV/c^2
- second veto: suppress cross-feed if π^- is actually from B_{tag}
  - combine each π^- of B_{tag} with $\overline{D}^0$ from $B^+ \to \overline{D}^0\pi^+\pi^-\ell^+\nu_\ell$ reconstruction
  - require $m(\overline{D}^0\pi^-) > 2.05$ GeV/c^2 for all combinations
- if at least one reconstructed $B \to D^{(*)}\pi\ell\nu_\ell$ and one reconstructed $B \to D^{(*)}\pi\pi\ell\nu_\ell$ candidate present in same event and both are in signal region, throw away all candidates of this event

Fit function for D^{**} mass distribution

- naive Breit-Wigner function

$$P(x;x_0,\omega_0) = \frac{1}{N}\frac{1}{(x_0-x)^2+\frac{1}{4}\omega_0^2}$$

- relativistic Breit-Wigner with "mass-dependent" width $\Gamma(m)$

$$\frac{dN}{dm} \propto \frac{m\cdot\Gamma(m)}{(m_0^2-m^2)^2+m_0^2\Gamma^2(m)}$$

$$\Gamma(m) = \Gamma_0\frac{m_0}{m}\left(\frac{q}{q_0}\right)^{2L+1}\frac{F_L(Rq)}{F_L(Rq_0)}$$

- q is momentum of one of the daughter particles in the resonance's rest frame

$$q = \frac{1}{2m}\sqrt{\left(m^2-(m_1+m_2)^2\right)\left(m^2-(m_1-m_2)^2\right)}$$

- q_0 uses constant peak mass m_0 instead of candidate-by-candidate mass m
- L is orbital angular momentum quantum number between resonance and bachelor particle
- $F_L(x)$ are Blatt-Weisskopf form factors
- R is meson radius, I used $R=5$ GeV $^{-1}\approx 1$ fm so far

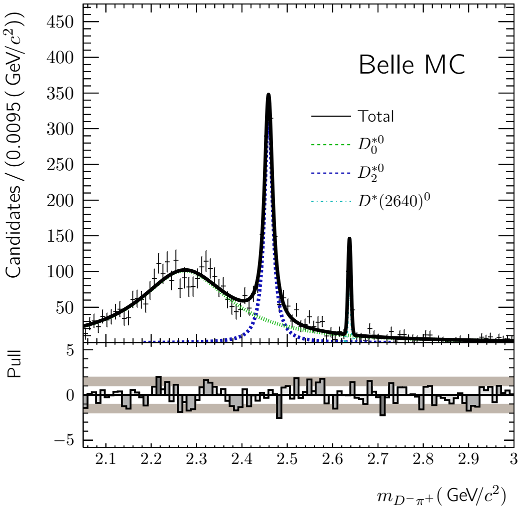
Fitting D^{**} signal MC

- MC production with out-dated values for peak, width and cut-off
- non-relativistic Breit-Wigner used for generation of resonances
- for resonances close to threshold relativistic BW necessary
- convolve BW with Gaussian of width 2 MeV/c^2 to account for resolution effects

			MC		fit		$\frac{2(\text{peak}-\text{threshold})}{\text{width}}$
	threshold	cut-off	peak	width	x_0	ω_0	
$D_0^{*+} \to D^0\pi^+$	2.004 40	2.097	2.4	0.1503	2.3889±0.0012	0.1530±0.0027	5.3
$D_0^{*0} \to D^-\pi^+$	2.009 22	2.101	2.4	0.1503	2.3895±0.0008	0.1419±0.0018	5.2
$D_1^{+} \to D^{*0}\pi^+$	2.146 42	2.153	2.423	0.0200	2.4220±0.0006	0.0210±0.0013	27.7
$D_1^{0} \to D^{*-}\pi^+$	2.149 83	2.1503	2.4223	0.0204	2.4213±0.0002	0.0212±0.0004	26.7
$D_2^{*+} \to D^0\pi^+$	2.004 40	2.1481	2.4601	0.037	2.4606±0.0004	0.0394±0.0008	24.6
$D_2^{*0} \to D^-\pi^+$	2.009 22	2.1521	2.4611	0.043	2.4612±0.0003	0.0454±0.0006	21.0
$D_1'^{+} \to D^{*0}\pi^+$	2.146 42	2.145	2.445	0.2503	2.410±0.007	0.243±0.017	2.4
$D_1'^{0} \to D^{*-}\pi^+$	2.149 83	2.145	2.445	0.2503	2.4096±0.0020	0.229±0.005	2.4

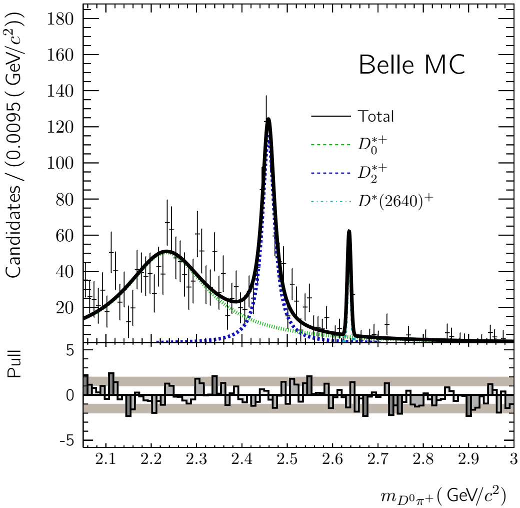
- except for D_1' states fitted peak masses more or less compatible with generated ones
- fitted width compatible with generated width within a few σ
- tried fitting with relativistic BW to test implementation
  - works, fit results close to non-relativistic model but plots indicate clear shape differences (see backup)

Fit of sweighted m(D^{**}) distribution for charged tags



- for now use sum of non-relativistic BW convolved with Gaussian (RooVoigtian)
- $m(D_0^{*0}) = (2.274 \pm 0.004)$ GeV/c^2
  - MC value $m(D_0^{*0}) = 2.308$ GeV/c^2
- $\sigma(D_0^{*0}) = (0.245 \pm 0.014)$ GeV/c^2
  - MC value $\sigma(D_0^{*0}) = 0.276$ GeV/c^2
- $m(D_2^{*0}) = (2.4588 \pm 0.0006)$ GeV/c^2
  - MC value $m(D_2^{*0}) = 2.4589$ GeV/c^2
- $\sigma(D_2^{*0}) = (0.0209 \pm 0.0011)$ GeV/c^2
  - MC value $\sigma(D_2^{*0}) = 0.023$ GeV/c^2
- additional $D^*(2640)^0$ component in generic MC with ultra-narrow width?

Fit of sweighted m(D^{**}) distribution for neutral tags



- for now use sum of non-relativistic BW convolved with Gaussian (RooVoigtian)
- $m(D_0^{*+}) = (2.233 \pm 0.008)$ GeV/c^2
  - MC value $m(D_0^{*+}) = 2.308$ GeV/c^2
- $\sigma(D_0^{*+}) = (0.223 \pm 0.022)$ GeV/c^2
  - MC value $\sigma(D_0^{*+}) = 0.276$ GeV/c^2
- $m(D_2^{*+}) = (2.4585 \pm 0.0012)$ GeV/c^2
  - MC value $m(D_2^{*+}) = 2.459$ GeV/c^2
- $\sigma(D_2^{*+}) = (0.0327 \pm 0.0016)$ GeV/c^2
  - MC value $\sigma(D_2^{*+}) = 0.025$ GeV/c^2
- additional $D^*(2640)^+$ component in generic MC with ultra-narrow width?