Search for the decay $B^0 \to \tau^+\tau^-$ at Belle

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Michael Ziegler | September 28, 2015

KARLSRUHE INSTITUTE OF TECHNOLOGY (KIT)

How to detect New Physics?

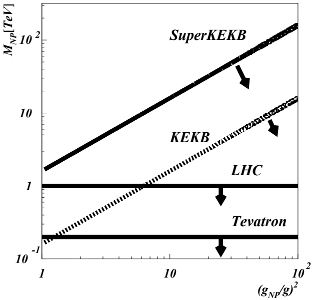
High Energy Frontier

- New resonances at high masses
- ...

or

High Intensity Frontier

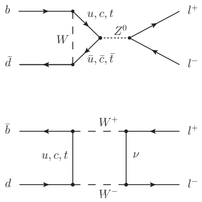
- Mixing in neutral meson systems, e.g. $K^0 - \bar{K}^0$, $B^0 - \bar{B}^0$
- Rare B decays
- ...



Rare B Decays

Small branching ratios in the SM $\Rightarrow$ effects from NP could be seen

$B^0 \to \ell^+\ell^-$



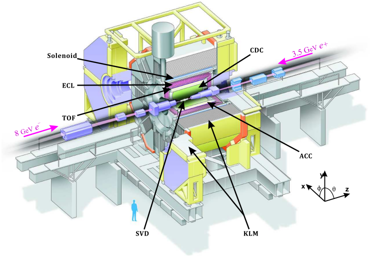
$$\mathcal{B}(B^0 \to e^+e^-)_{\text{SM}} = (2.48 \pm 0.21) \times 10^{-15}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-)_{\text{SM}} = (1.06 \pm 0.09) \times 10^{-10}$$
$$\mathcal{B}(B^0 \to \tau^+\tau^-)_{\text{SM}} = (2.22 \pm 0.19) \times 10^{-8}$$

Values from: Bobeth, C. et al., $B_{s,d} \to \ell^+\ell^-$ in the Standard Model with Reduced Theoretical Uncertainty. Phys. Rev. Lett. 112, 101801 (2014)

Search for $B^0 \to \tau^+\tau^-$ at Belle

Experimental Setup

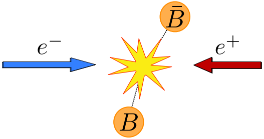
- KEKB: asymmetric energy e^+e^- collider
- $\sqrt{s} \approx M(\Upsilon(4S))$
- Final data sample: $\mathbf{772 \times 10^6}$ $B\bar{B}$ pairs



Reconstruction

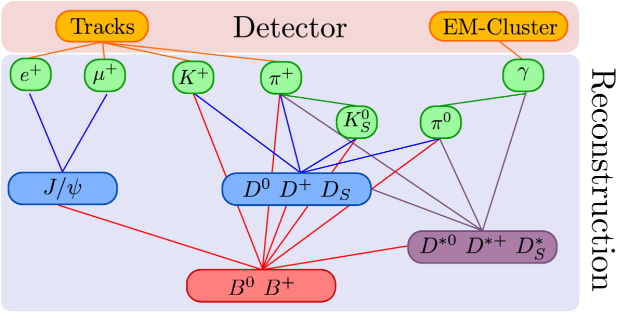
Challenge of $B^0 \to \tau^+\tau^-$

τ leptons decay in the detector $\to$ at least 2 neutrinos in the final state



- But at Belle: only two B mesons in an event
- Initial state well known
- Reconstruct one of them in a hadronic final state - called B_{Tag}
- In the rest of the event, search for the signal side - called B_{Sig}

Tag Side - The hadronic full reconstruction

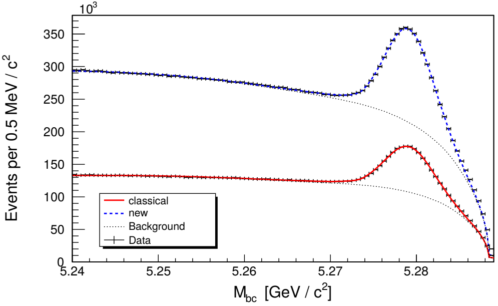


- B_{Tag} reconstructed in a large number of hadronic decay channels
- Multivariate selection at each stage
- Final probability for reconstructed B_{Tag} candidate being a B meson
- Remaining tracks and energy deposition in the detector must come from second B meson

Results of the Full Reconstruction

Beam constraint mass

$$M_{\mathrm{bc}}^{\mathrm{tag}} = \sqrt{E_{\mathrm{beam}}^2 - \vec{p}_{\mathrm{tag}}^{\,2}}$$



Efficiency of Full reconstruction: $\mathcal{O}(10^{-3})$

Signal Side

Reconstruct τ in different channels ...

Decay mode	$\mathcal{B}$ in %
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$	$17,83$
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$	$17,41$
$\tau^- \to \pi^- \nu_\tau$	$10,83$

... and combine two oppositely charged τ candidates to B_{Sig}

Selection

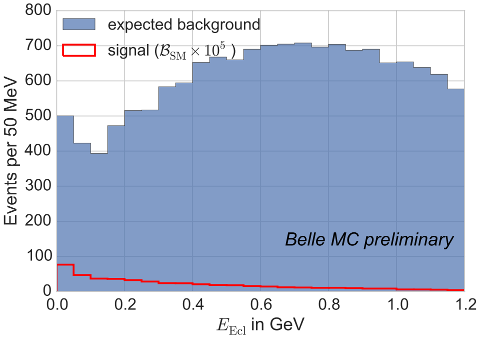
- No charged track and π^0 in rest of event
- More cuts on kinematic variables like missing mass, ...

Afterwards

Divide sample according to the final state

What do we expect so far?

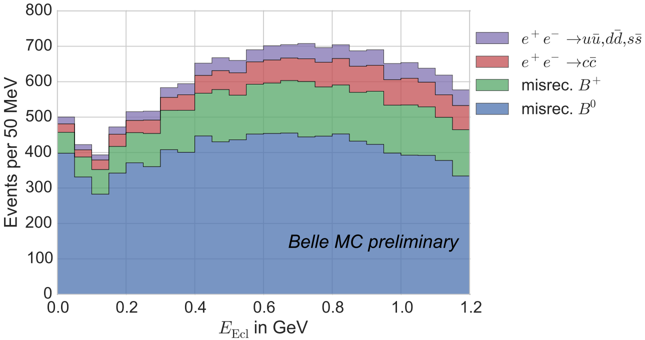
Final state: one τ decays to e the other to π (+ neutrinos)



What is $E_{\mathbf{Ecl}}$?

Remaing energy in the calorimeter that is not used in the reconstruction

Background Composition



- Background from light quarks suppressed
- Main background: misreconstucted B^0. e.g.:

$$B^0 \to D^-(\to K_L \pi^-) e^+ \nu_e$$

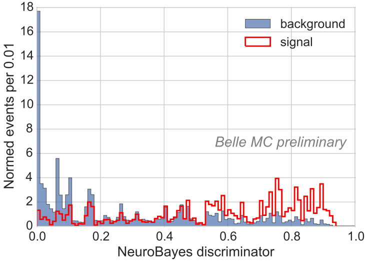
Background Suppression

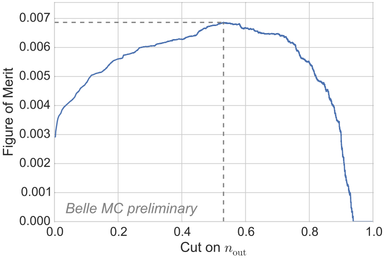
NeuroBayes networks are used

Input variables

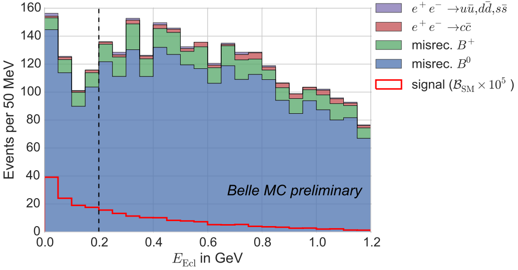
- Missing mass
- Invariant mass of the charged tracks
- M_{bc} of B_{Tag} candidate
- ...

$$\mathrm{FOM} = \frac{\epsilon}{\sigma/2 + \sqrt{\mathrm{N_B}}}$$





E_{Ecl} after the cut

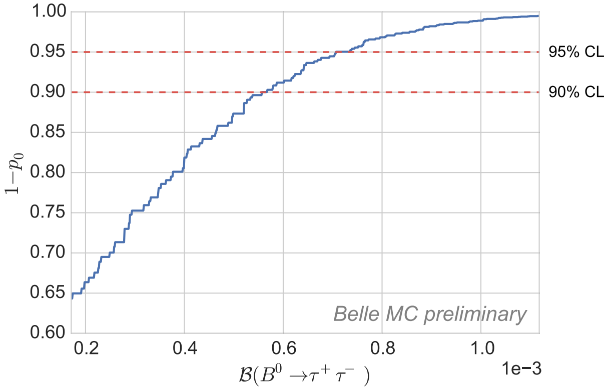


Signal extraction

Counting experiment in the signal window $E_{\text{Ecl}} < 0.2$ GeV

Expected Sensitivity

A scan over different branching ratios for $B^0 \to \tau^+\tau^-$ is performed to estimate the expected sensitivity



$$\mathcal{B}(B^0 \to \tau^+\tau^-)_{\text{expected}} < 7.5 \times 10^{-4}$$

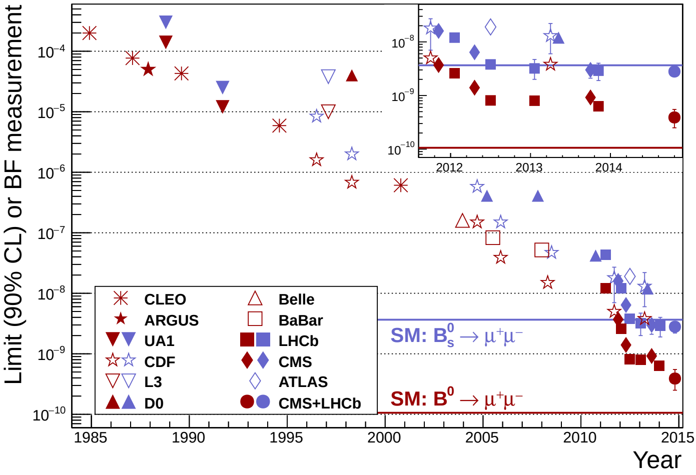
Conclusion

- NP can be seen in rare B decays
- Knowledge of the initial state makes reconstruction of decays with many neutrinos in the final state possible
- Expected limit (@ 95% CL):

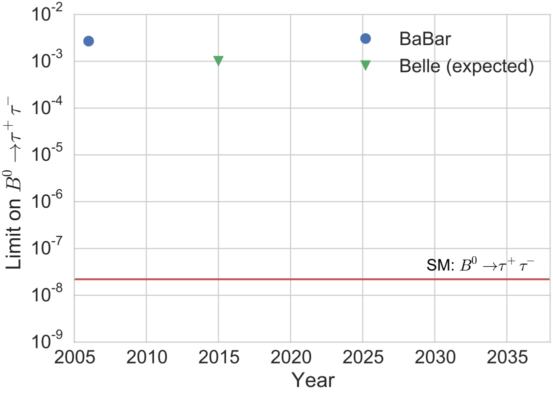
$$\mathcal{B}(B^0 \to \tau^+\tau^-)_{\text{expected}} < 7.5 \times 10^{-4}$$

- Just the beginning of the search for $B^0 \to \tau^+\tau^-$

Results for $B^0 \to \mu^+\mu^-$



Source: LHCb & CMS Collaborations, Nature, 522 (2015), p. 68-72



10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
Limit on $B^0 \to \tau^+ \tau^-$
2005
2010
2015
2020
2025
2030
2035
Year
BaBar
Belle (expected)
SM: $B^0 \to \tau^+ \tau^-$