Search of lepton flavor violation $B \to K\ell\ell'$ at Belle

2020.9.12

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for Belle Collaboration

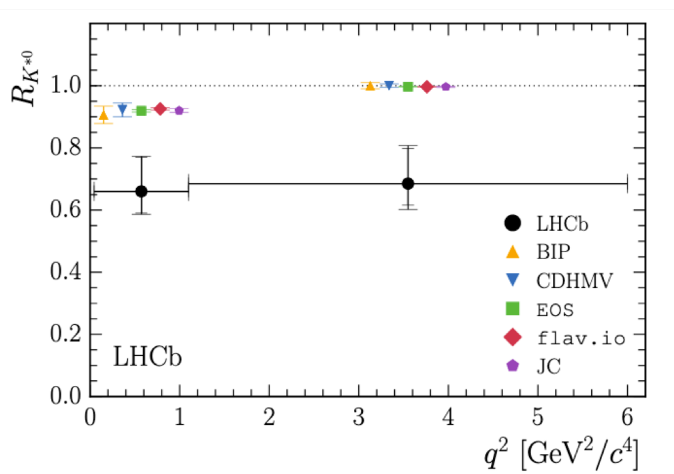
Motivation

- Lepton-flavor violating(LFV) decay is strongly forbidden in SM.
- However, it is not necessarily protected if lepton-flavor universality(LFU) is violating.

LFUV → (If it is true) → LFV ⇒ $B \to K \ell \ell'$

Many NP allows it to explain $b \to s$ anomalies

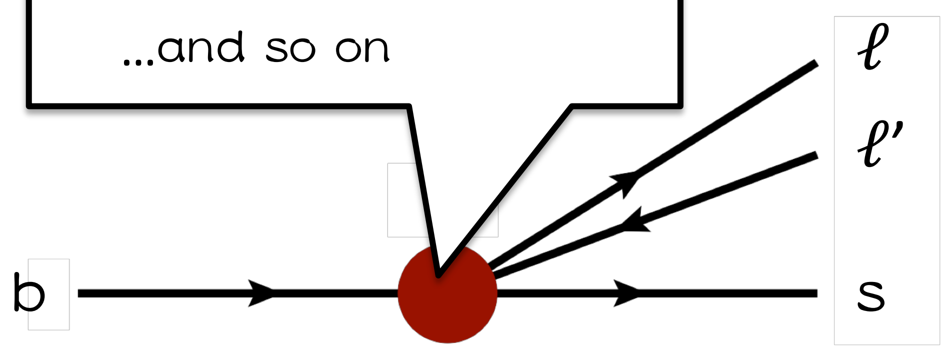
No longer clearly forbidden!



JHEP 08, 055(2017)

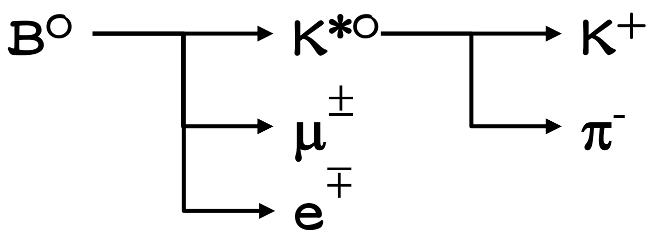
- Scalar Leptoquark
- Vector Leptoquark
- Z' model

...and so on



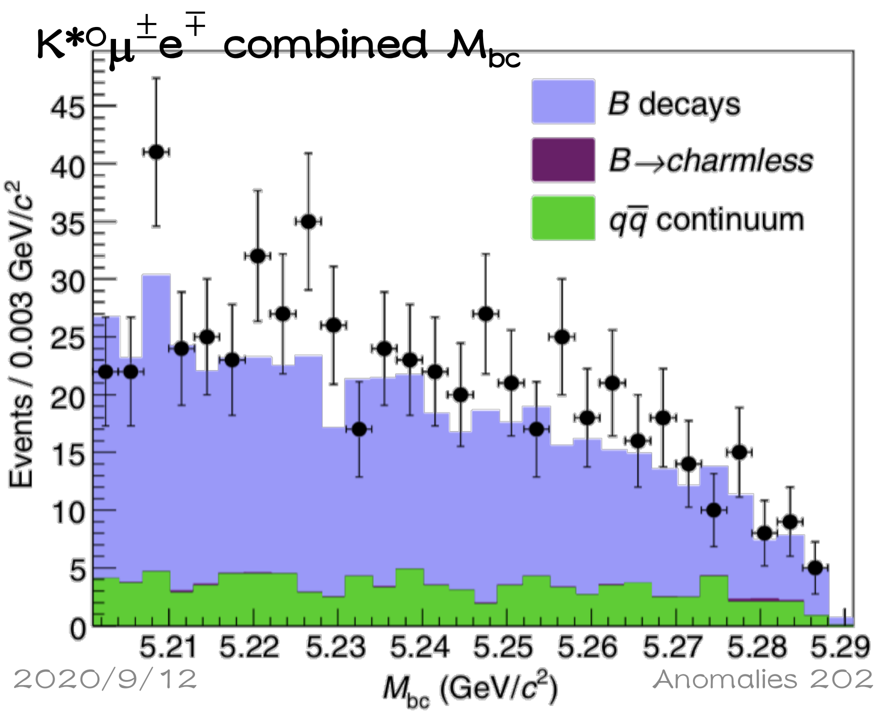
$B^0 \to K^{*0} \mu e$ at Belle

Signal



BG

- Both BB pair SL decay
- $B \to D^{(*)} X l^+ \nu$ followed by
  $D^{(*)} \to X l^- \nu$
- Hadronic decay with miss-ID



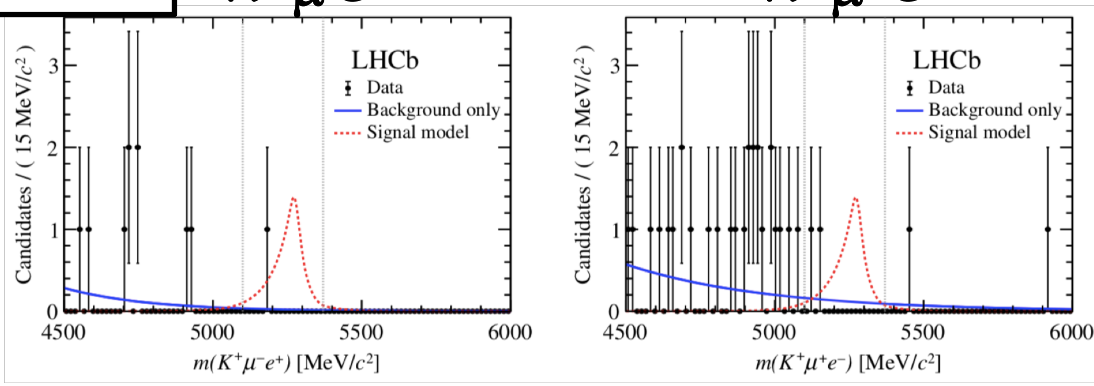
- [PRD98,071101(R)(2018)](#)
- Using Belle full dataset (772M BB pairs)
- Neural netowork cut is applied qq and BB separately.
- Vetoes are applied to suppress K/π miss-ID BG.
  - Invariant masses of $\ell^+\ell^-$, K^+e^-, and $\pi^-\mu^+$.
- Control sample : $B^0 \to K^{*0} J/\psi$.
- BR upper limits (90% C.L.) :
  - $BR(B^0 \to K^{*0}\mu^+e^-) < 1.2\times10^{-7}$
  - $BR(B^0 \to K^{*0}\mu^-e^+) < 1.6\times10^{-7}$
  - $BR\left(B^0 \to K^{*0}\mu^\pm e^\mp\right) < 1.8\times10^{-7}$

The stringent constraints were set

B→Kμe at LHCb/Belle

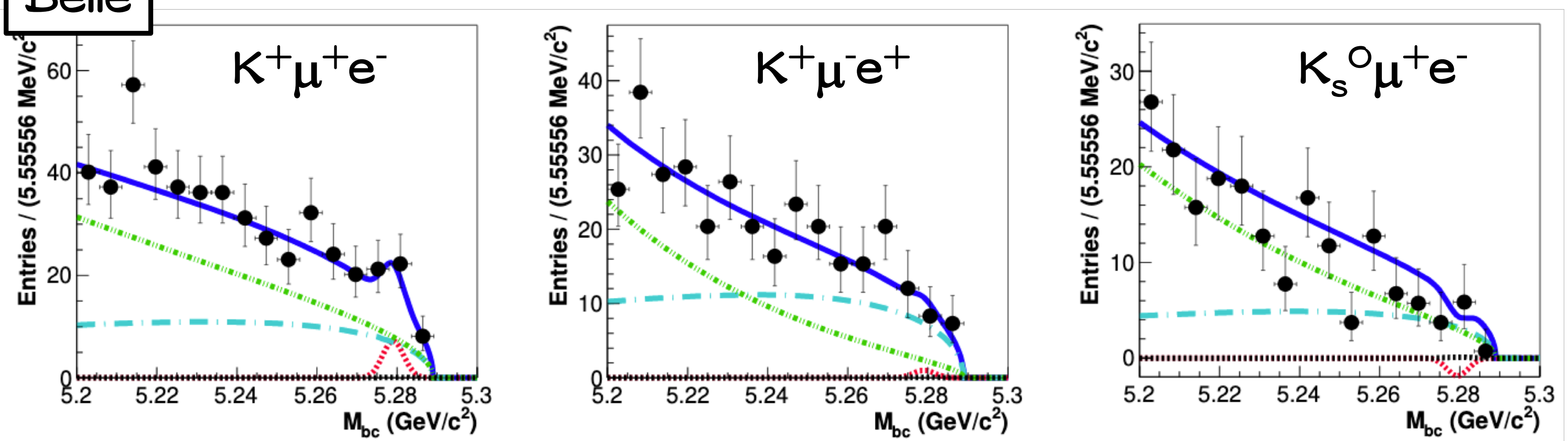
PRL123,241802(2019) (LHCb)
arXiv:1908.01848v1 (Belle)

LHCb



Mode	BR U.L. (90% CL)
$B^+ \to K^+\mu^-e^+$	$<7.0\times10^{-9}$ (LHCb) $<3.0\times10^{-8}$ (Belle)
$B^+ \to K^+\mu^+e^-$	$<6.4\times10^{-9}$ (LHCb) $<8.5\times10^{-8}$ (Belle)
$B^0 \to K_s^0\mu^{\pm}e^{\mp}$	$<1.8\times10^{-7}$ (Belle)

Belle

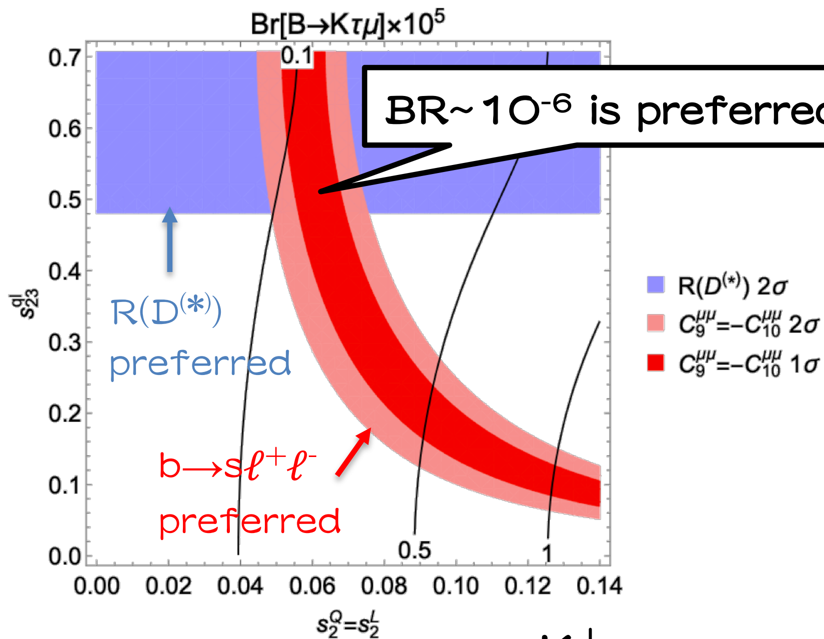


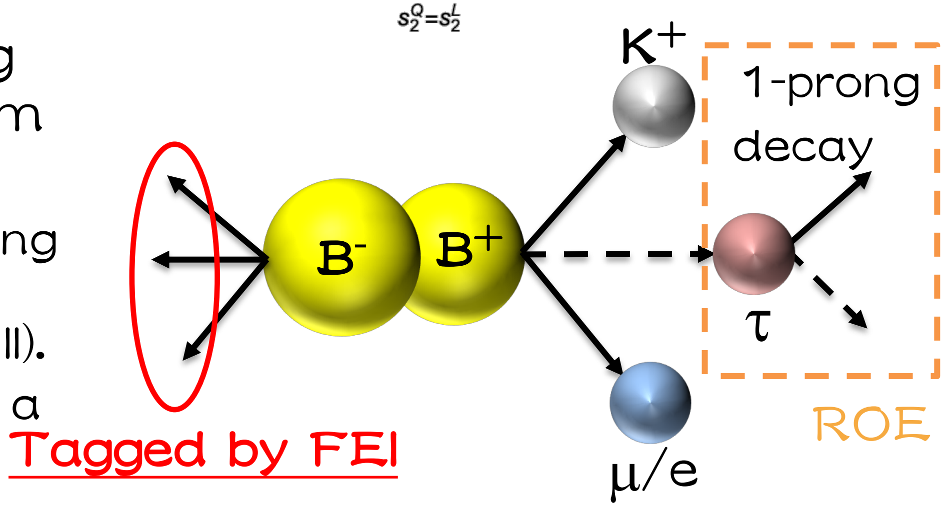
Study of $B^+ \to K^+\tau\mu$ / $B^+ \to K^+\tau e$

Mode	Upper limit of BR
$B^+ \to K^+\tau\mu$	$<4.8\times10^{-5}$ (BaBar)
$B^+ \to K^+\tau e$	$<3.0\times10^{-5}$ (BaBar)
$B^+ \to K^+\tau^+\mu^-$	$<3.9\times10^{-5}$ (LHCb)

- The anomalies of $R(K^{(*)})$ indicates the NP effect appears more in μ than e.
  → **NP search with τ (3rd) is very important**
- BR~O(10^{-6}) is the target.
- The analysis is more challenging because of missing particle from τ decay.
  - The most standard way is tagging method (FEI = tagging package for Belle II).
  - Observable : **τ invariant mass** as a recoil information.

L. Calibbi (arXiv:1709.00692)





Background

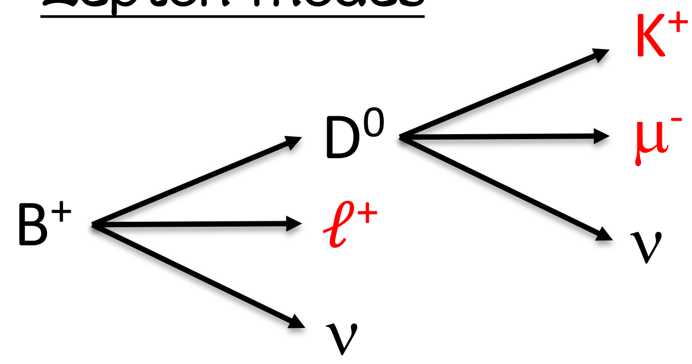
$\tau\to\mu$	#	Ratio
D0 mu nu	**101**	**36.1%**
D*0 mu nu	**71**	**25.4%**
$J/\psi\ K\ \pi^0\ \pi^0$	23	8.2%
Mixed origin	16	5.7%
$\psi(2S)\ K^{*+}$	10	3.6%

$\tau\to e$	#	Ratio
D0 e nu	**203**	**36.2%**
D*0 e nu	**156**	**27.9%**
Mixed origin	65	11.6%
D0 e nu gam	24	4.3%
D*0 e nu gam	15	2.7%

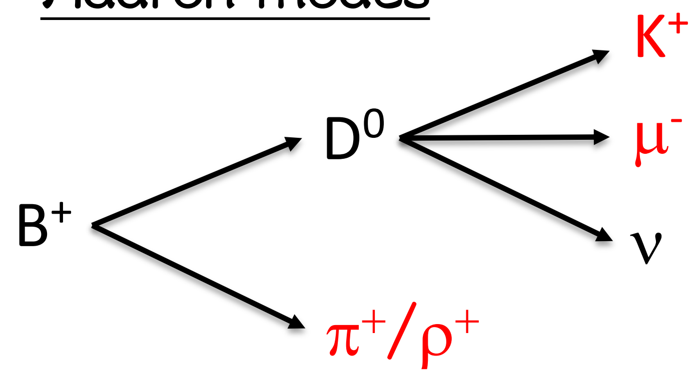
$\tau\to\pi$	#	Ratio
Mixed origin	128	13.5%
D*0 rho	**89**	**9.4%**
D*0 pi	**88**	**9.3%**
rho D0	84	8.8%
D0 pi	67	7.1%

$\tau\to\rho$	#	Ratio
rho D0	**121**	**15.2%**
D*0 rho	**120**	**15.1%**
Mixed origin	112	14.1%
D*0 a_1	52	6.6%
a_1 D0	21	2.6%

Lepton modes



Hadron modes

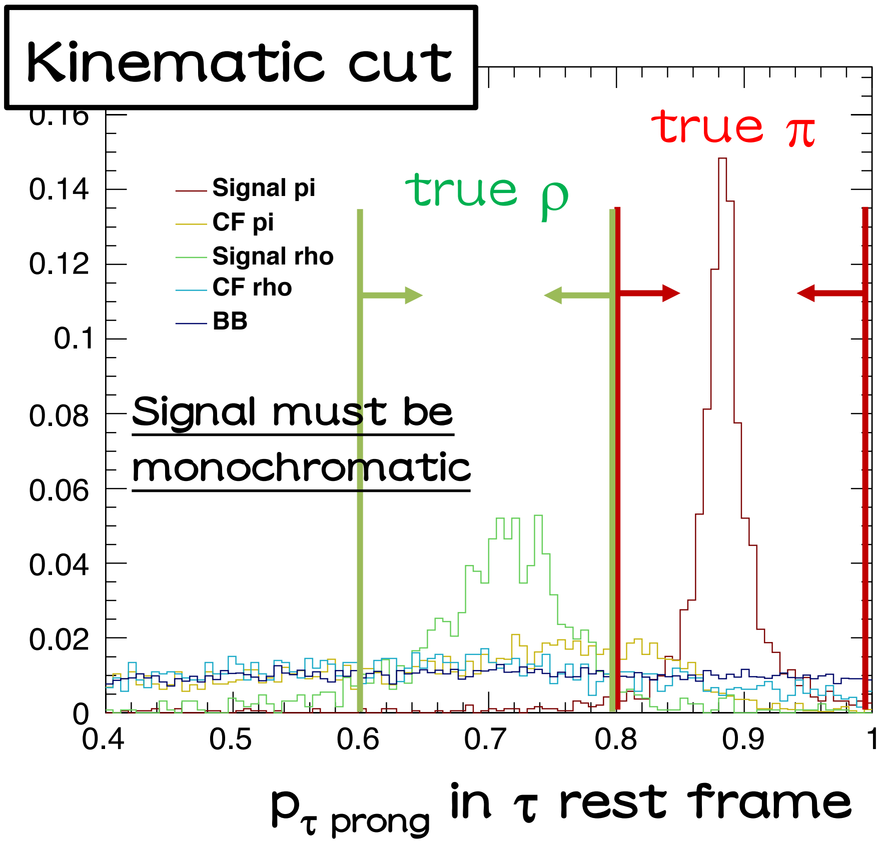


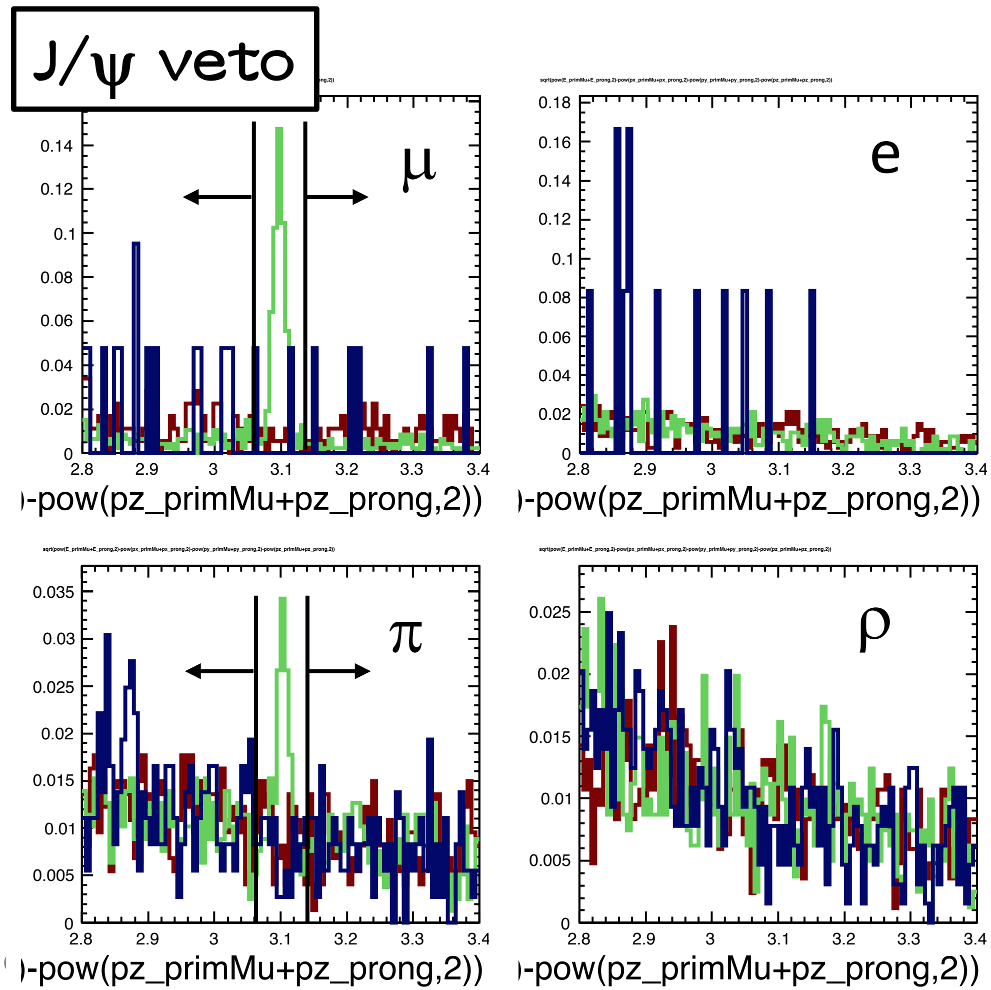
* The number of events are scaled to 1 stream.

- The main BG is $D^0 l\nu$ and $D^0 h$.
- A dedicated MVA (FBDT) will be trained for BB sup.

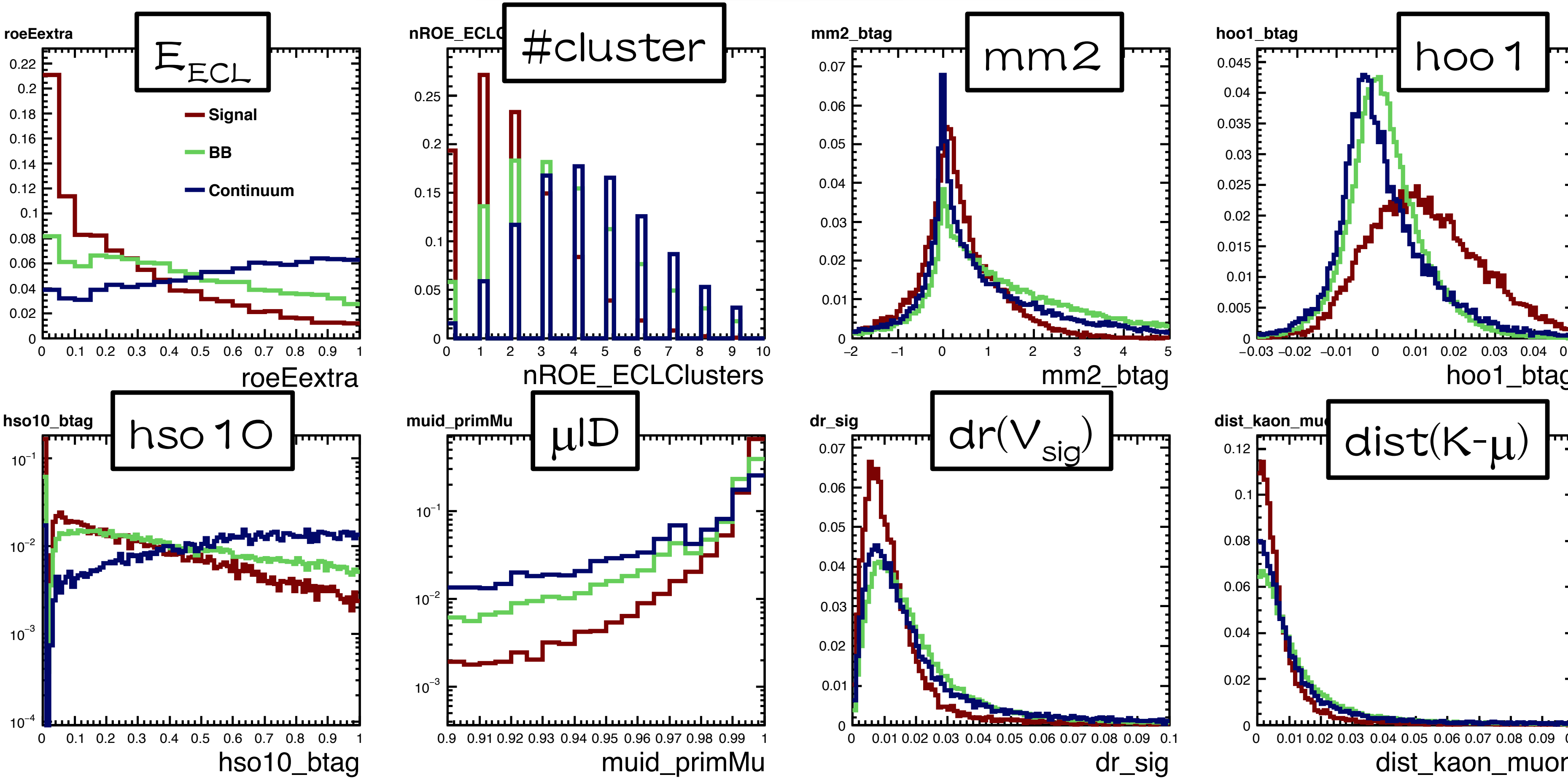
Hadron kinematic cut & J/ψ veto

- **Kinematic cut**
  - τ prong momentum at τ rest frame for hadronic modes (τ→π/ρ modes).
- **J/ψ veto**
  - Invariant mass of primary μ and τ prong for J/ψ veto.





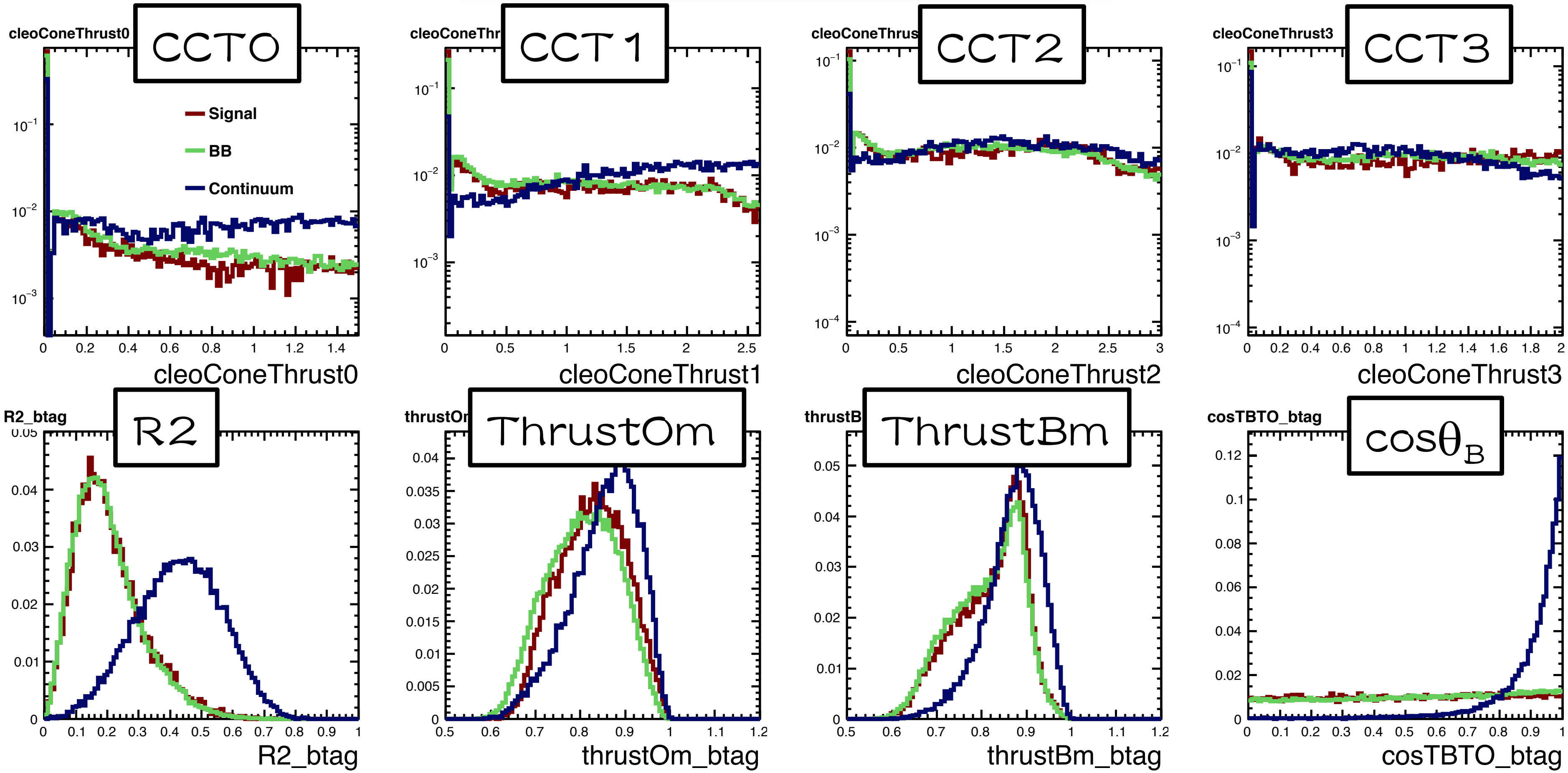
BB suppression



...and so on

- EECL, number of ECL clusters.
- KSFW (modified Fox-Wolfram moments) input parameters.
- μID of primary muon.
- Distance b/w primary kaon and muon.
- etc.

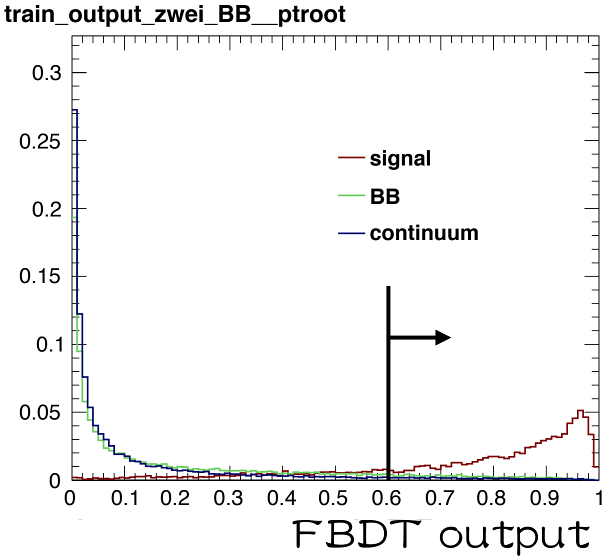
qq suppression

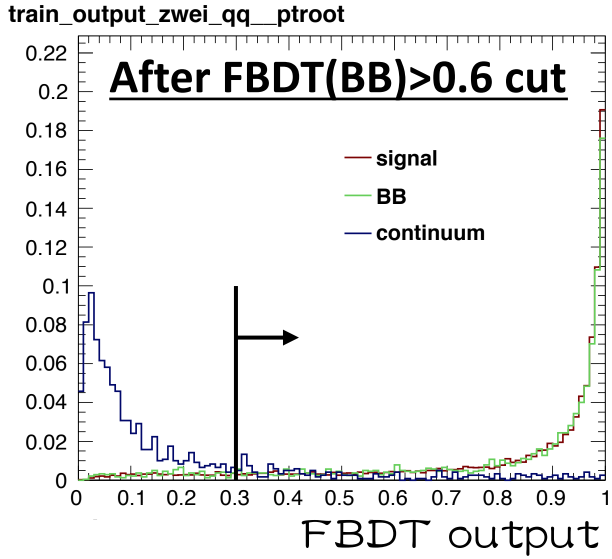


…and so on

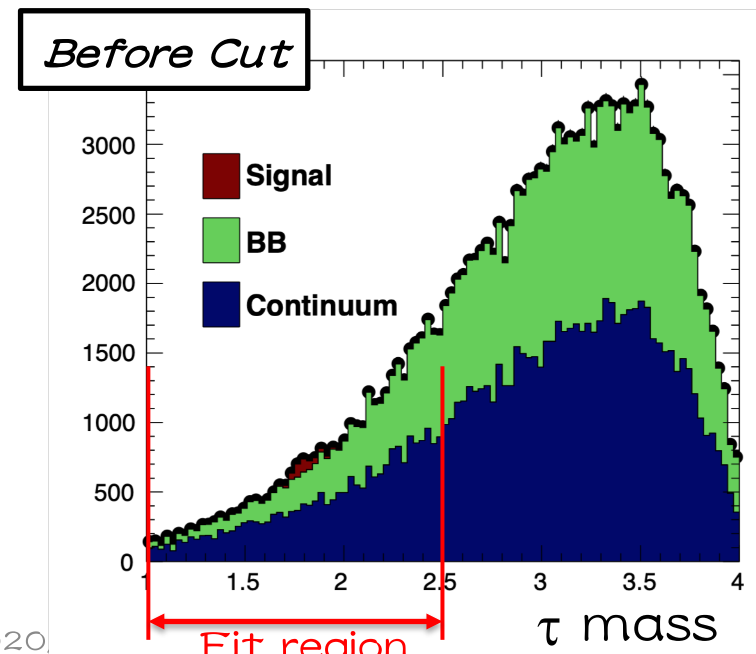
- CleoConeThrust (modified thrust information)
- R2
- cosθ
- etc.

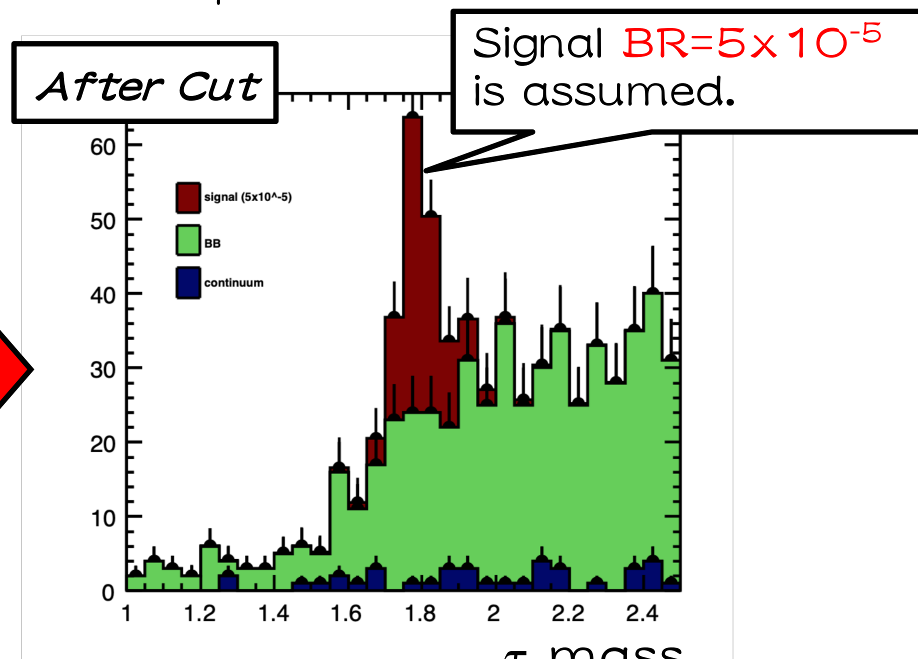
Output



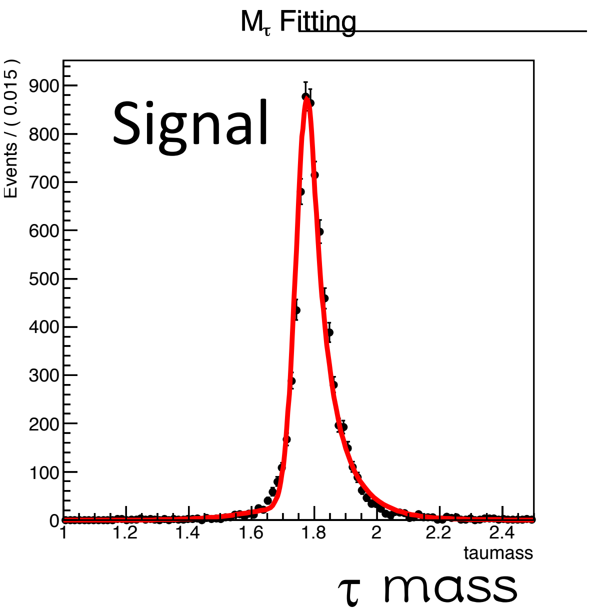


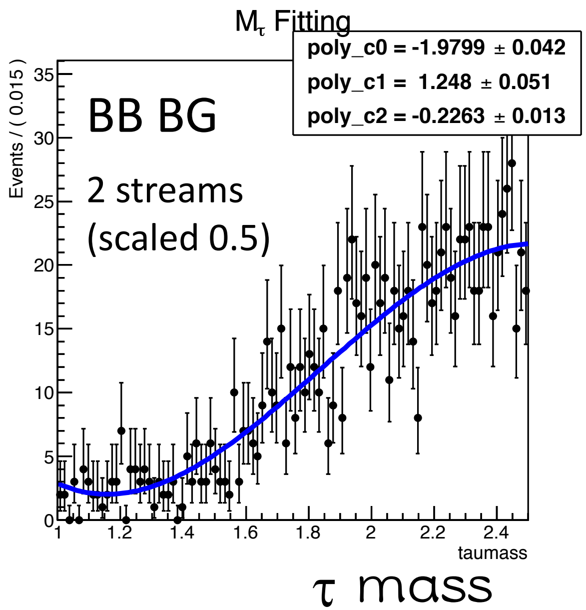
- After BB suppression, qq still remains a bit.
- Another FBDT dedicated for qq suppression is applied to kill all of qq background.

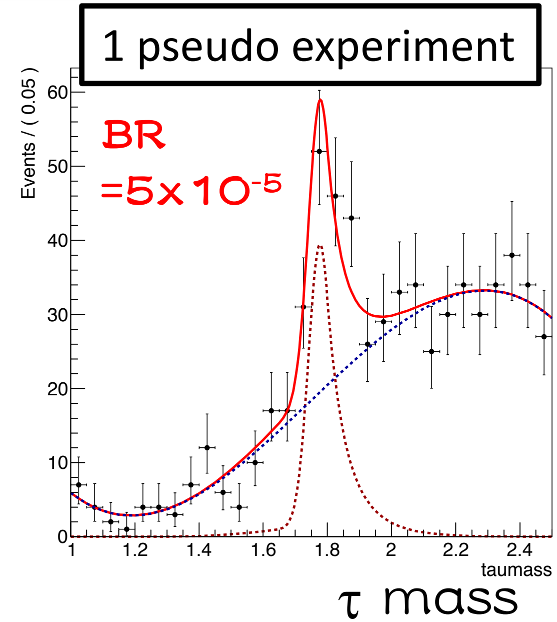




Fitting







Fitting condition

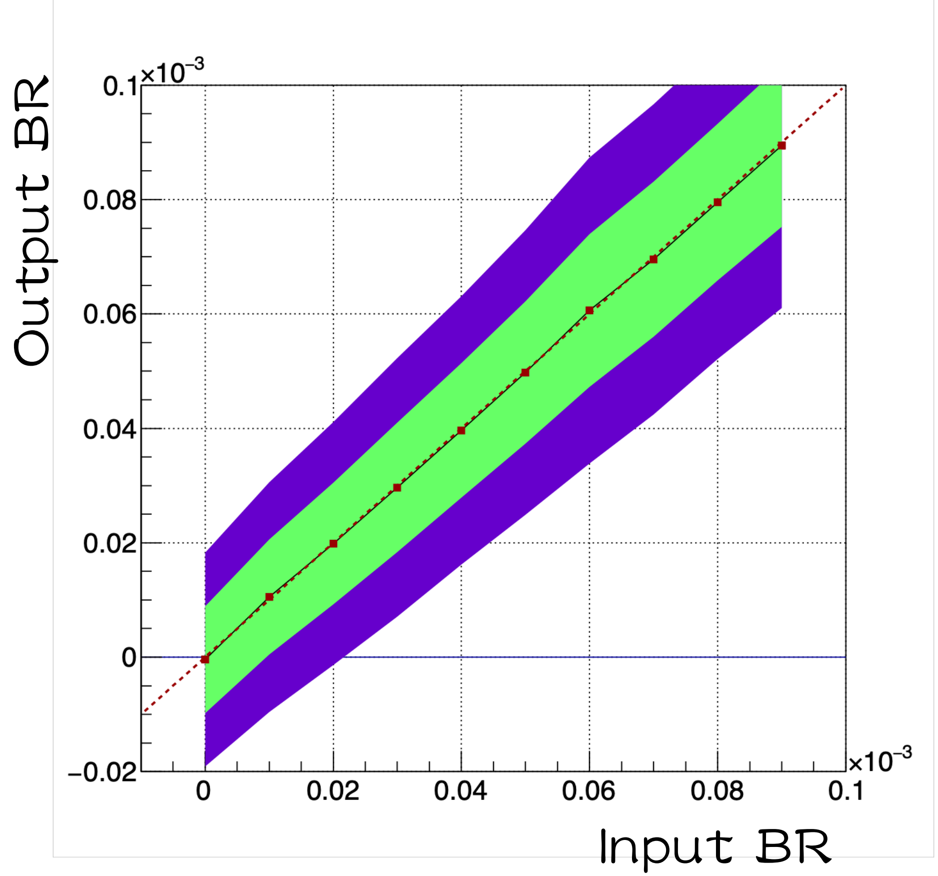
- Signal : CBS+Gaussian
- BG : 3rd order Chebyshev polynomial
- Signal shapes will be fixed by MC.
- BG shapes (c0, c1, and c2) are all floated.

Sensitivity study

- Toy-MC studies are repeated for several BR assumptions.

Sensitivity estimation

- A good linearity can be seen between input/output BR.
  - No bias
  - Pull distributions are also OK
- According to 0-signal case, **BR<1.8x10^{-5}** (95% C.L.) is possible.
  - Only statistical uncertainty is taken into account.
- Possibly will be improved.
  - Cut optimization, simultaneous fit for each τ channels, other tagging techniques, ...
  - O(10^{-6}) level will be achieved at Belle II.



Summary and plan

- Recent anomalies related with $R(K^{(*)})$ indicates lepton flavor universality violation (LFUV).
- <u>**Many NP models allows LFV if LFUV exists.**</u>
  - $B \to Kll'$ is possible LFV mode
  - $BR(B \to K^{(*)}\mu e)$ upper limits were set by Belle and LHCb (10^{-9} for K^+ mode, 10^{-7} for K_s mode, 90% C.L.).
- $BR(B^+ \to K^+\tau\mu(e))$ is interesting if NP contributes 3rd generation more.
  - The analysis is more challenging because of ν.
  - $O(10^{-6})$ is preferred by leptoquark scenario.
- $BR(B \to K^+\tau^+\mu^-) < 1.8 \times 10^{-5}$ (stat. only, 95% C.L.) is estimated according to MC simulation for Belle.

- Other channels ($B \to K^+\tau^-\mu^+$, $B \to K^+\tau e$) are being studied as well.

BACKUP

BACKUP

Kτμ at LHCb

- $B_{s2}^{*0} \to B^+K^-$, $B^+ \to K^+\mu^-\tau^+$
- High quality tracks K^+ and μ^- are selected, not associated with any PV.
- An additional track from t is selected whose charge is opposite against m.
- B^+ direction is decided from secondary $K^+\mu^-$ vertex and PV, from where K^- (opposite charge against signal decay K^+) also originates.
- E_B solution can be evaluated assuming a kinematic information.
- In signal kinematics, M_{miss} has a characterized distribution.

$$E_B = \frac{\Delta^2}{2E_K}\frac{1}{1-(p_K/E_K)^2\cos^2\theta}\left[1 \pm \sqrt{d}\right], \text{ where}$$
$$d = \frac{p_K^2}{E_K^2}\cos^2\theta - \frac{4m_B^2 p_K^2\cos^2\theta}{\Delta^4}\left(1-\frac{p_K^2}{E_K^2}\cos^2\theta\right),$$
$$\Delta^2 = m_{BK}^2 - m_B^2 - m_K^2,$$