Precision Measurement of $R(D^{(*)})$ with Inclusive Tagging Methods at Belle II

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ABSTRACT

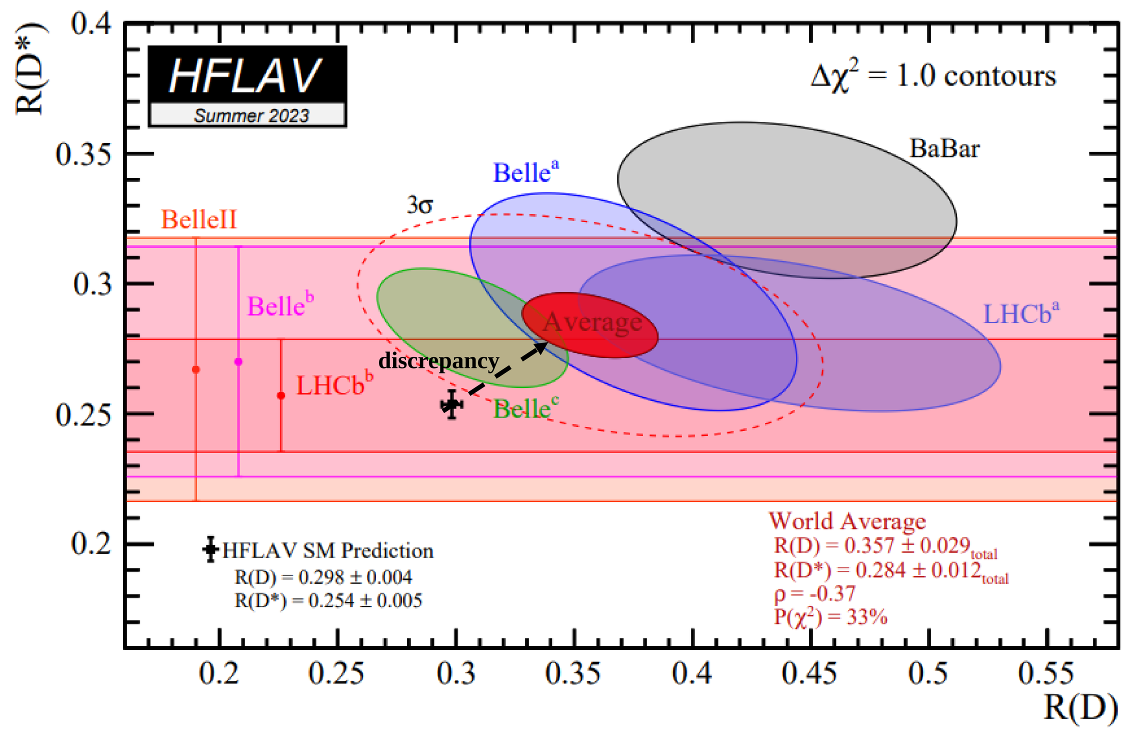
The standard model provides an excellent description for the fundamental forces of nature. However, recent experimental measurements provide results that are inconsistent with the standard model predictions. Currently, the largest discrepancy is the symmetry of lepton flavor universality. In particular, the experimentally measured branching ratio of the weakly interacting leptons suggests the heavier tauon does not undergo the same weak physical interactions as the electron and the muon.

The current results are slightly higher than the standard model prediction. However, at over 3σ, the results not significant enough to throw out the standard model. In an attempt to refine these results and disprove lepton flavor universality, the physical decay properties of $B^{\pm} \to D^{(*)0}\ell^{\pm}\nu_{\ell}$ and $B^{\pm} \to D^{(*)0}\tau^{\pm}(\to \ell^{\pm}\nu_{\ell}\nu_{\tau})\nu_{\tau}$ where $\ell = e$ or μ are investigated with the Belle II Analysis Framework (basf2).

Lepton Flavors: $e^{\pm}$, $\mu^{\pm}$, $\tau^{\pm}$

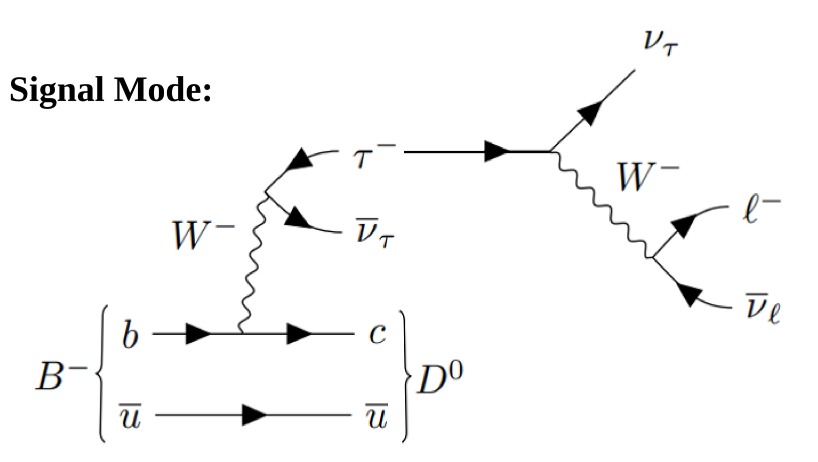
- **Lepton Flavor Universality**: weak interactions are "flavor independent"
- Both $e^{\pm}$ and $\mu^{\pm}$ have been shown to have similar properties
- The heavy, short-lived, $\tau^{\pm}$ has shown consistent deviations but there is not enough statistical signif

– at least not yet

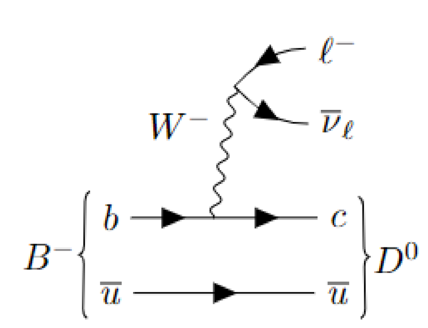


- If $\tau^{\pm}$ does not interact like $e^{\pm}$ and $\mu^{\pm}$, the symmetries of the SM break!
- To experimentally determine the similarities of the interactions, a precision measurement is made on

Signal Mode:



Normalization Mode:



Applying the definition of the branching fraction,

$$\mathcal{BF} = \frac{N_{sig}}{N_{B\,gen} * \mathcal{B}_{forced} * \varepsilon_{sig}},$$

The decay ratio may be written as

Most uncertainties cancel out

$$R(D^{(*)}) = \frac{BF(B \to D^0\tau\nu)}{BF(B \to D^0\ell\nu)} = \frac{N(D^{(*)}\tau\nu)}{N(D^{(*)}\ell\nu)} \frac{\varepsilon(D^{(*)}\ell\nu)}{\varepsilon(D^{(*)}\tau\nu)} \frac{1}{\mathcal{B}(\tau)}$$

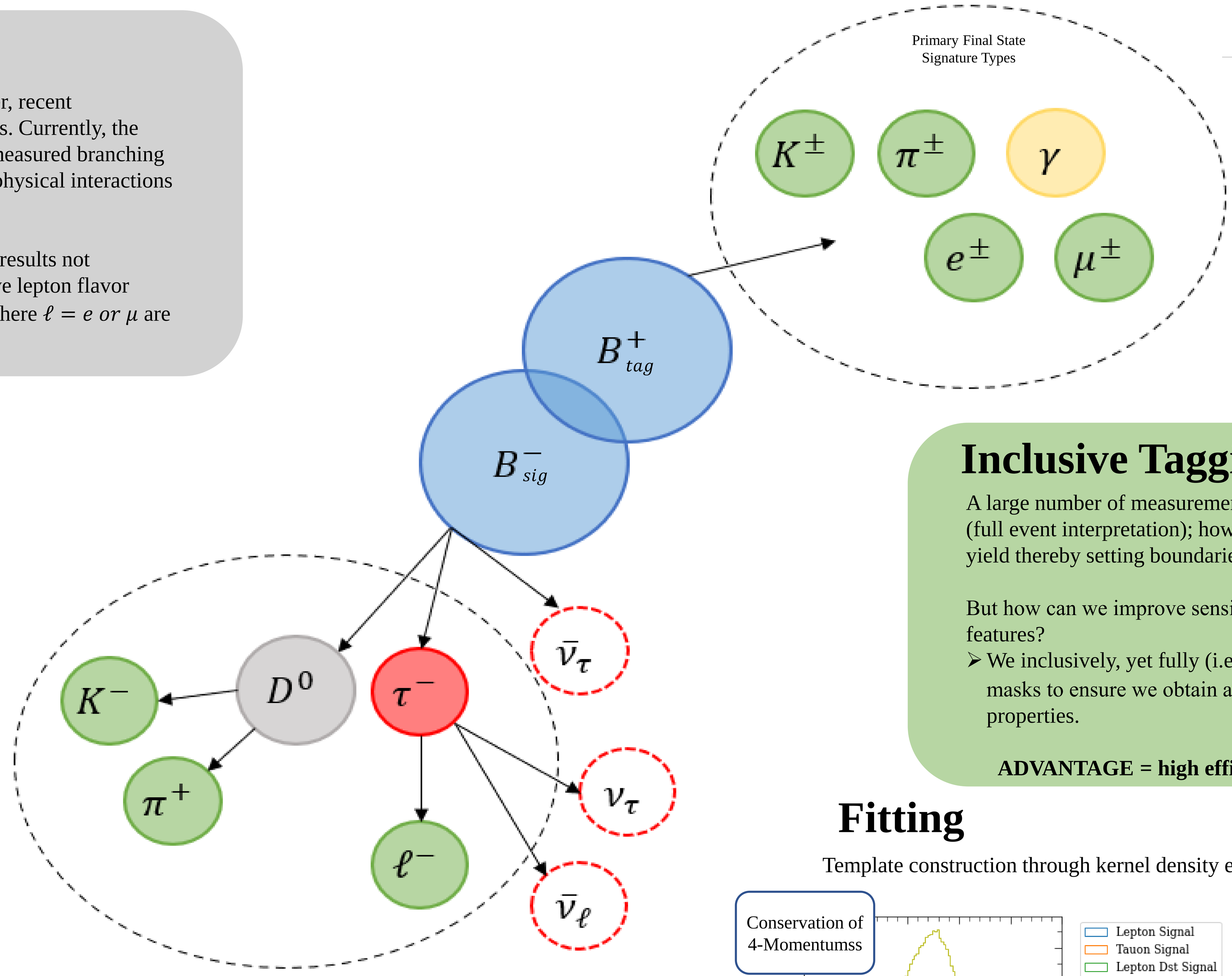
$N(D^{(*)}\tau\nu)$ = fitted signal yield for $B \to D^{(*)}\tau(\to \ell\nu\nu)\nu$

$N(D^{(*)}\ell\nu)$ = fitted signal yield for $B \to D^{(*)}\ell\nu$

Determined through fitting

ε = signal efficiency

$\mathcal{B}(\tau)$ = world average branching fraction for fixed $\tau \to \ell\nu\nu$ mode



ROE

Remaining tracks and energy deposits are associated with the accompanying B meson (B_{tag}), a.k.a Rest of Event (ROE)

Inclusive ROE = Decay channel not important so long as good B_{tag} candidate obtained

- B_{tag} selected with track and cluster criteria via minimizing widths of Mbc_{ROE} and ΔE_{ROE}

Lepton Veto

- Better resolution for signal fit means tag side (ROE) has no missing mass

→ Event cut.: $(\#\, e^{\pm}\ candidates + \#\, \mu^{\pm}\ candidates) \leq 1$

Signal

All signal mode candidates simultaneously reconstructed by identifying 3 charged signatures: K^-, π^+, ℓ^- and exploiting kinematic properties of decay

$B \to D^0\, e\, \nu$	Kpi
Reconstruction	0.271 ± 0.001
Rest of Event	
ℓ Veto2	0.253 ± 0.001
5.2<Mbc	0.191 ± 0.001
-4<deltaE<2	0.190 ± 0.001
Background Suppression	
SignalProb>0.7	0.077 ± 0.002
Best Candidate Selection	
B vertex chiProb	0.077 ± 0.002

$B \to D^0\, \tau(\to e\nu\nu)\, \nu$	Kpi
Reconstruction	0.222 ± 0.001
Rest of Event	
ℓ Veto2	0.207 ± 0.001
5.2<Mbc	0.158 ± 0.001
-4<deltaE<2	0.157 ± 0.001
Background Suppression	
SignalProb>0.7	0.126 ± 0.002
Best Candidate Selection	
B vertex chiProb	0.126 ± 0.002

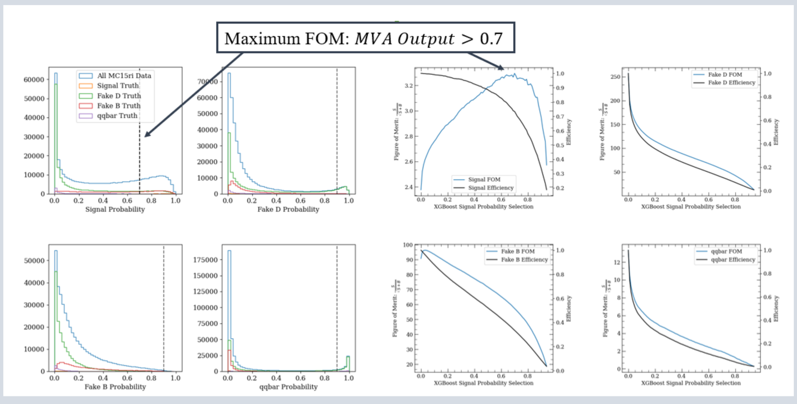
With *inclusive* tagging we get efficiency of $\mathcal{O}(10\%)$

With *hadronic and semi-leptonic tagging*, the efficiency is $\mathcal{O}(\leq 1\%)$

Background Suppression

Application of XGBoost multivariate analysis (MVA) with signal mode:

$$B \to (D^0 \to K\pi)(\tau \to e\nu\bar{\nu})\nu$$

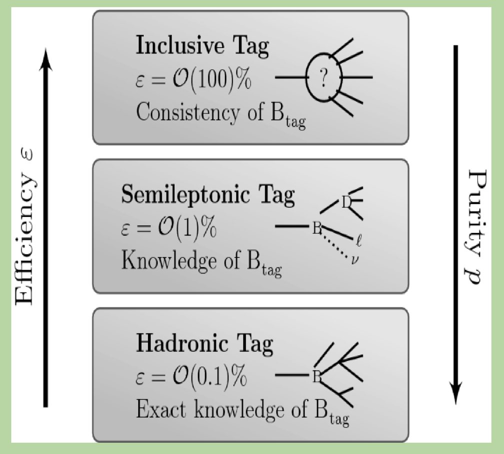


Inclusive Tagging

A large number of measurements have been made using exclusive tagging through FEI (full event interpretation); however, this method causes a significant decrease in signal yield thereby setting boundaries on measurements.

But how can we improve sensitivity while taking advantage of Belle II's excellent features?

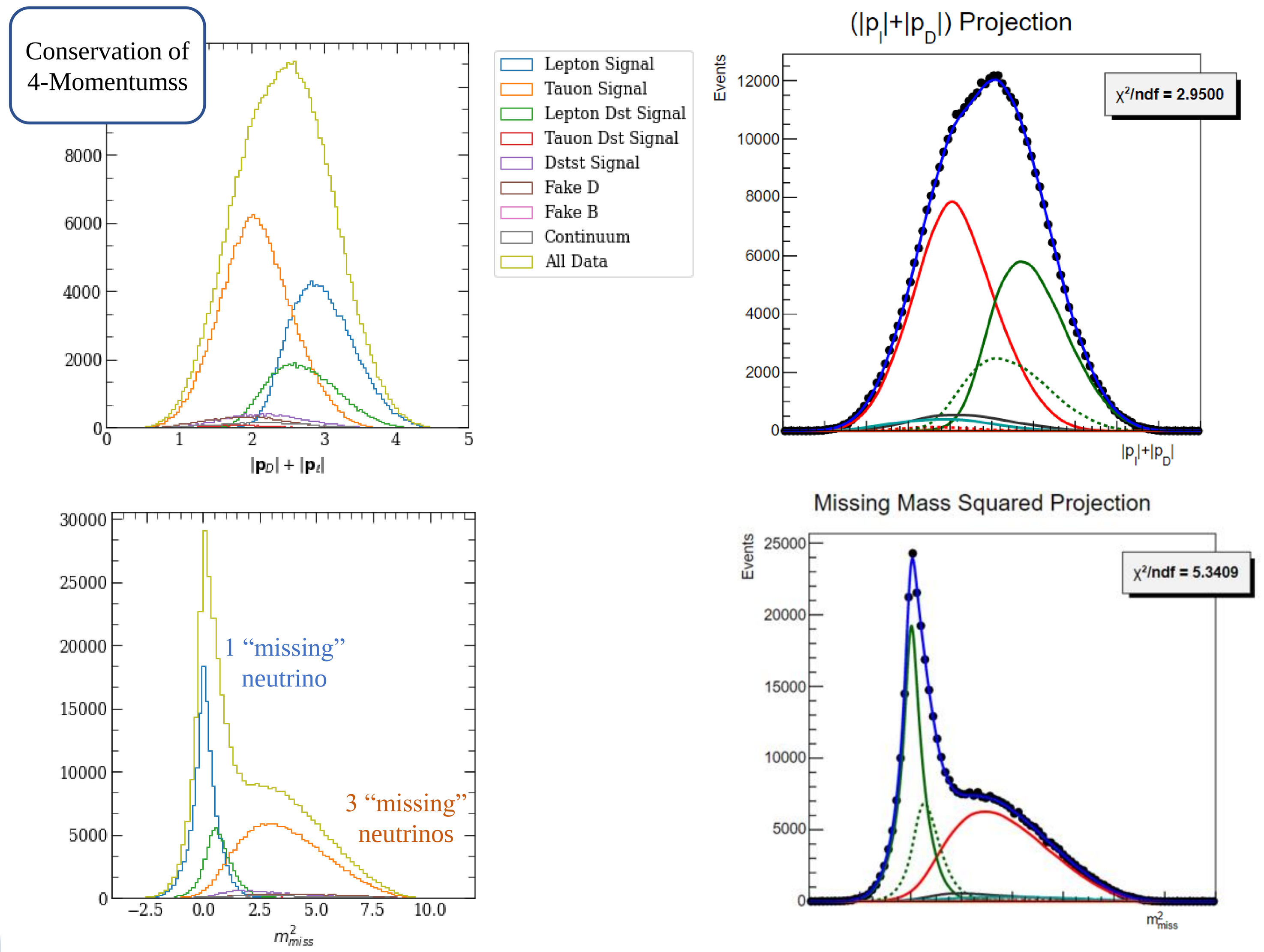
➢ We inclusively, yet fully (i.e. no neutrinos), reconstruct the B_{tag} by placing simple masks to ensure we obtain a "good" candidate to aid in extraction of signal properties.



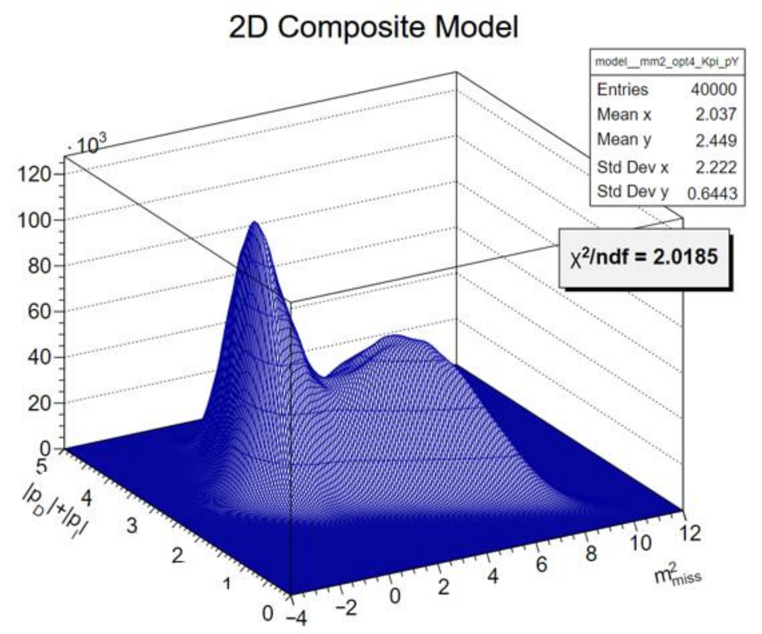
ADVANTAGE = high efficiency **DISADVANTAGE = low purity**

Fitting

Template construction through kernel density estimate followed by a maximum likelihood estimation of the composite model.



RIGHT: 1D MC truth plots for the variables fitted to extract signal yields. **LEFT**: 1D-projections of MLE fit of composite PDF of primary signal and background components. **TOP**: $p_D + p_\ell$ distribution where the tauon signals have a lower mean when compared to the electron signal considering $m_e \ll m_\tau$. **BOTTOM**: m^2_{miss} distribution where the tauon signals have a higher and "smeared" distribution compared to the electron as there are 2 additional neutrinos.



2D surface plot of composite model used for extraction of signal yields. The date utilized to complete these fits include signal MC + 7 main backgrounds (mis reconstructed $B^{\pm}$, mis reconstructed $B^0/\bar{B}^0$, 5 $q\bar{q}$ classes - $u\bar{u}, d\bar{d}, c\bar{c}, s\bar{s}, \tau^+\tau^-$). As the χ^2/ndf in the 2D and 1D projection, improvements must be made on the quality of the fit.

Acknowledgements

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