Tree-level New Physics searches in semileptonic decays at Belle

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Outline of this talk

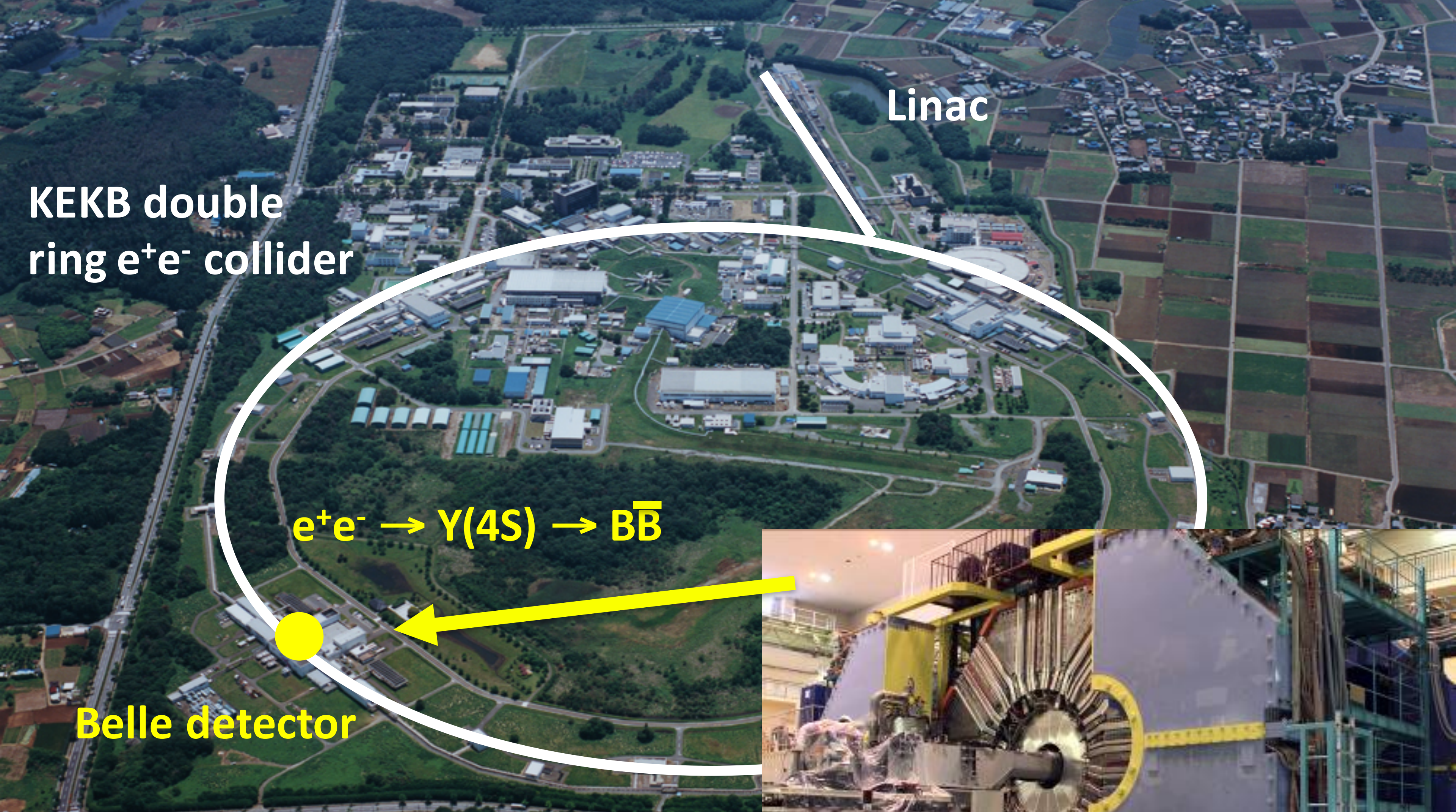
- Measurement of $B^0 \rightarrow D^{*-}\tau^+\nu$ with semileptonic tag (winter 2016 preliminary)

  arXiv:1603.06711

- Search for $B^0 \rightarrow \pi^-\tau^+\nu$ with hadronic tag

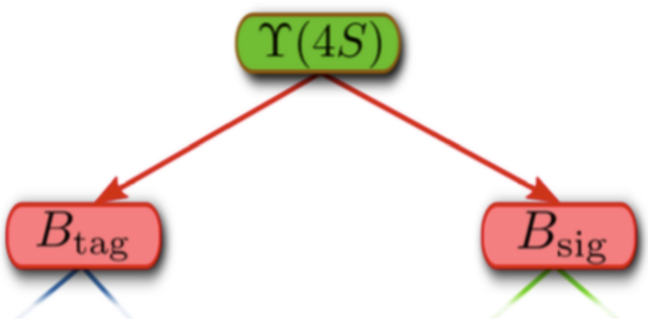
  Phys. Rev. D93, 032007 (2016)

1999 – 2010: B factory at KEK (Japan)



- World largest B meson sample ~771 million $B\bar{B}$ events
- Over 450 Belle physics publications

Tagging techniques for Υ(4S) events



- Tagging provides:
  - Background suppression
  - Information on B_{sig} (4-momentum)

PURIT
Y
EFFICIENCY

Untagged
- No requirement on B_{tag}
- High efficiency,
  low purity

Semileptonic tag
- $B_{tag} \rightarrow D^* l \nu$
- Efficiency ~O(0.2%)

Hadronic tag
- $B_{tag} \rightarrow$ hadrons
- Efficiency ~O(0.1%)

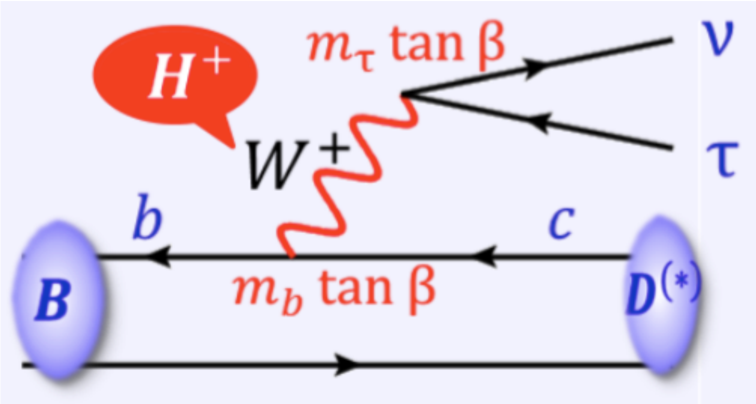
$B \rightarrow D^{*}\tau\nu$ with semileptonic tag

New Physics in $B \to D^* \tau \nu$

Semitauonic B decays of type $b \to c\tau\nu$ are sensitive probes to search for New Physics. NP can change the branching ratio and the D^*/τ polarization.

Type II 2HDM

- A charged Higgs of spin 0 mediates the decay instead of the W
- Can enhance or decrease the BR of $B \to D^*\tau\nu$



Leptoquark models

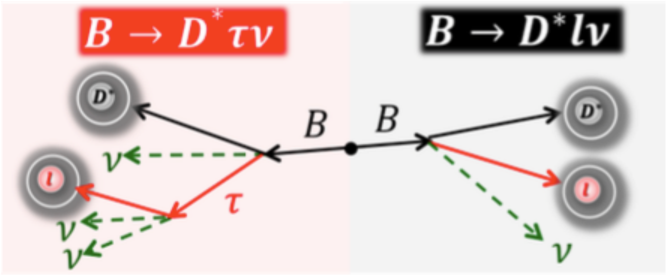
- LQs are bosons which couple to a lepton-quark pair
- Carry color and electric charge, baryon and lepton number

- LQ models which generate an effective tensor operator lead to an effect in $B \to D^*\tau\nu$

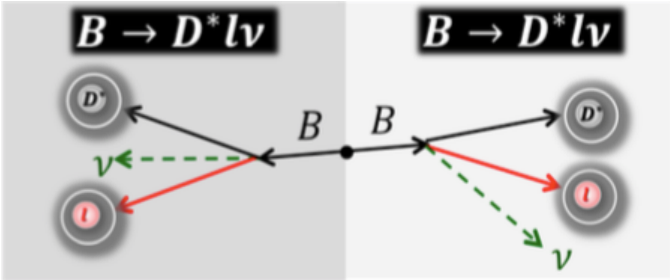
Principle of the measurement

- Simultaneously reconstruct signal and normalization events
- D^* reconstruction:
  $D^{*+} \to D^0\pi^+, D^+\pi^0$ (~100%)
  - 10 D^0 modes (~37%)
  - 5 D^+ modes (~22%)
- Semileptonic tag: combine D^{*+} with an oppositely charged lepton, calculate $\cos\theta_{B,D^*l}$
- Require two tagged B candidates per event of opposite charge

Signal event

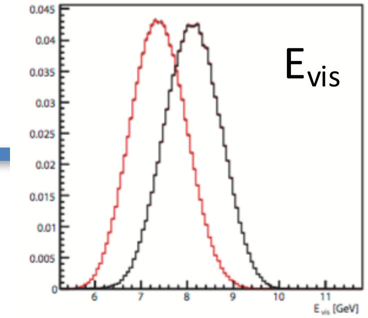


Normalization event

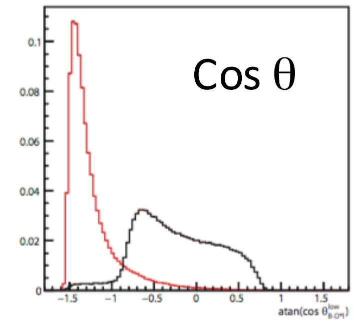


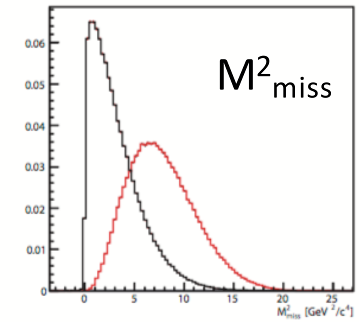
$$\cos\theta_{B\text{-}D^*\ell} \equiv \frac{2E_{\text{beam}}E_{D^*\ell} - m_B^2 - M_{D^*\ell}^2}{2|\vec{p}_B| \cdot |\vec{p}_{D^*\ell}|}$$

Principle of the measurement (2)



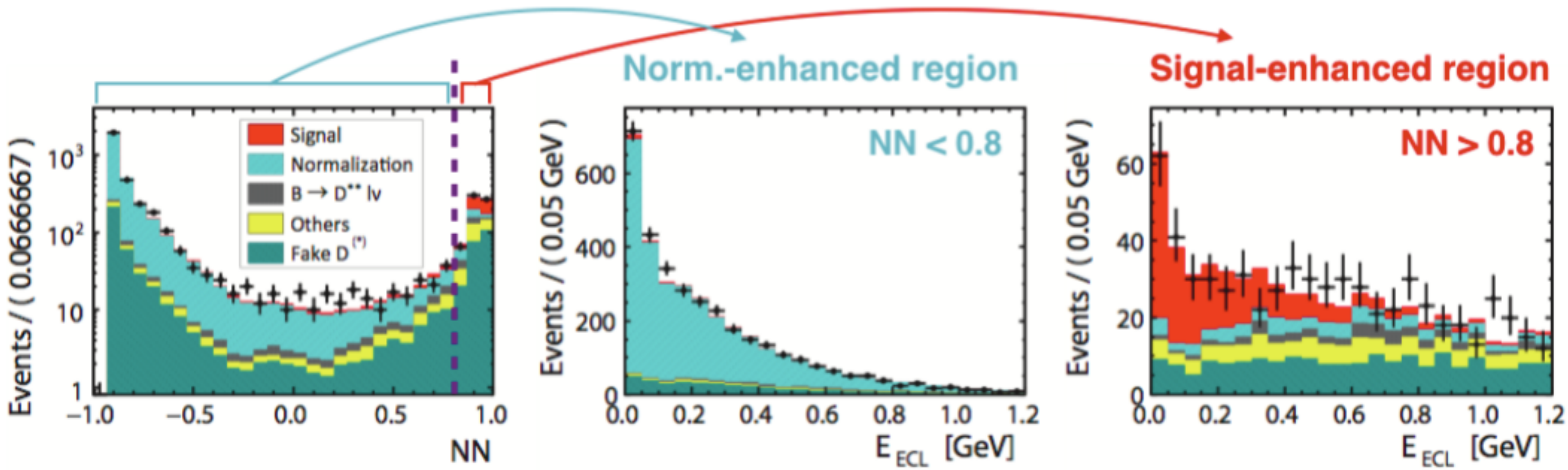
- Neural network to separate signal and normalization events using:
  - signal-side $\cos\theta_{B,D^*l}$
  - missing mass squared
  - visible energy





- Determine the number of signal and normalization events by a two dimensional maximum likelihood fit
  - Fit variable 1: neural network output
  - Fit variable 2: sum of energies of neutral clusters not associated to reconstructed particles E_{ECL}
  - Signal, normalization and $B \rightarrow D^{**}l\nu$ yields are floated in the fit, other components are fixed to MC expectation

Fit result



$$\mathcal{R}(D^*) = \frac{\mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\tau)}{\mathcal{B}(B^0 \to D^{*-}\ell^+\nu_\ell)} \qquad \mathcal{R}(D^*) = \frac{1}{\mathcal{B}(\tau^- \to l^-\bar{\nu}_l\nu_\tau)} \cdot \frac{\varepsilon_{\text{norm}}}{\varepsilon_{\text{sig}}} \cdot \frac{N_{\text{sig}}}{N_{\text{norm}}}$$

$$\boxed{\mathcal{R}(D^*) = 0.302 \pm 0.030(\text{stat}) \pm 0.011(\text{syst}) \quad (13.8\sigma)}$$

Systematic uncertainty / stability

	$\mathcal{R}(D^*)$ [%]		
Sources	$\ell^{\rm sig} = e, \mu$	$\ell^{\rm sig} = e$	$\ell^{\rm sig} = \mu$
MC statistics for PDF shape	2.2%	2.5%	3.9%
PDF shape of the normalization	$^{+1.1}_{-0.0}\%$	$^{+2.1}_{-0.0}\%$	$^{+2.8}_{-0.0}\%$
PDF shape of $B \to D^{**}\ell\nu_\ell$	$^{+1.0}_{-1.7}\%$	$^{+0.7}_{-1.3}\%$	$^{+2.2}_{-3.3}\%$
PDF shape and yields of fake $D^{(*)}$	1.4%	1.6%	1.6%
PDF shape and yields of $B \to X_c D^*$	1.1%	1.2%	1.1%
Reconstruction efficiency ratio $\varepsilon_{\rm norm}/\varepsilon_{\rm sig}$	1.2%	1.5%	1.9%
Modeling of semileptonic decay	0.2%	0.2%	0.3%
$\mathcal{B}(\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau)$	0.2%	0.2%	0.2%
Total systematic uncertainties	$^{+3.4}_{-3.5}\%$	$^{+4.1}_{-3.7}\%$	$^{+5.9}_{-5.8}\%$

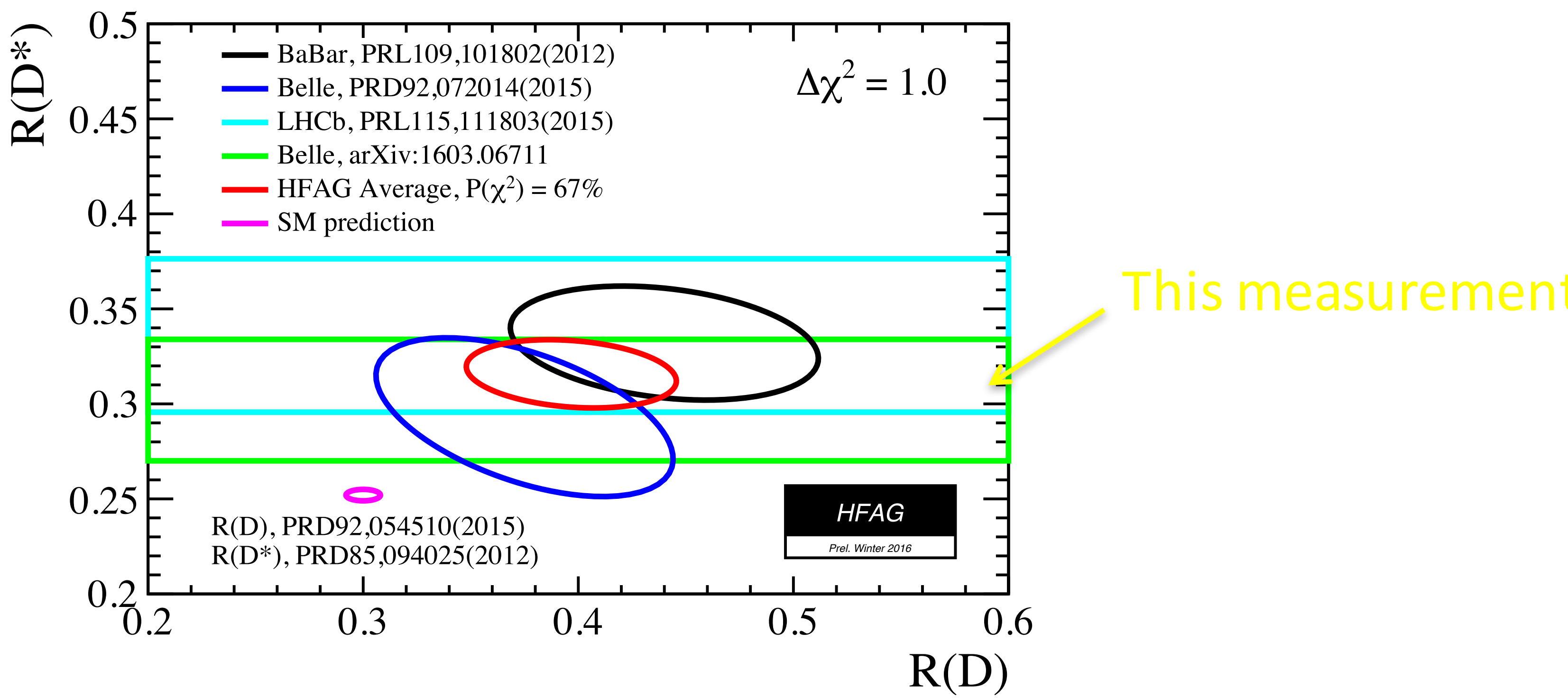
Consistent results for individual samples (separated @ $B_{\rm sig}$)

$$\mathcal{R}(D^*) = 0.311 \pm 0.038 \pm 0.013 \quad (\ell^{\rm sig} = e)$$

$$\mathcal{R}(D^*) = 0.304 \pm 0.051 \pm 0.018 \quad (\ell^{\rm sig} = \mu)$$

Comparison to other measurements

$$\mathcal{R}(D^{(*)}) \equiv \frac{\mathcal{B}(B \to D^{(*)}\tau\nu_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\nu_\ell)} \qquad (\ell = e, \mu)$$



- The difference with the SM prediction is at the level of 4.0 sigma for all four measurements combined

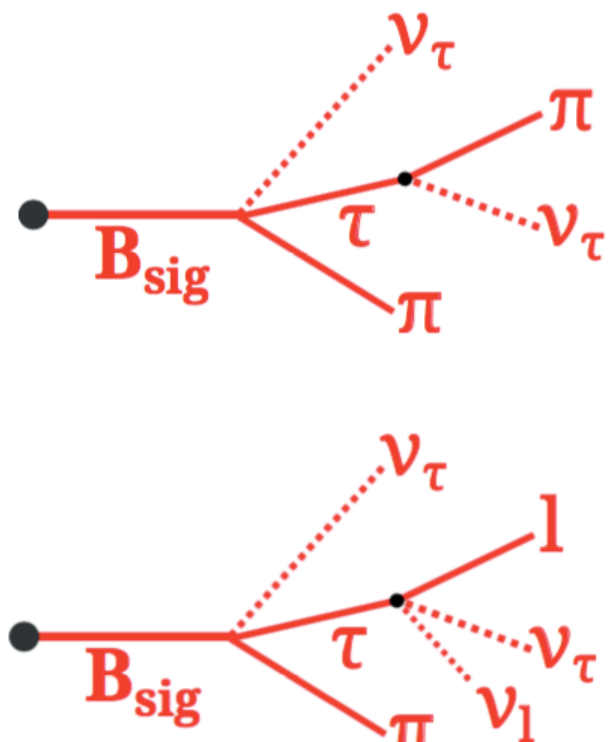
$B \to \pi\tau\nu$ with hadronic tag

Motivation

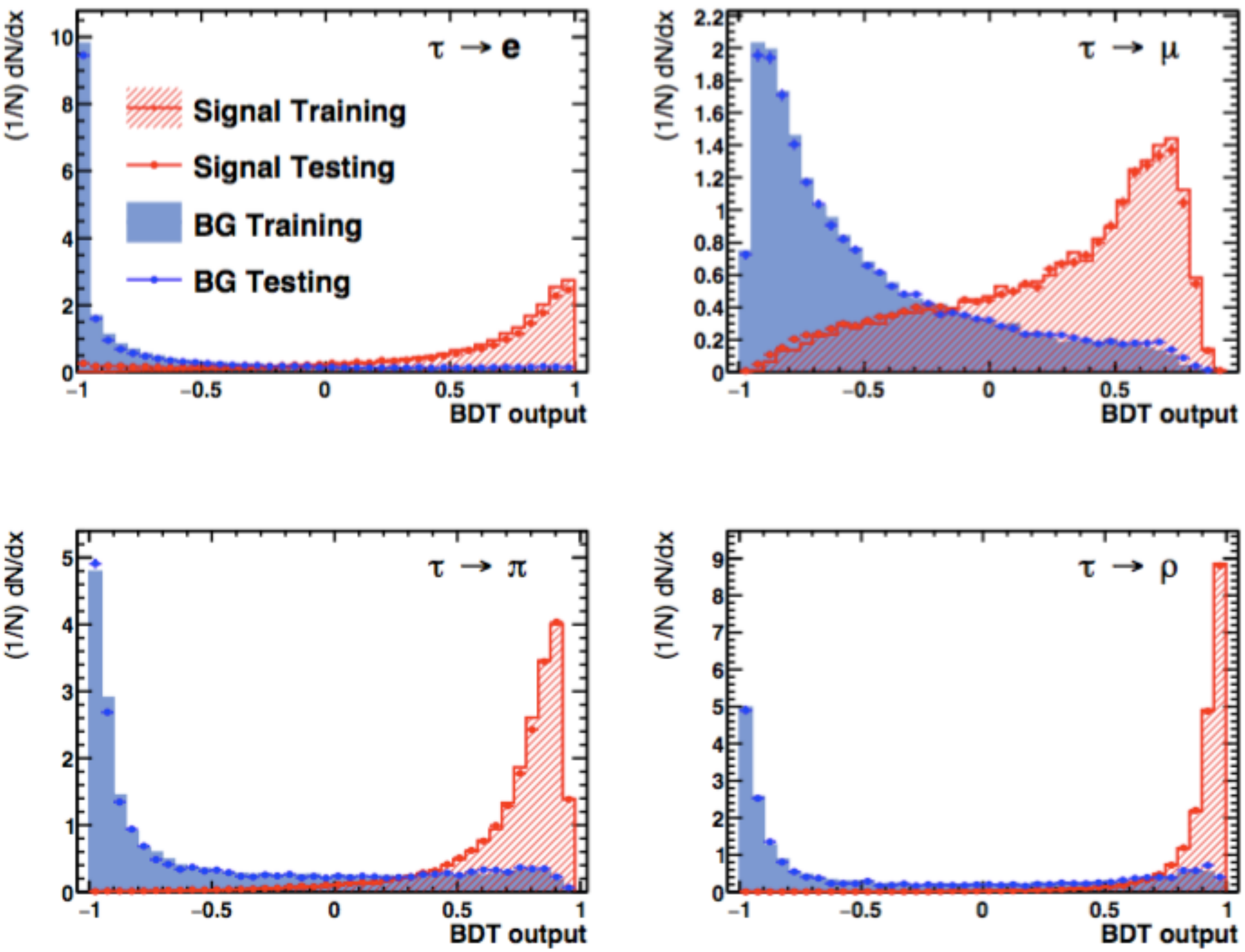
- Within the type II 2HDM, the branching fraction of $B \rightarrow \pi\tau\nu$ can be modified similarly to $B \rightarrow D^{(*)}\tau\nu$
- Current experimental situation: $B \rightarrow \tau\nu$ branching fraction is SM-like while $B \rightarrow D^{(*)}\tau\nu$ exhibits a ~4σ anomaly
- $B \rightarrow \pi\tau\nu$ thus provides additional insight and in particular is an independent probe of the $b \rightarrow u\tau\nu$ transition

Principle of the measurement

- B_{tag} reconstructed in a hadronic mode
- τ reconstruction (~71%):
  - $\tau \to e/\mu\nu\nu$
  - $\tau \to \pi/\rho(\pi\pi^0)\ \nu$
- Background is suppressed with a multivariate discriminator (boosted decision trees)
- Signal is extracted from a one-dimensional fit to E_{ECL}



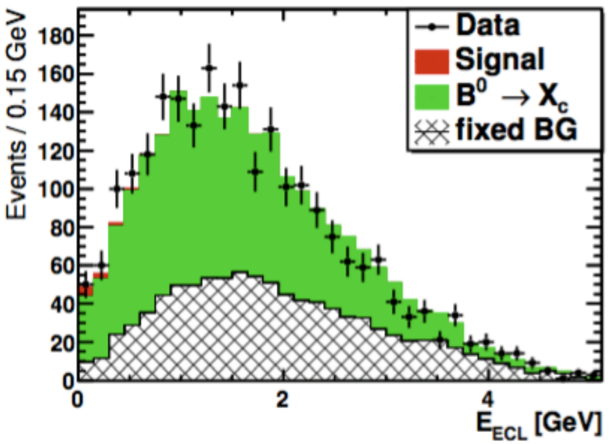
Boosted decision trees (BDTs)



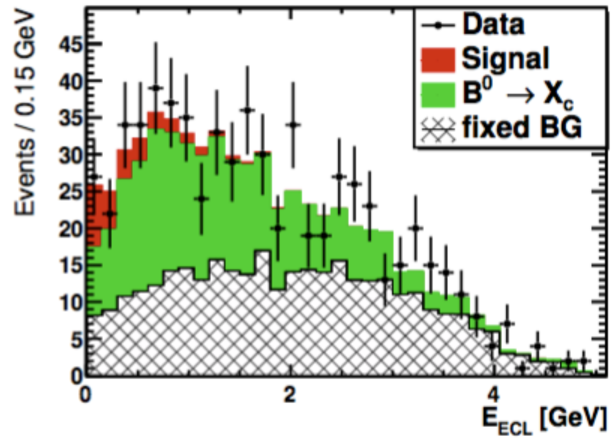
- One BDT for every τ mode
- Discriminant variables:
  - Missing energy and momentum
  - K_L veto
  - …
- Background: dominant $b \to c$ decays

Fit result

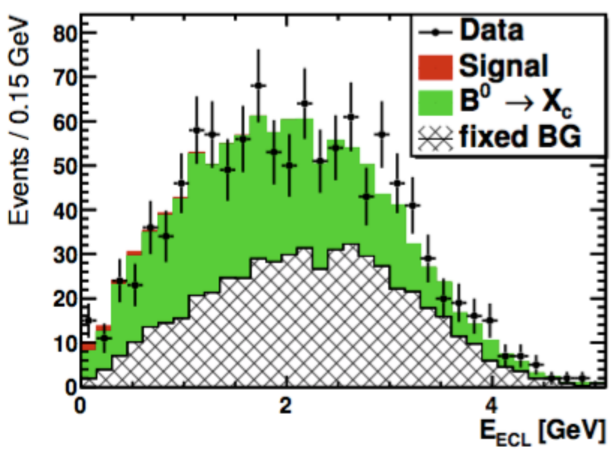
Electron mode



Pion mode



Rho mode



Signal events: 52 ± 24

$$\mathcal{B}(B^0 \to \pi^- \tau^+ \nu_\tau) = (1.52 \pm 0.74 \pm 0.13) \cdot 10^{-4}$$

Significance level: 2.4σ

$$\mathcal{B}(B^0 \to \pi^- \tau^+ \nu_\tau) < 2.5 \cdot 10^{-4} \ @\ 90\% CL$$

Systematic uncertainty

systematic	relative uncertainty [%]
e ID	1.4
π ID	1.6
π^0 ID	1.0
Track efficiency	0.7
N($B\bar{B}$)	1.4
K_L veto	3.2
BG $\mathcal{B}$	2.8
$D^{(*)}\ell\nu$ model	0.5
Tagside	4.6
$\lvert V_{ub} \rvert$	2.8
Rare MC	2.0
$B \to X_u \tau \nu$	2.2
Background Fit	0.2
Signal model	1.8
total	8.3

SUMMARY

Summary

- New preliminary Belle result for $R(D^*)$ obtained with semileptonic tagging [arXiv:1603.06711]
  - $R(D^*) = 0.302 \pm 0.030(\text{stat}) \pm 0.011(\text{syst})$
  - Confirms the excess seen by other experiments and brings to tension with the SM to 4.0σ
- Search for $B^0 \to \pi^- \tau^+ \nu$ at Belle [Phys. Rev. D93, 032007 (2016)]
  - $Br(B^0 \to \pi^- \tau^+ \nu) < 2.5 \times 10^{-4}$ @ 90% C.L.
- We need the Belle II data to clarify the experimental situation

BACKUP