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Searching for lepton flavour violating decays in $B^0 \to \tau^{\pm}\ell^{\mp}$ ($\ell = e/\mu$) channel

Belle

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Motivation

- Standard Model decay via neutrino oscillations is highly suppressed ($\mathcal{B} \approx 10^{-50}$)
- decay sensitive to New Physics e.g. leptoquarks ($\mathcal{B} \approx 10^{-9}$)

- previous studies by CLEO(2004), Babar(2008), LHCb(2019) and Belle(2021)
- most stringent upper limits:
  - $\mathcal{B}(B^0 \to \tau^\pm e^\mp) < 1.6 \cdot 10^{-5}$ at 90% CL (Belle)
  - $\mathcal{B}(B^0 \to \tau^\pm \mu^\mp) < 1.2 \cdot 10^{-5}$ at 90% CL (LHCb)

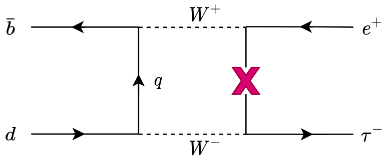


Figure: Standard Model

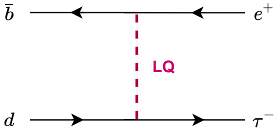
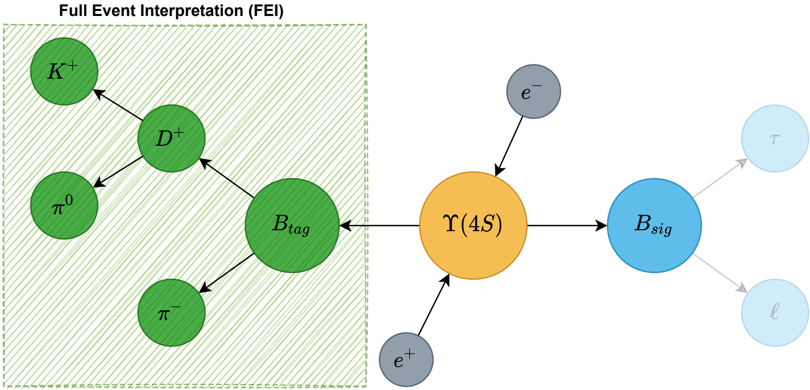


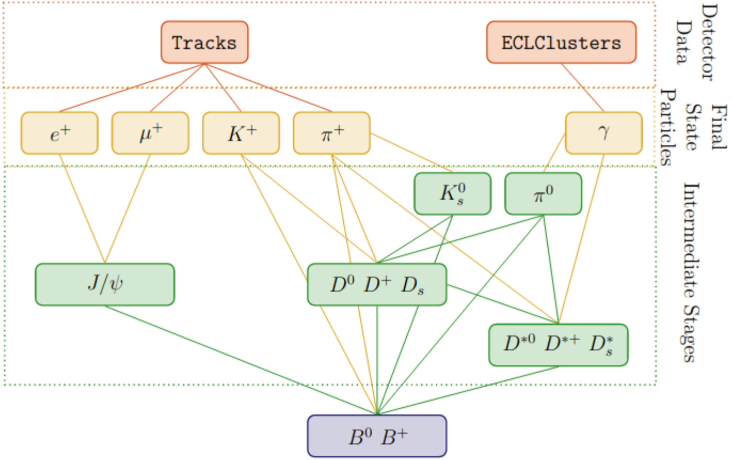
Figure: Leptoquarks

Signal Decay



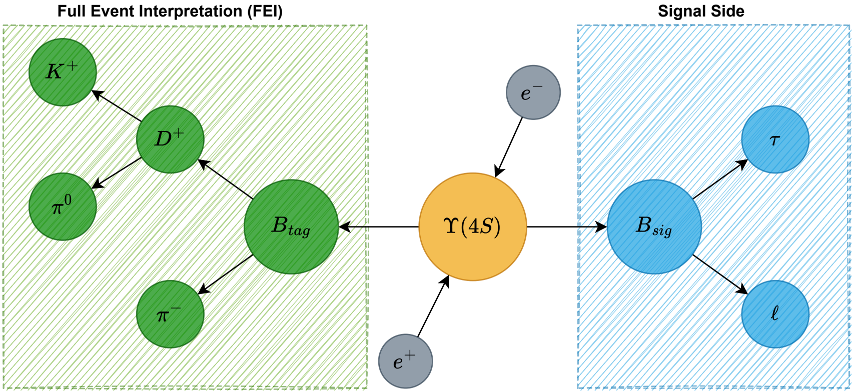
- tag-side B meson reconstructed with FEI in hadronic decay modes

Full Event Interpretation



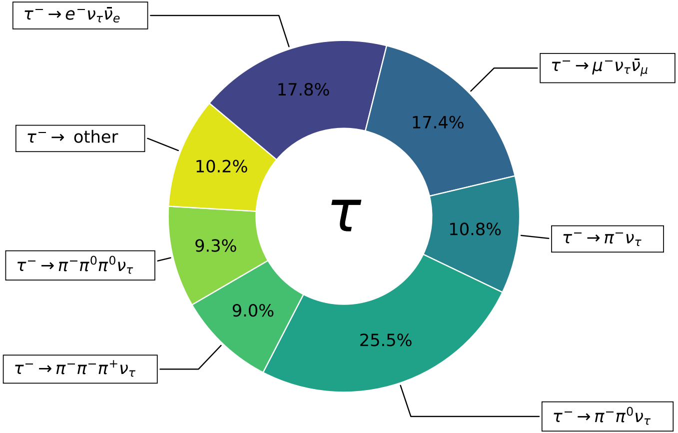
- hierarchical machine learning approach to identify B meson decay reconstruction in approx. 10,000 channels
- kinematics and vertex information in each reconstruction step used to limit the number of reconstructed candidates
- each reconstructed B meson candidate gets a signal probability

Signal Decay



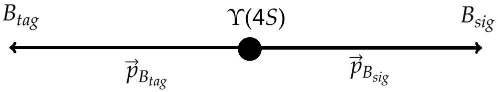
- tag-side B meson reconstructed with FEI in hadronic decay modes
- high momentum of lepton to identify signal
- lepton mono-energetic in B_{sig} rest frame
- No additional particles in event after $\Upsilon(4S)$ for signal events

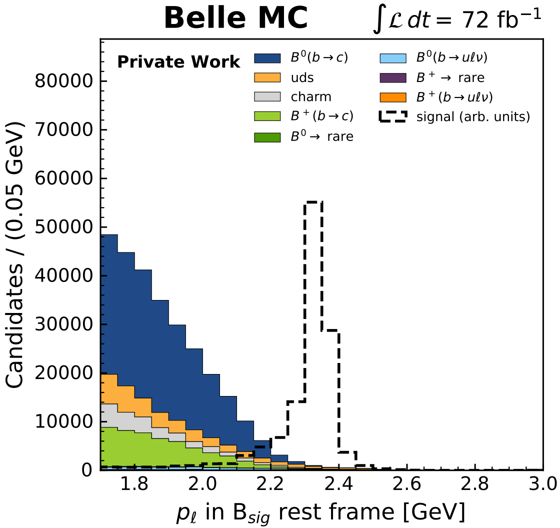
τ Decay Modes



$\approx 90\%$ of all τ decay modes are reconstructed

Lepton Momentum





Reduction of Background Contributions

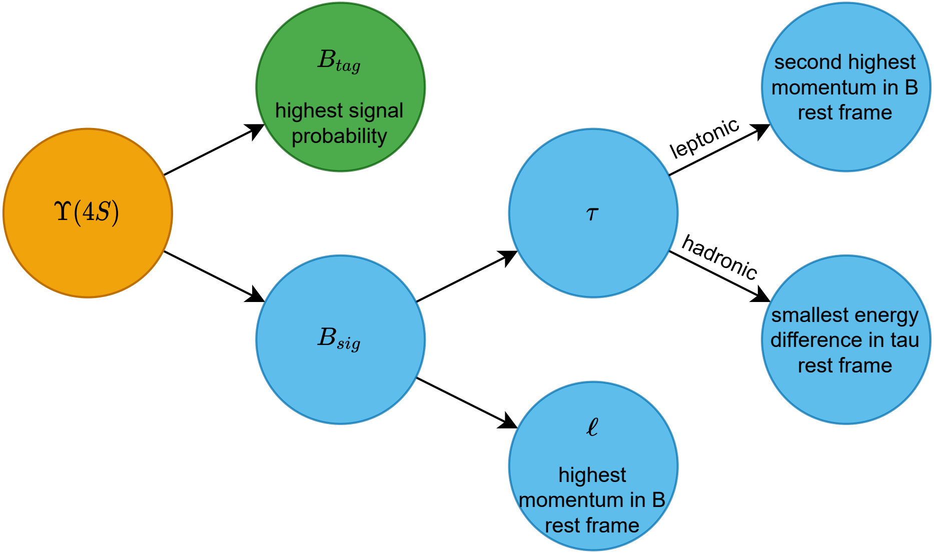
Multiplicity

$$\text{Multiplicity} = \frac{\text{Number of reconstructed } \Upsilon(4S)}{\text{Number of events}}$$

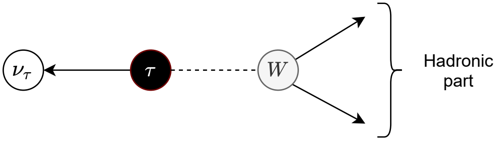
MC Event Type	Multiplicity of $\Upsilon(4S)$
signal	4.35
charm	8.12
uds	7.99
$B^0(b \to c)$	7.62
$B^+(b \to c)$	6.45
$B^0 \to$ rare	5.42
$B^+ \to$ rare	5.59
$B^0(b \to u\ell\nu)$	6.38
$B^+(b \to u\ell\nu)$	5.35

Cross-feed between the τ decay modes is the dominant source of the high multiplicity.

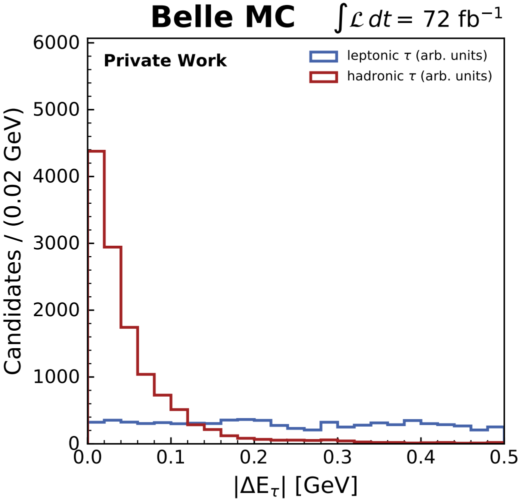
Best Candidate Selection



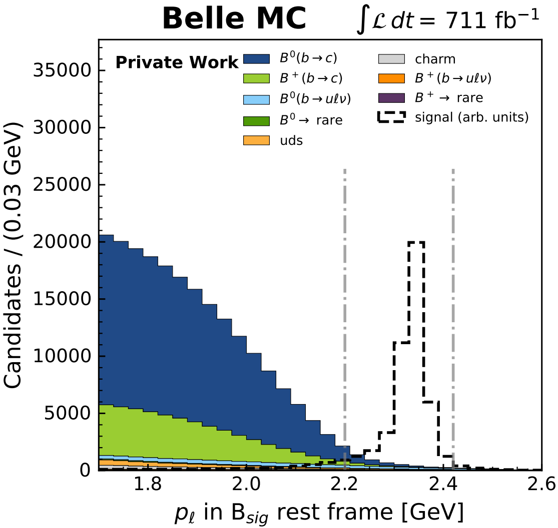
Best Candidate Selection: ΔE



- $\Delta E_\tau = E_H + |p_\nu| - m_\tau$ with $\vec{p_\nu} = -\vec{p_H}$
- select hadronic τ with smallest ΔE_τ
- events with hadronic and leptonic τ candidate
  - if $\Delta E_\tau \geq 0.1$ GeV for hadronic $\tau \rightarrow$ **leptonic τ**
  - if $\Delta E_\tau < 0.1$ GeV for hadronic $\tau \rightarrow$ **hadronic τ**



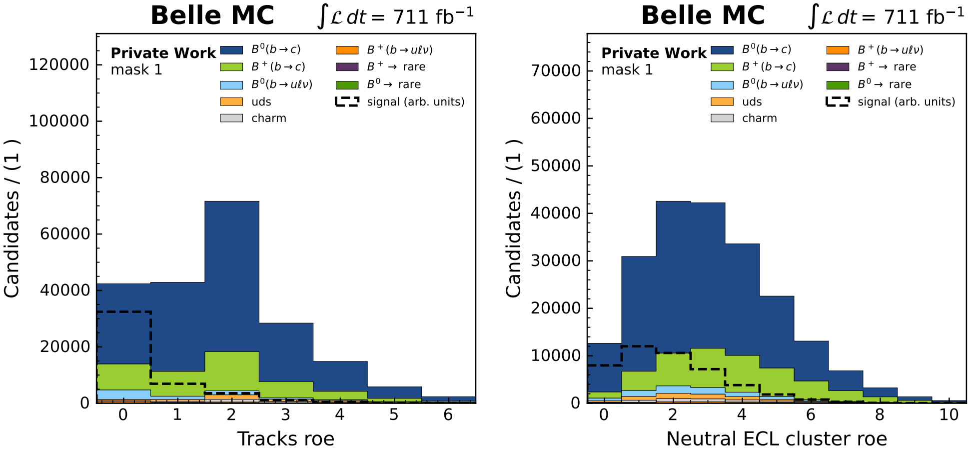
Lepton Momentum in B_{sig} Rest Frame



Signal region of lepton momentum: 2.20 - 2.42 GeV in B_{sig} rest frame.

Rest of the Event

Rest of the event: all particles not associated with B_{sig} or B_{tag} reconstruction.

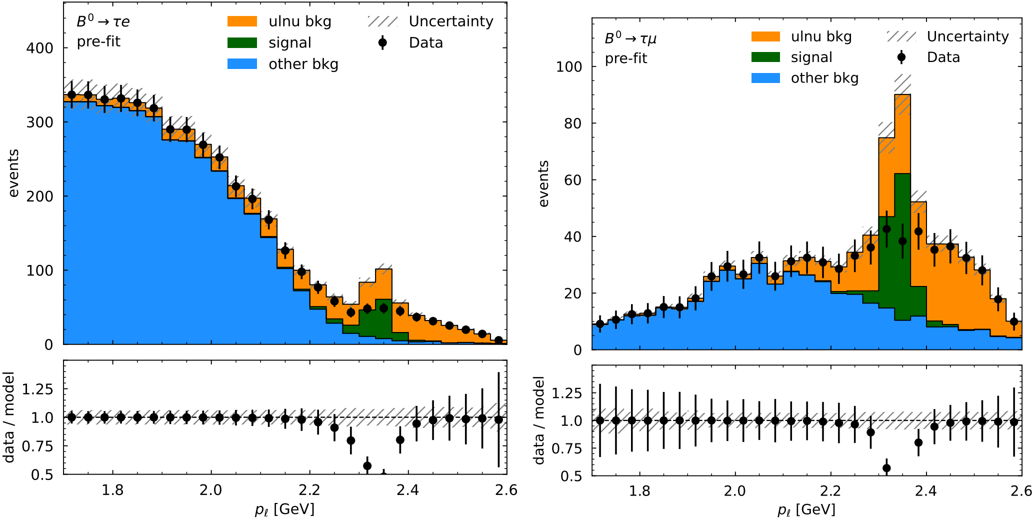


For correctly reconstructed signal events the rest of the event is empty.
⇒ Trained boosted decision trees to reduce the background contributions in the signal region.

Fit of the Lepton Momentum Distribution

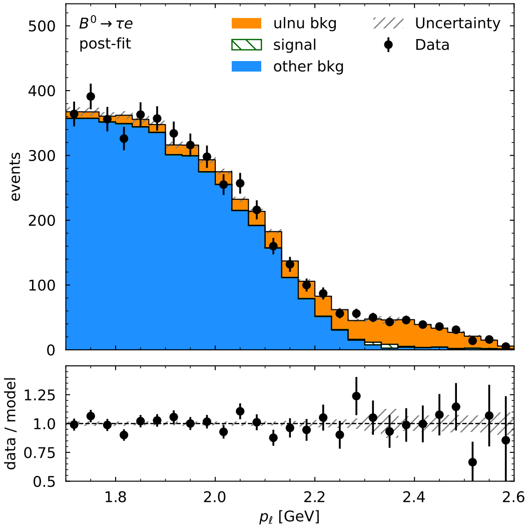
with a binned maximum likelihood fit implemented with pyhf

Pre-fit Distribution of Lepton Momentum



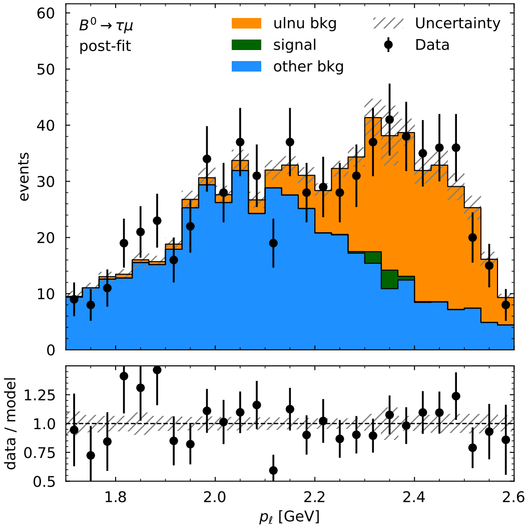
The fit is tested on Asimov data containing zero signal events.

Fit for $B^0 \to \tau e$ Decays on Belle Data



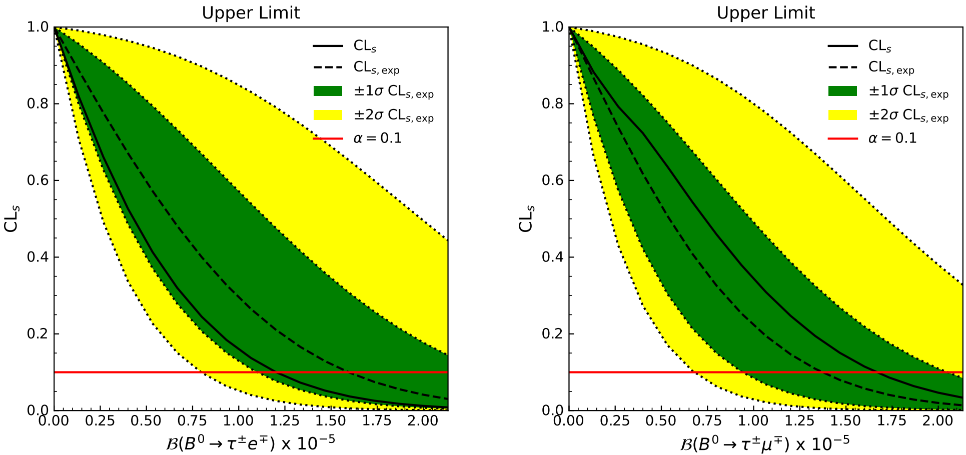
	Belle data
n_{sig}	-15.07 ± 18.61
$n_{u\ell\nu}$	598.04 ± 49.12
n_{other}	4121.01 ± 71.53
goodness of fit p-value	0.61

Fit for $B^0 \to \tau\mu$ Decays on Belle Data

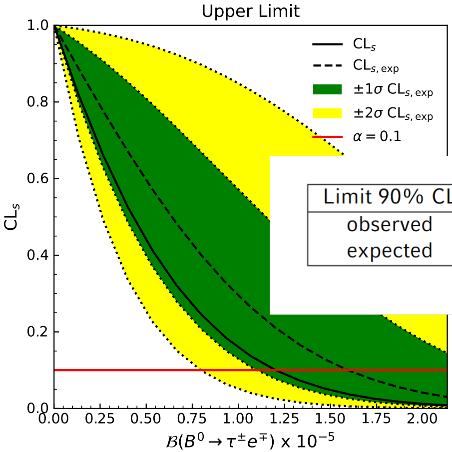


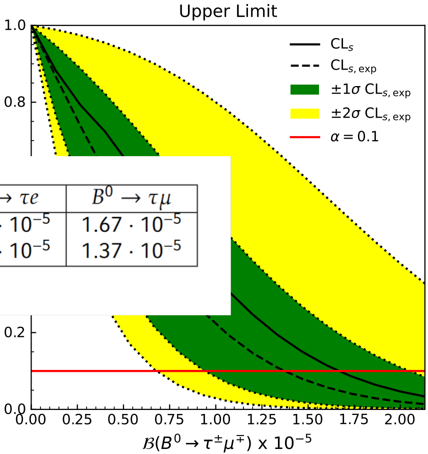
	Belle data
n_{sig}	6.71 ± 12.48
$n_{u\ell\nu}$	239.08 ± 27.65
n_{other}	451.20 ± 27.92
goodness of fit p-value	0.53

Upper Limit Scan



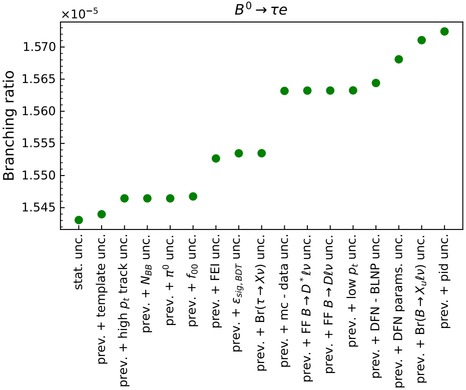
Upper Limit Scan

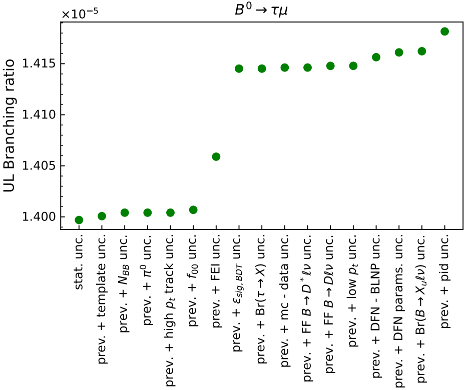




Limit 90% CL	$B^0 \to \tau e$	$B^0 \to \tau\mu$
observed	$1.20 \cdot 10^{-5}$	$1.67 \cdot 10^{-5}$
expected	$1.60 \cdot 10^{-5}$	$1.37 \cdot 10^{-5}$

Impact of Systematic Uncertainties on Limit





The systematic uncertainties only have a small impact on the upper limit of the branching ratios.

Summary & Outlook

Summary

- $B^0 \to \tau^\pm \ell^\mp$ sensitive to New Physics
- high lepton momentum in the signal B rest frame
- B_{tag} reconstructed with hadronic FEI

- applied best candidate selection to reduce the multiplicity
- trained BDT to reduce the B meson background contribution in the signal region

- fitted the lepton momentum distribution of the Belle data (consistent with zero signal events)
- determined the upper limits on the branching ratios
- best upper limit $B(B^0 \to \tau^\pm e^\mp) < 1.2 \cdot 10^{-5}$ at 90% CL

Thank you

for your attention