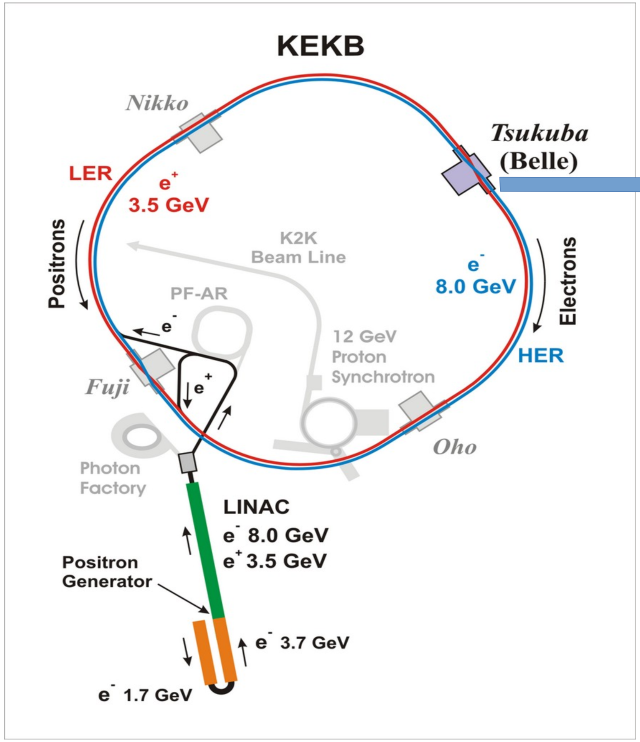
Searches for lepton flavor violation in meson decays at Belle

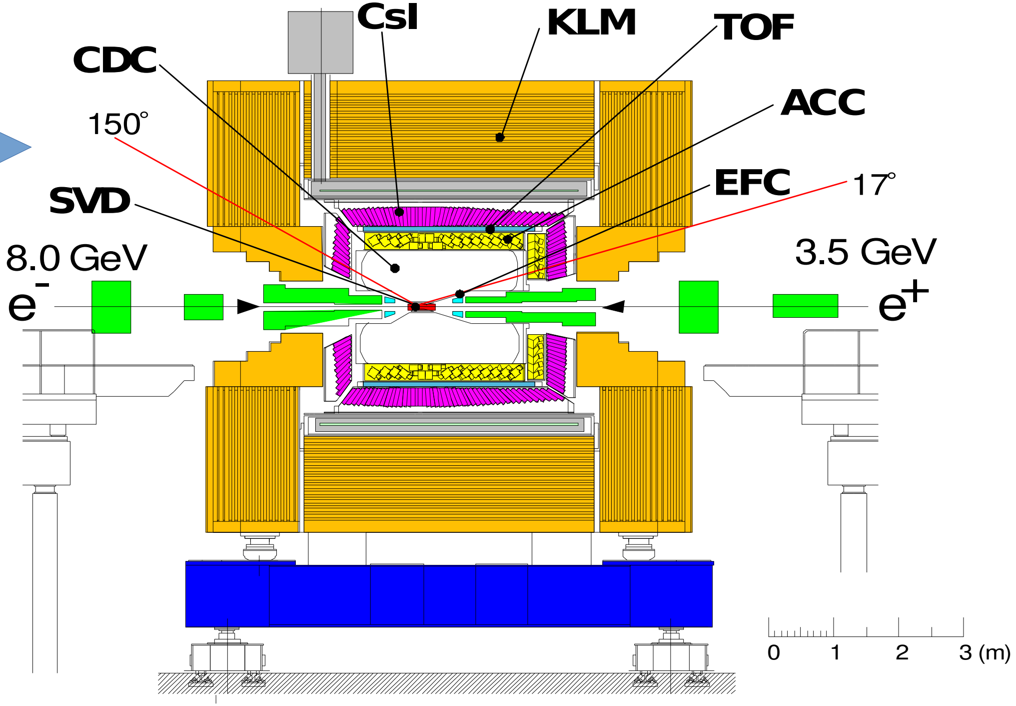
Sourav Patra

on behalf of
Belle Collaboration

4th December, 2023
TAU2023

Belle Experiment

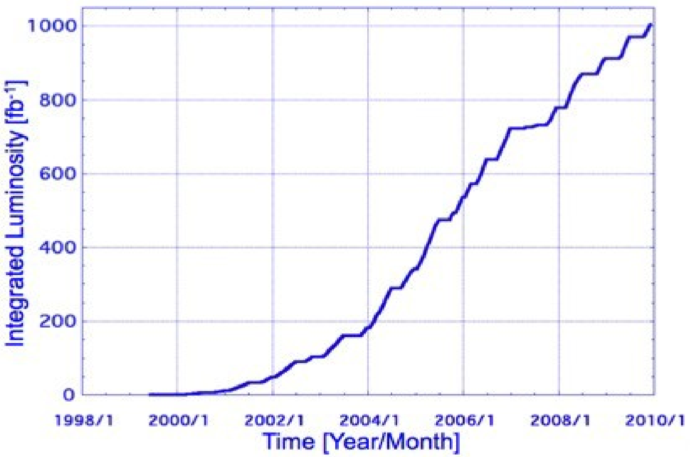




Belle accumulated ~1 ab^{-1} of data.

Search for LFV at Belle

- Considering the observation of neutrino oscillations, charged lepton flavor violation (LFV) is allowed, but at an exceedingly small rate: BR($\tau^{\pm} \to \mu^{\pm} \gamma$)~$10^{-54}$ in the Standard Model (SM).
- LFV can be studied by precisely measuring the beyond SM parameters involving LFV phenomena.
- Low background and full event reconstructions make Belle an ideal place to search for LFV.



Resonance	Energy (GeV)			Luminosity (fb^{-1})
	HER	LER	$\sqrt{s}$	
$\Upsilon(1S)$	7.1511	3.1286	9.4603	6
$\Upsilon(2S)$	7.5750	3.3141	10.023	25
$\Upsilon(3S)$	7.8262	3.4240	10.355	3
$\Upsilon(4S)$	7.9988	3.4995	10.579	711
$\Upsilon(5S)$	8.2150	3.5941	10.860	121

$$N_{\tau\tau} = 918 \times 10^6$$

Recent LFV searches at Belle

- Search for $B^0_s \to \ell^{\pm}\tau^{\mp}$ ($\ell = e, \mu$) with the semi-leptonic tagging method JHEP 08 2023, 178 (2023)

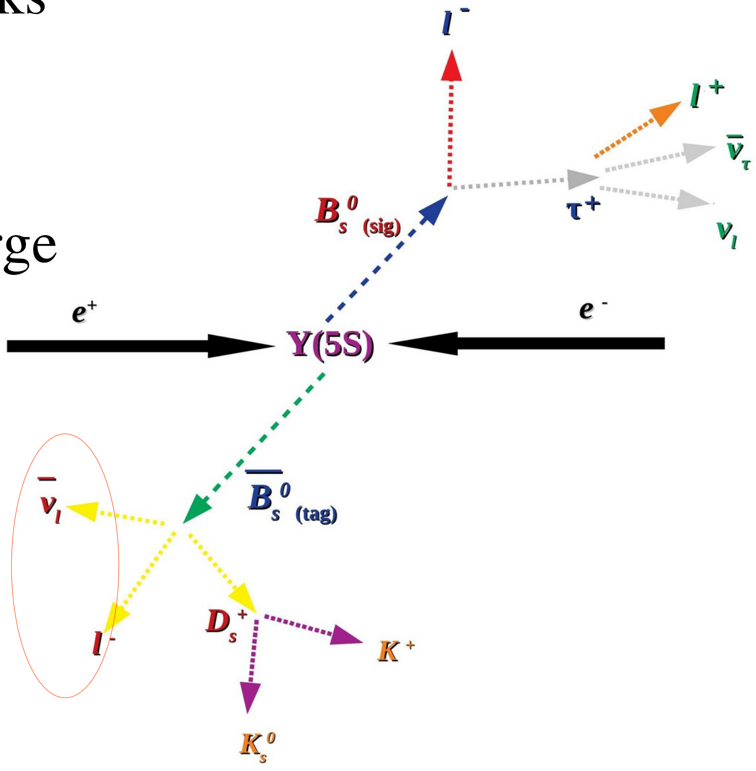
- Search for the lepton flavor violating decays $B^+ \to K^+\tau^{\pm}\ell^{\mp}$ at Belle PRL 130, 261802 (2023)

- Search for lepton flavor violating decays of $\Upsilon(1S)$ JHEP 05 2022, 095 (2022)

Search for $B^0_s \to \ell^\pm \tau^\mp$

- Beyond SM models containing Z' and leptoquarks predict the enhancements in the decay rate of $B^0_s \to \ell^\pm \tau^\mp$.
- The branching fraction of $B^0_s \to \ell^\pm \tau^\mp$ can be as large as 10^{-5}. Mod. Phys. Lett. A 33 (2018) 1850019
- Previous bound by LHCb:
  $\mathcal{B}(B^0_s \to \mu^\pm \tau^\mp) < 3.4 \times 10^{-5}$ PRL 123 (2019) 211801
- There is no available bound on $B^0_s \to e^\pm \tau^\mp$ decay.

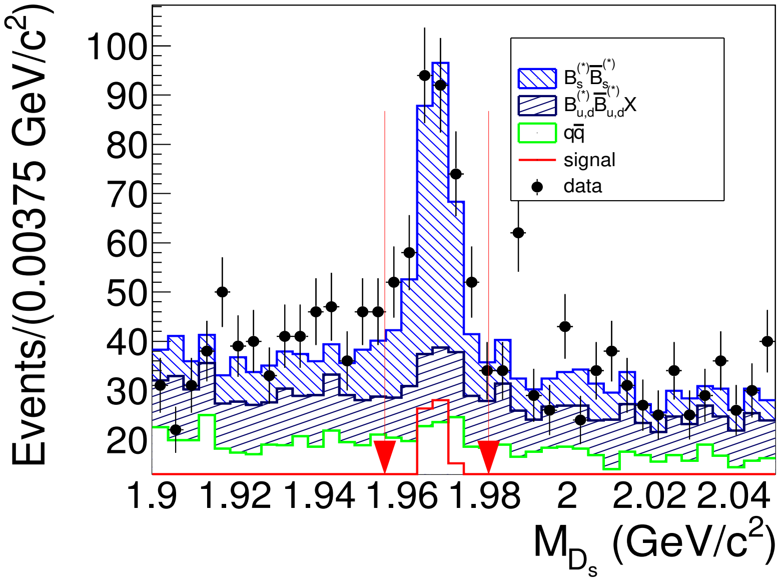
$121\mathrm{fb}^{-1}$ $\Upsilon(5S)$ sample



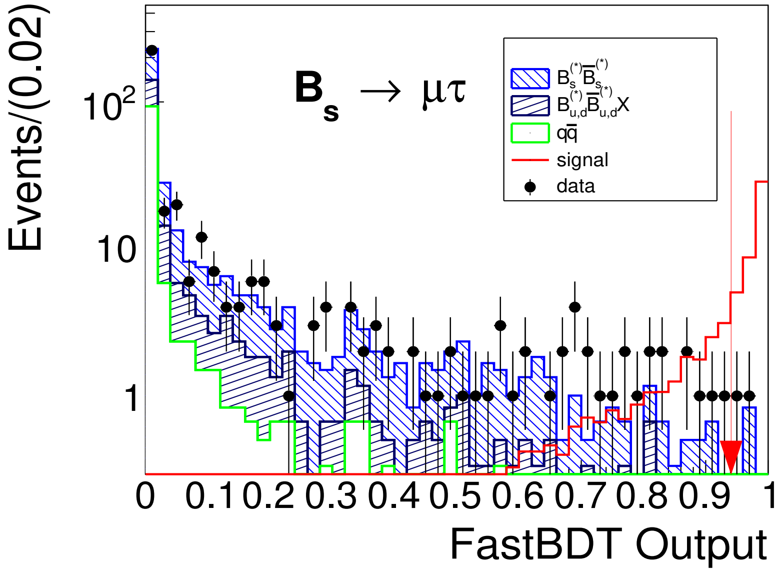
Semi-leptonic Tag

Search for $B^0_s \to \ell^\pm \tau^\mp$

Using B_{tag} information



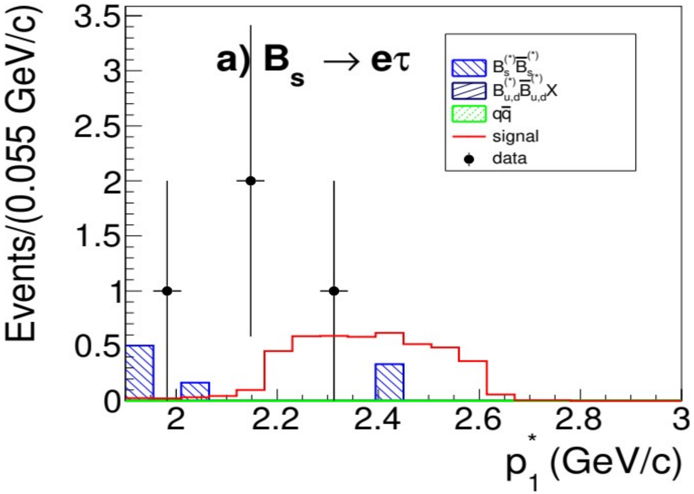
Using B_{tag} and B_{sig} information

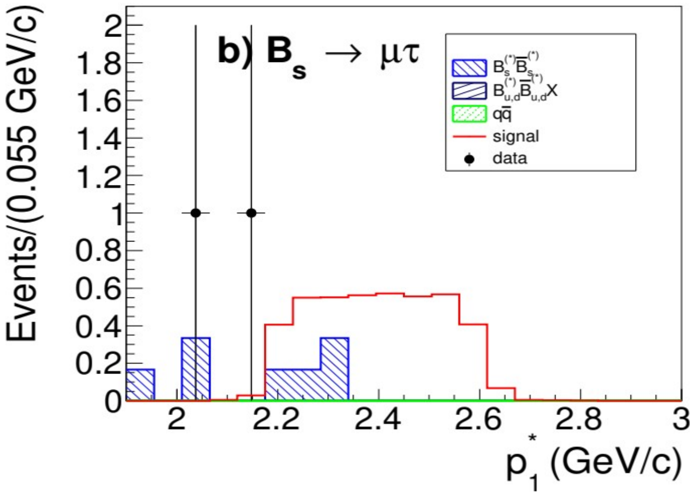


$D_s^+ \to \phi\pi^+, \bar{K}^{*0}K^+, \phi\rho^0\pi^+, K_S^0K^+, \phi\rho^+$

Search for $B^0_s \to \ell^\pm \tau^\mp$

We extract signal yield from momentum of primary lepton in c.m. frame (p^*_1).





Decay mode	ϵ (%)	$N^{\rm exp}_{\rm bkg}$	$N_{\rm obs}$	$\mathcal{B}$ ($\times 10^{-4}$)	$f_s \times \mathcal{B}$ ($\times 10^{-4}$)
$B_s \to e^\pm \tau^\mp$	3.1	0.7 ± 0.7	3	< 14.1	< 5.5
$B_s \to \mu^\pm \tau^\mp$	3.0	0.8 ± 0.8	1	< 7.3	< 2.9

We provide the first result on $B^0_s \to e^\pm \tau^\mp$ decays.

JHEP 08 2023, 178 (2023)

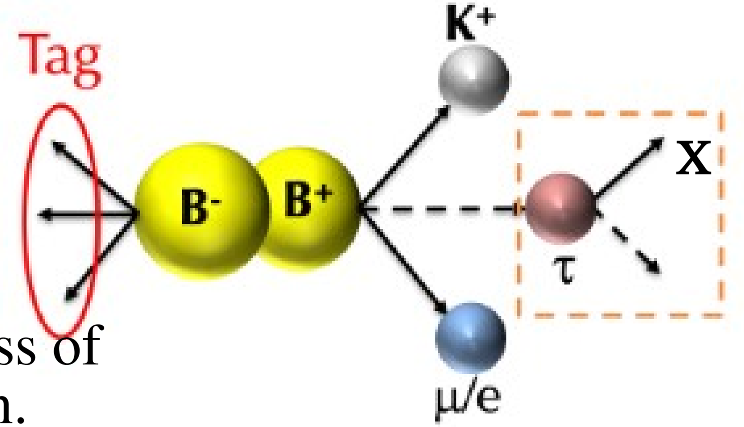
Search for $B^+ \to K^+ \tau^\pm \ell^\mp$

$711\mathrm{fb}^{-1}$ $\Upsilon(4S)$ sample

- Models with vector leptoquark (U_1) provide interesting lower bounds on $b \to s\tau\mu$ transition.
  $\mathcal{B}(B \to K\tau\mu) > 0.7 \times 10^{-7}$ PRD 104, 055017 (2021)

- Tag side B meson is fully reconstructed in the hadronic decay modes.

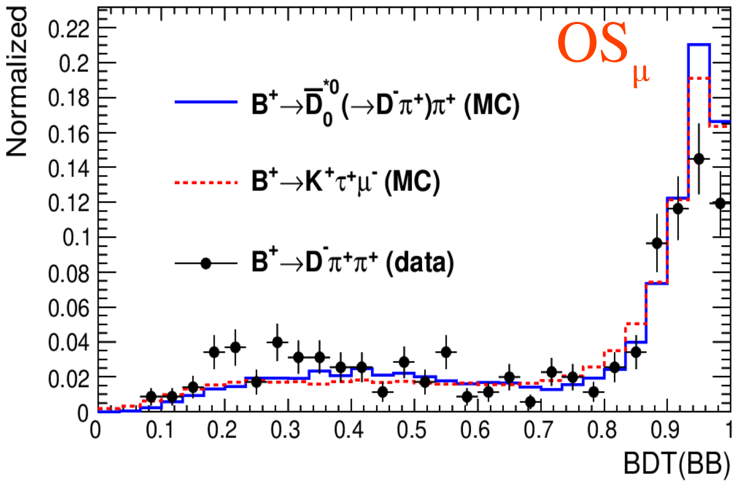
- Signal yield is extracted by fitting the recoil mass of the system containing K^+ and the primary lepton.

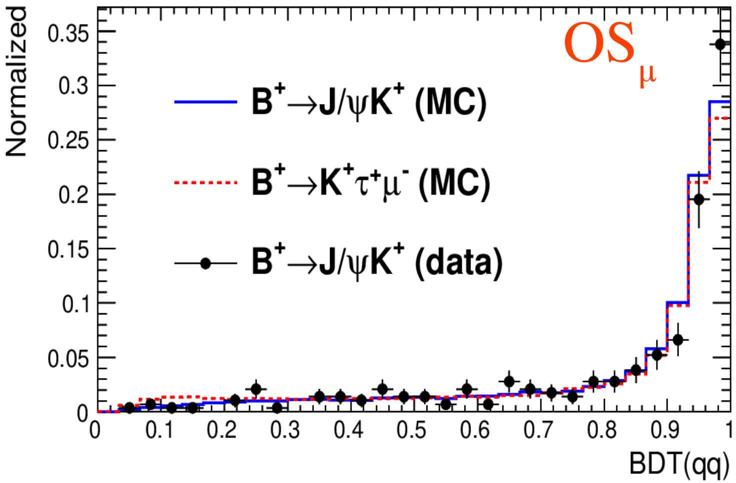


- Signal modes are categorized into two categories:
  $OS_{\mu/e} \Rightarrow \mu/e$ and signal B have opposite charge
  $SS_{\mu/e} \Rightarrow \mu/e$ and signal B have the same charge

$X \Rightarrow e, \mu, \pi$

Search for $B^+ \to K^+ \tau^\pm \ell^\mp$





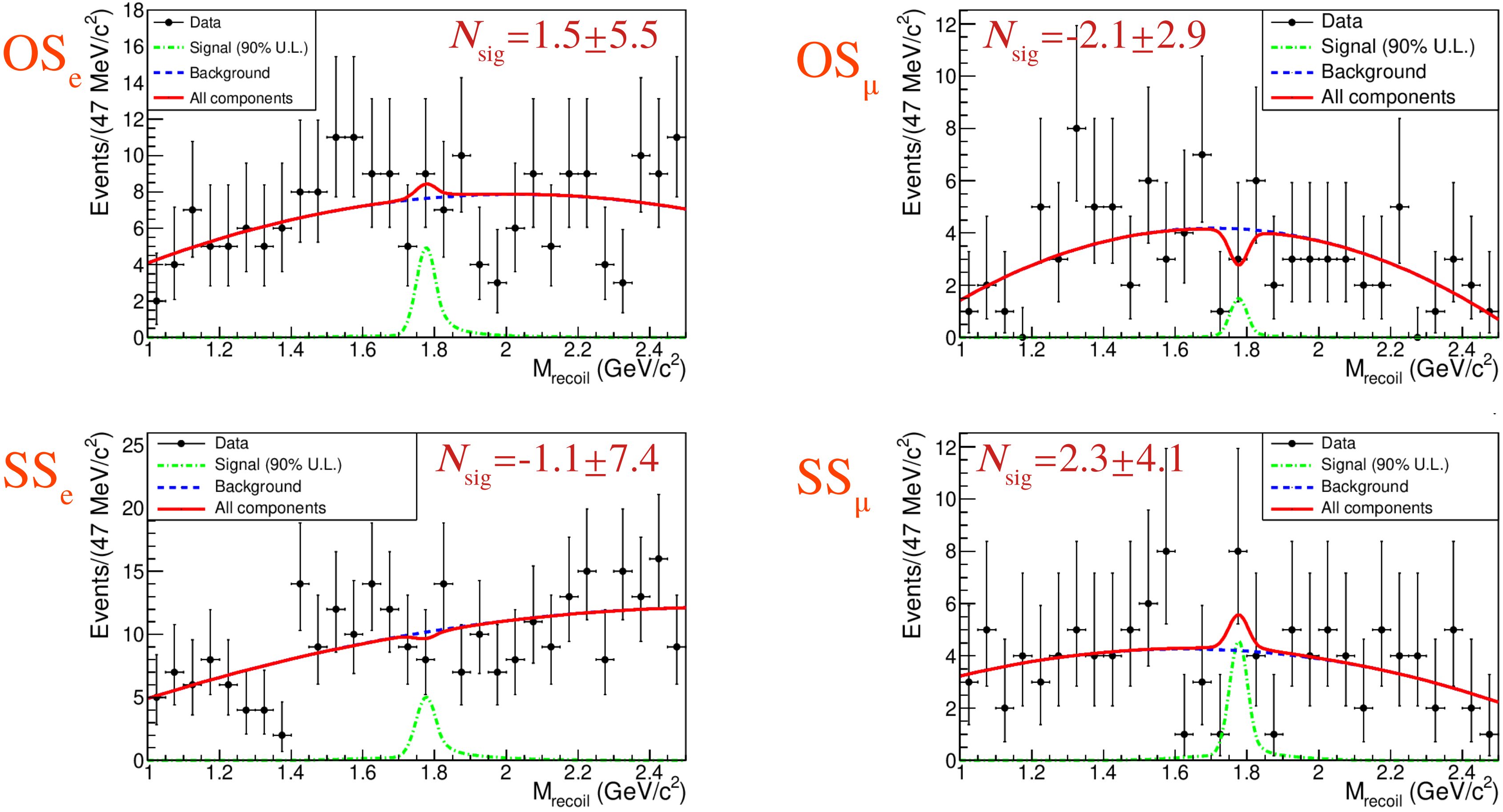
- Dominant background for:

  $OS_{\mu/e}$ mode comes from $B^+ \to X^+ D^0$ decays

  $SS_{\mu/e}$ mode comes from $B^+ \to (\mu/e)^+ D^0 \nu$ decays

- Two BDT classifiers have been trained to suppress $b\bar{b}$ backgrounds and $q\bar{q}$ backgrounds.

Search for $B^+ \to K^+ \tau^\pm \ell^\mp$



Search for $B^+ \to K^+ \tau^\pm \ell^\mp$

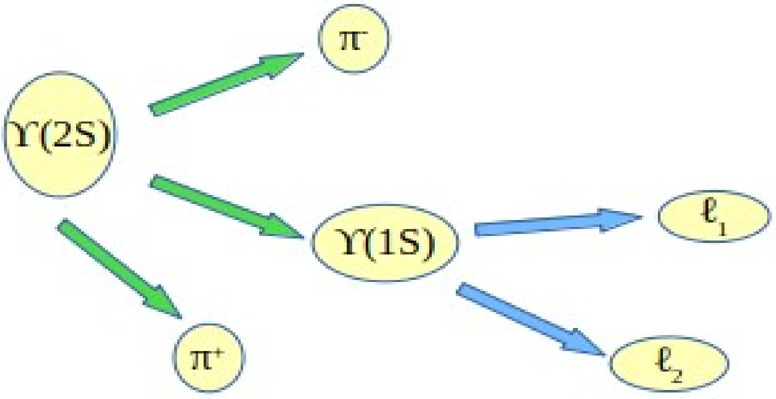
Experiment	Upper limit at 90% CL			
	$\mathcal{B}(B^+ \to K^+ \tau^+ \mu^-)$ x10^{-5}	$\mathcal{B}(B^+ \to K^+ \tau^- \mu^+)$ x10^{-5}	$\mathcal{B}(B^+ \to K^+ \tau^+ e^-)$ x10^{-5}	$\mathcal{B}(B^+ \to K^+ \tau^- e^+)$ x10^{-5}
BaBar PRD 86, 012004 (2012)	<2.8	<4.5	<1.5	<4.3
LHCb JHEP 06 (2020) 129	<3.9	-	-	-
Belle PRL 130, 261802 (2023)	<0.6	<2.5	<1.5	<1.5

Our results are most stringent results to date.

Search for $\Upsilon(1S) \to \ell_1^{\pm}\ell_2^{\mp} / \gamma\ell_1^{\pm}\ell_2^{\mp}$

$25\mathrm{fb}^{-1}$ $\Upsilon(2S)$ sample

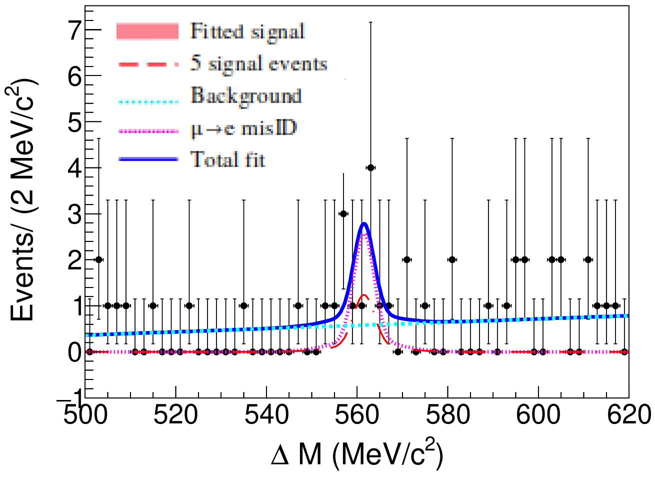
- Obtained results on $\Upsilon(1S) \to \ell_1^{\pm}\ell_2^{\mp}$ decays put constraints on LFV via vector, dielectric, and tensor operators. PRD 94, 074023 (2016)
- Three-body $\Upsilon(1S) \to \gamma\ell_1^{\pm}\ell_2^{\mp}$ decays prove the LFV operators which are inaccessible in two-body decays. PRD 94, 074023 (2016)
- To avoid the QED backgrounds, we use $\Upsilon(1S)$ states with di-pion tagging.
- We extract the signal for $\Upsilon(1S) \to e^{\pm}\mu^{\mp}$ and $\Upsilon(1S) \to \ell^{\pm}\tau^{\mp}$ decays by fitting $\Delta M = M_{\pi\pi e\mu} - M_{e\mu}$ and $M_{recoil}(\pi\pi\ell)$, respectively.



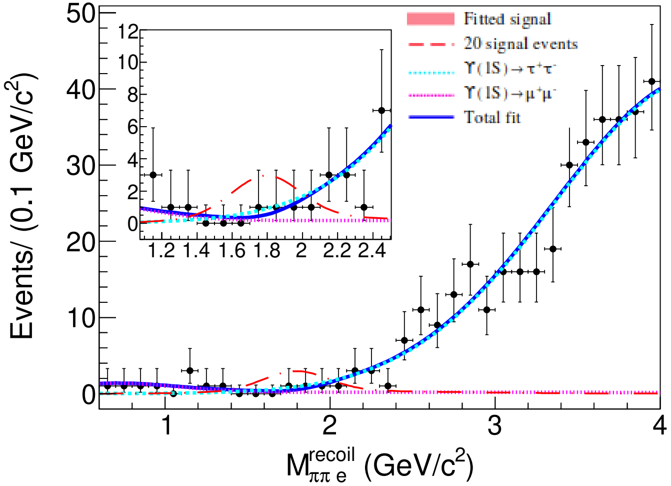
$\ell_1, \ell_2 \Rightarrow$ combinations of e, μ, τ

Search for $\Upsilon(1S)\to\ell_1^{\pm}\ell_2^{\mp}$

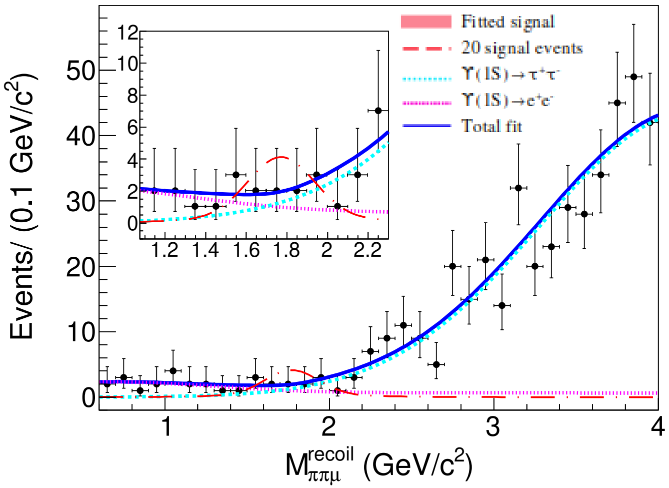
$\Upsilon(1S)\to e^{\pm}\mu^{\mp}$



$\Upsilon(1S)\to\mu^{\pm}\tau^{\mp}$



$\Upsilon(1S)\to e^{\pm}\tau^{\mp}$



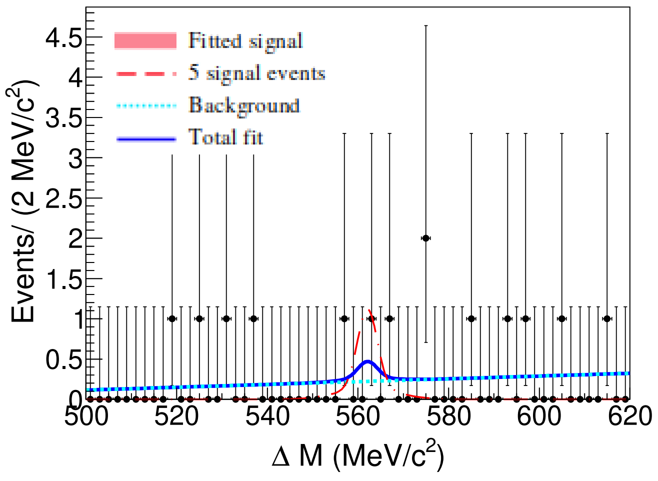
Decay	ϵ (%)	$N_{\rm sig}^{\rm fit}$	$N_{\rm sig}^{\rm UL}$	UL (90%CL)	CLEO result
$\Upsilon(1S)\to e^{\pm}\mu^{\mp}$	32.5	-1.3 ± 3.7	3.6	3.9×10^{-7}	–
$\Upsilon(1S)\to \mu^{\pm}\tau^{\mp}$	8.8	-1.5 ± 4.3	6.8	2.7×10^{-6}	6.0×10^{-6}
$\Upsilon(1S)\to e^{\pm}\tau^{\mp}$	7.1	-3.5 ± 2.7	5.3	2.7×10^{-6}	–

Our results are most stringent results to date.

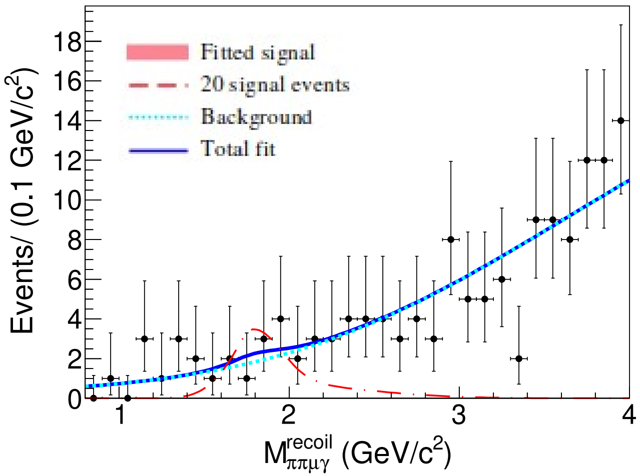
JHEP 05 2022, 095 (2022)

Search for $\Upsilon(1S) \to \gamma \ell_1^{\pm} \ell_2^{\mp}$

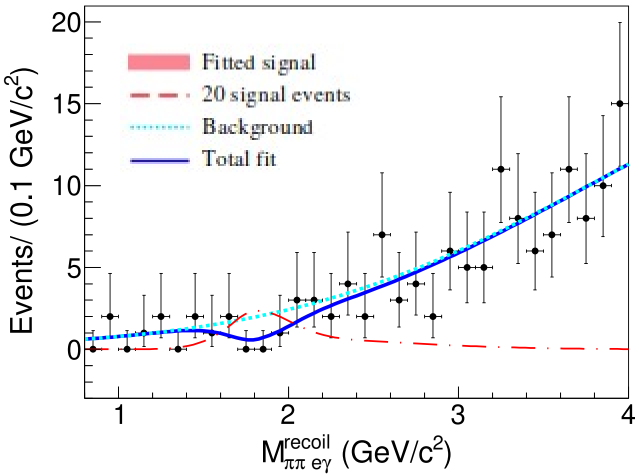
$\Upsilon(1S) \to \gamma e^{\pm} \mu^{\mp}$



$\Upsilon(1S) \to \gamma \mu^{\pm} \tau^{\mp}$



$\Upsilon(1S) \to \gamma e^{\pm} \tau^{\mp}$



Decay	ϵ (%)	$N_{\rm sig}^{\rm fit}$	$N_{\rm sig}^{\rm UL}$	UL (90%CL)	Previous result
$\Upsilon(1S) \to \gamma e^{\pm}\mu^{\mp}$	24.6	$+0.8 \pm 1.5$	2.9	4.2×10^{-7}	–
$\Upsilon(1S) \to \gamma \mu^{\pm}\tau^{\mp}$	5.8	$+2.1 \pm 5.9$	10.0	6.1×10^{-6}	–
$\Upsilon(1S) \to \gamma e^{\pm}\tau^{\mp}$	5.0	-9.5 ± 6.3	9.1	6.5×10^{-6}	–

We have searched for the first time.

JHEP 05 2022, 095 (2022)

Summary

- $B^0_s \to \ell^\pm \tau^\mp$ search: we reconstruct the tag side using semi-leptonic decays, and we provide the first result on $B^0_s \to e^\pm \tau^\mp$ decays.

- $B^+ \to K^+ \tau^\pm \ell^\mp$ search: we use hadronic tagging method, and obtained results are most stringent to date. For $B^+ \to K^+ \tau^+ \mu^-$ decay, the obtained UL is one order of magnitude less than the corresponding previous result.

- $\Upsilon(1S) \to \ell_1^\pm \ell_2^\mp / \gamma \ell_1^\pm \ell_2^\mp$ search: we use di-pion tagging with $\Upsilon(2S)$ data sample. All results are most stringent to date.

Thanks for your attention