Search for $B^0 \to \ell\tau$ using hadronic tagging

@ ジャ BELLE EXPERIMENT

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Outline

- Motivation and the Previous Searches
- Studied Modes and Event Reconstruction
- Variables used in this Analysis
- Summary and Future Plans

Motivation and the Previous Searches

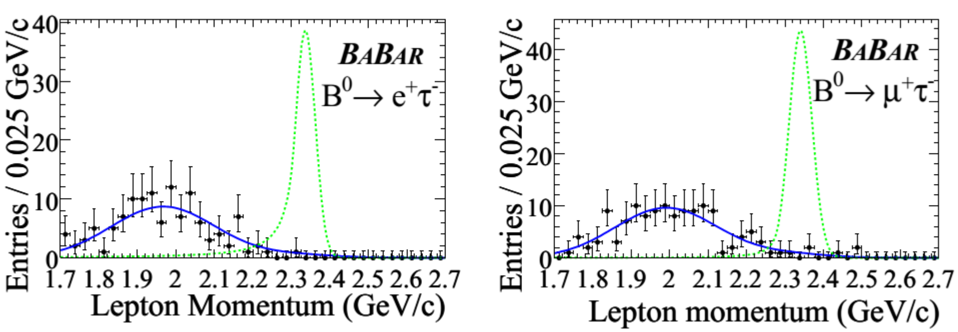
Motivation for the Search

- $B \to \ell\tau\ (\ell \neq \tau)$
  - Search for Lepton Flavor Violation (LFV)
  - 'Nearly' forbidden in the Standard Model (SM)
    - Only allowed via ν-oscillations
  - A SUSY seesaw [PLB 549, 159-169 (2002)] predicts enhanced B.F @ $O(10^{-10})$... yet why not?
    - Could leave a useful reference for our upcoming Belle-2!
  - The first study on this topic at Belle
  - Analysis somewhat similar to my previous analysis of $B \to \ell\nu$

Previous Result from Babar[PRD 77, 091104 (2008)]

- $342\ fb^{-1}$ (371M) $B\bar{B}$ pairs / half of Belle data
- Uses hadronic tagging
- In short
  - Continuum suppression using :
    R_2 / angle btw. Thrust axes of B_{tag} & other-side particles.
  - Uses missing momentum info & E_{ECL} for further BG reduction.
  - 1-D unbinned ML fits in the primary lepton's (ℓ's) momentum.
- No signal observed (n_{SIG}~0) within $p_\ell^{Bsignal}$ signal region.

	n_{BKG} (~6% total err.)	ϵ_{SIGNAL} (~13% total err.)	U.L(BF)@90% C.L.
$e\tau$	$9.35 \pm 0.35(stat)$	0.032%	$< 2.8 \times 10^{-5}$
$\mu\tau$	$13.03 \pm 0.31(stat)$	0.027%	$< 2.2 \times 10^{-5}$



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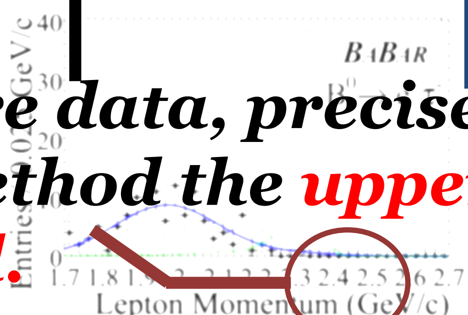
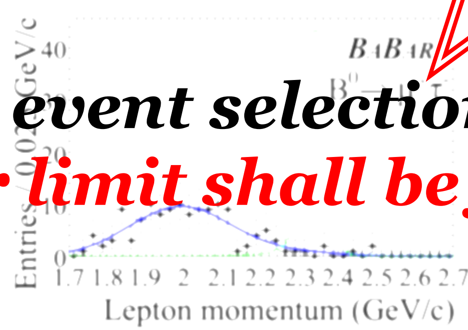




- ***With more data, precise event selection, and fitting method the upper limit shall be further improved.***

Studied Modes and Event Reconstruction

Modes under Investigation

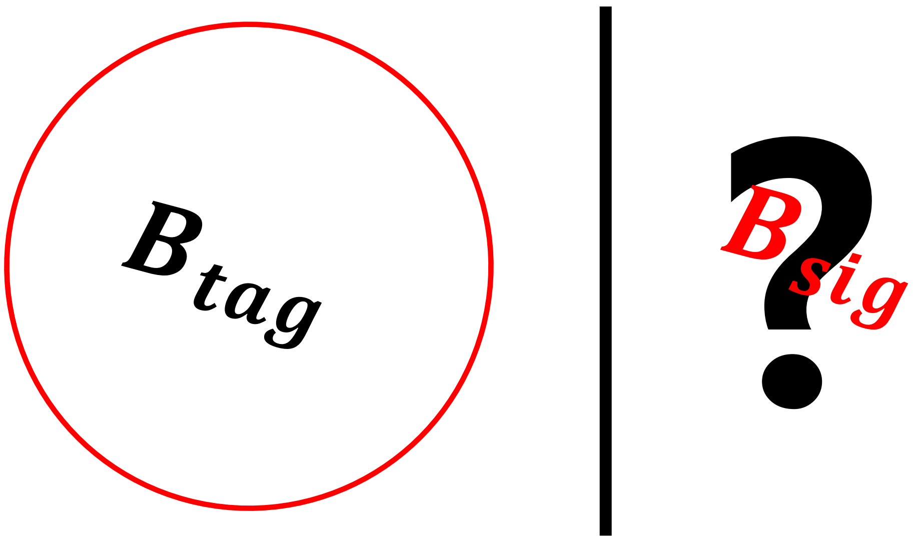
			B.F. ratio of τ decays
$B^0 \to$	$e^\pm \tau^\mp$	$\tau^+ \to e^+ \nu_e \bar{\nu_\tau}$	$17.83 \pm 0.04\%$
	$\mu^\pm \tau^\mp$	$\mu^+ \nu_\mu \bar{\nu_\tau}$	$17.41 \pm 0.04\%$
		$\pi^+ \bar{\nu_\tau}$	$19.83 \pm 0.06\%$
		$\rho^+(\pi^+\pi^0)\bar{\nu_\tau}$	$25.52 \pm 0.09\%$

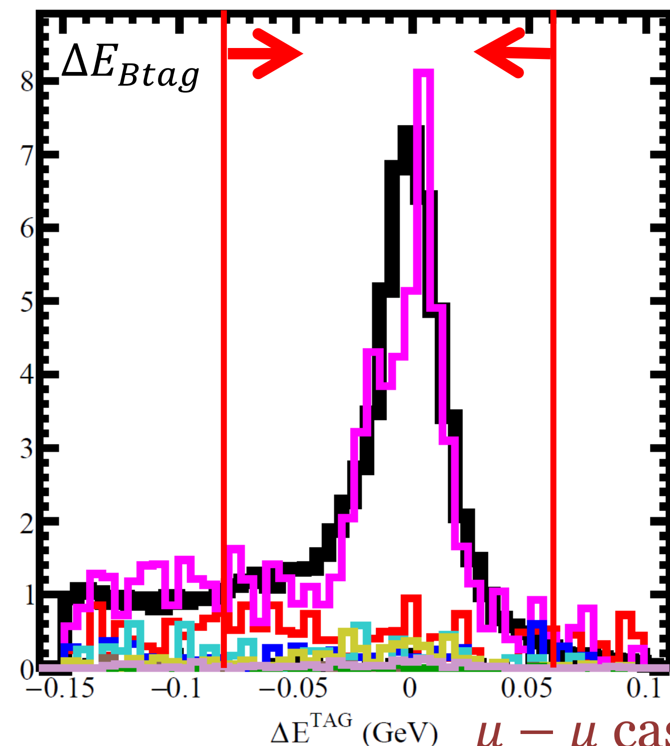
Covers up 81% of the total τ decays!

- 10M HUGE samples for each Signal MC modes generated
- 4 x data of $b \to c$ and $e^+e^- \to q\bar{q}(q = udsc)$ [continuum] MC
- Large $b \to s, d$ samples / $b \to u\ell\nu$ samples
- Depending on the ρ^+ mode, could add some more resonances: e.g. $\pi^+\pi^+\pi^-$ or $\pi^+\pi^0\pi^0$ which BaBar used...
  - Or might not use even ρ

Event Reconstruction (1/3)

- **B_{tag} side (I guess you know this very well by now!)**
  - One of Bs is tagged by something EKP fullrecon.
  - Per event, the best NeuroBayes output (o_{tag}) candidate is chosen.
  - $-0.08 < \Delta E_{Btag}(= E_{Btag} - E_{beam}) < 0.06$ applied.
    - That variable already used in the NeuroBayes.

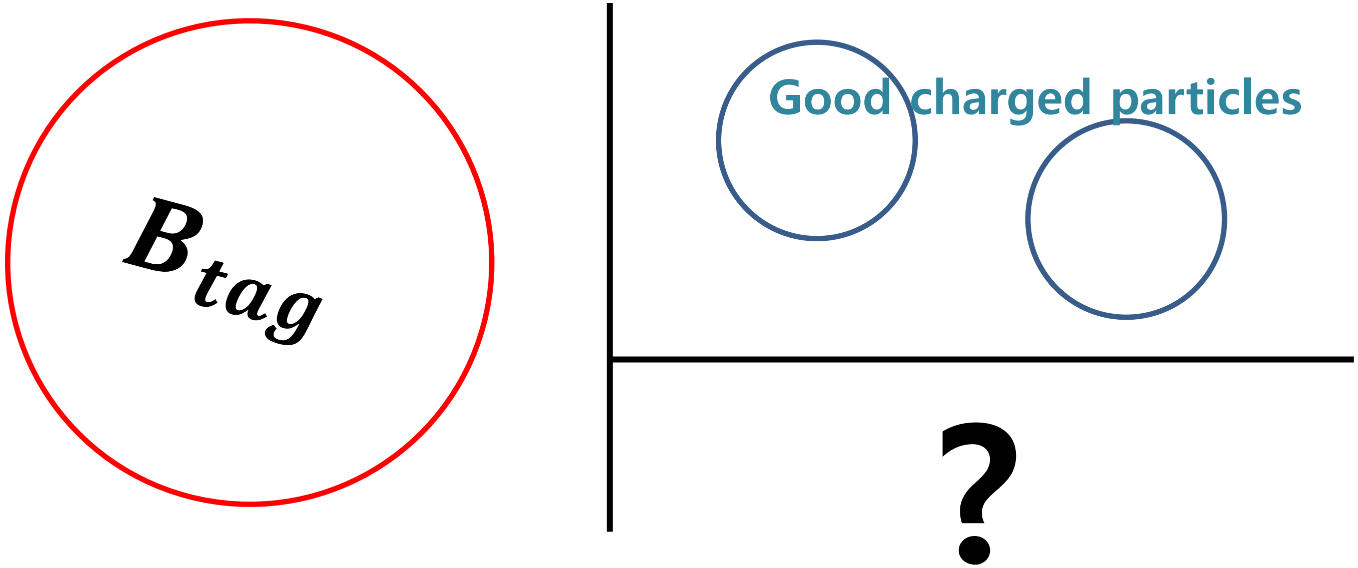




$\mu - \mu$ case

Event Reconstruction (2/3)

- B_{sig} **side**
  - 2 GOOD charged tracks required
    - Expected to originate near IP. Should have opposite charge
      - Distance from the impact: $dr < 0.05cm$ / $|dz| < 1.5cm$
    - At least one LEPTON ($e > 0.9$ || $\mu > 0.9$).
    - No K^+ or P^+ ($\pi/K > 0.6$ & $\pi/P > 0.6$).



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    - At least one LEPTON ($e > 0.9 \,||\, \mu > 0.9$).
    - No K^+ or P^+ ($\pi/K > 0.6$ & $\pi/P > 0.6$).

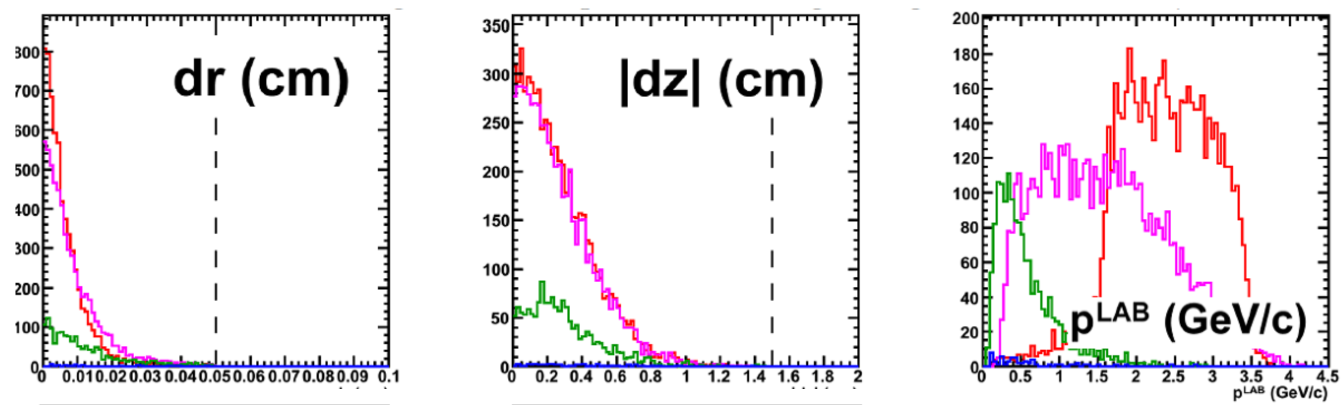
$e\pi$-mode
2M generated

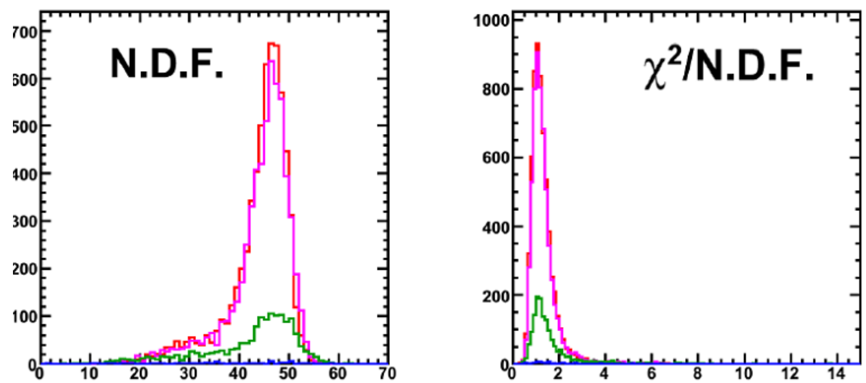
B_{tag} cuts

$-0.08 < \Delta E < 0.06$
$\ln(o_{TAG}) < 6.0$ / $M_{bc} > 5.27$

&

$dr < 0.05$ / $|dz| < 1.5$

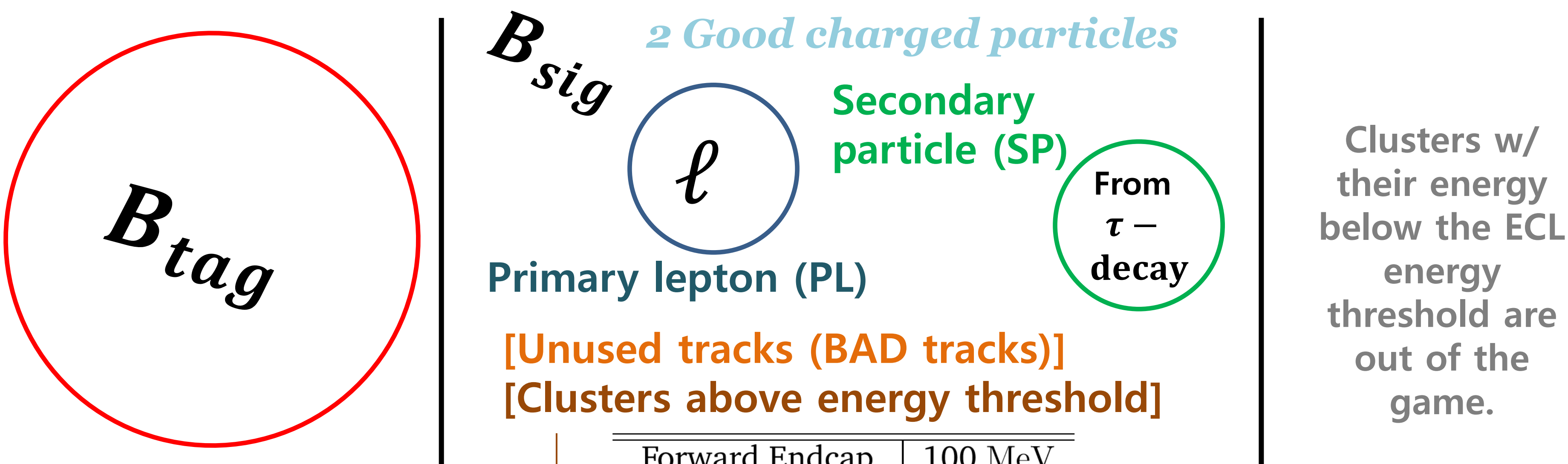




Primary lepton : 6292
Secondary particle : 5966
Others from B : 1516
Others not from B : 60
I want to get rid of this!

Event Reconstruction (3/3)

- **B_{sig} side**
  - $\tau -$ decay mode decision
    - Both are leptons: higher p^{Bsig} (mmt. @ signal B rest frame) becomes ℓ.
    - P_{Bsig} refers to B_{tag} only for its direction w/ mass constrained.
    - Only one lepton: $\tau \to \pi\nu$ or $\tau \to \rho\nu$
    - $\Delta E_\tau \equiv E^\tau_{\pi(+\pi^0)} + p^\tau_{\pi(+\pi^0)} - m_\tau$ minimizing combination selected.
      - τ-rest frame obtained similarly to the B_{sig}'s, but also considers P_ℓ



Forward Endcap	100 MeV
Barrel Region	50 MeV
Backward endcap	150 MeV

Event Reconstruction (3/3)

- B_{sig} **side**
  - τ – decay mode decision
    - Both are leptons: higher p^{Bsig} (mmt. @ signal B rest frame) becomes ℓ.
    - P_{Bsig} refers to B_{tag} only for its direction w/ mass constrained.
    - Only one lepton: $\tau \to \pi\nu$ or $\tau \to \rho\nu$
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[@ τ-rest frame]

ν_τ $\longleftarrow$ τ $\longrightarrow$ π^+ or ρ^+

$(\vec{p}, |\vec{p}|)$ $(\vec{0}, m_\tau)$ $(-\vec{p}, E_{\pi/\rho})$

Ideally : $m_\tau = E_{\pi/\rho} + |\vec{p}| = E_{\pi/\rho} + p_{\pi/\rho} \rightarrow \Delta E_\tau = 0$

Variables used in this Analysis

Not optimized yet

Variables used in this analysis (prepared)

- B_{tag} variables
  - M_{bc} $(= \sqrt{E_{beam}^2 - p_{Btag}^2}) > 5.27$
  - o_{tag} cuts needed for the continuum BG heavy SP:ρ modes
- Kinematic variables
  - p_ℓ^B / p_{SP}^τ: interested in $2.2 < p_\ell^B < 2.5$ (GeV/c)
  - M_{miss}^2(ideal)$\equiv \left[P_{Bsig} - P_\ell - P_{SP}\right]^2$
  - $M_{\ell\ell}$ for J/ψ and ψ' vetoes when PL = SP = ℓ
  - E_{ECL}: sum of E not associated with B_{tag} nor PL nor SP
- Continuum suppression
  - L_{KSFW}: $LR(KSFW, \cos\theta_B)$
    - likelihood ratio based on shape variables of modified Fox-Wolfram Moments and the angle between the beam direction and the B_{tag}.
- SP:ρ mode exclusively
  - $M_\rho \equiv M_{\pi^+\pi^0}$
  - $\cos\theta_{\rho\tau}^{Bsig} \equiv (2E_\tau E_\rho - m_\tau^2 - m_\rho^2)/(2p_\tau p_\rho)$

Challenges?

- Not much in the purely leptonic final state channels
- $\tau^+ \to \pi^+ \nu$
  - Higher continuum BG level
  - The $b \to u\ell\nu$ BG mostly from $B^0 \to \pi^- \ell^+ \nu$ & $B^0 \to \rho^- \ell^+ \nu$
    - Same (similar) final states! $\pi(+\pi^0)\ell + invisible$
- $\tau^+ \to \rho^+ \nu$
  - (on top of above…)
  - + misconstruction in the $\tau^+ \to \pi^+ \nu$ mode (missing π^0)

- Following plots are scaled to luminosity with B_{tag} correction from a $B \to D^{(*)}\ell\nu$ control sample study.

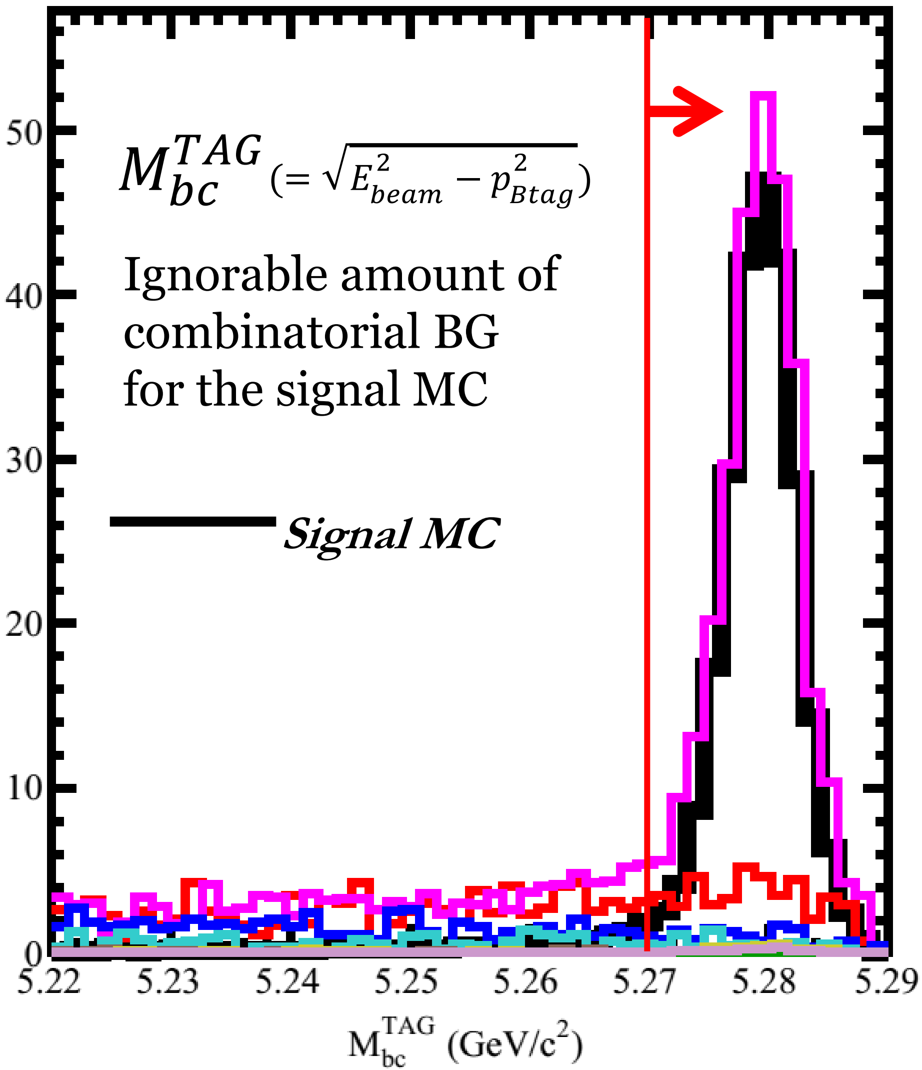
Variables used in this Analysis

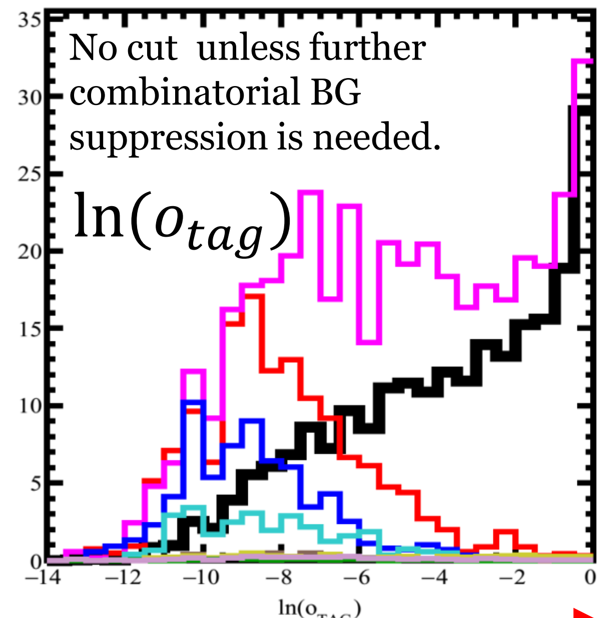
An easy case: leptonic

Variables in the case of $\mu - e$ mode

- B_{tag} variables

charged b→c
neutral b→c
e⁺e⁻→cc̄
e⁺e⁰→qq̄ (q=u,d,s)
charged b→ulν
neutral b→ulν
charged b→s,d or leptonic
neutral b→s,d or leptonic

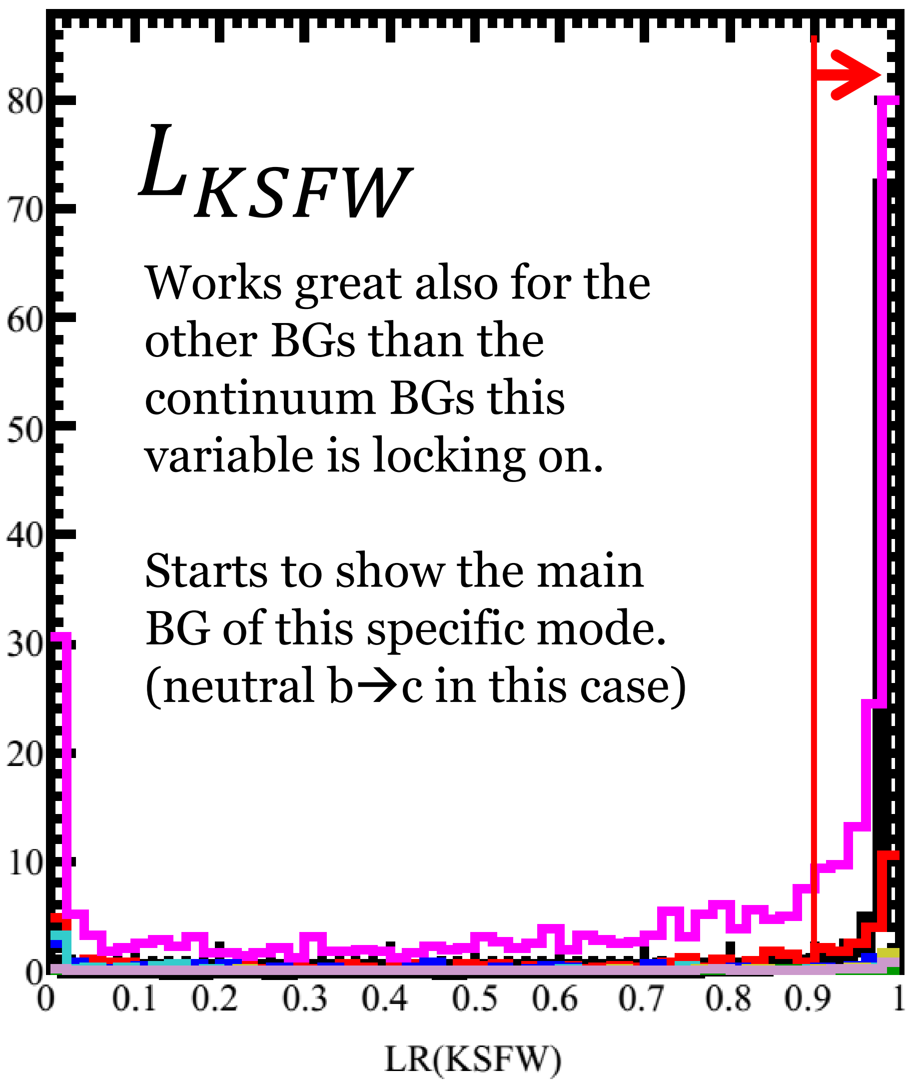




More likely to be a correct B meson

Variables in the case of $\mu - e$ mode

- $Continuum\ suppression \rightarrow L_{KSFW}: LR(KSFW, \cos\theta_B)$



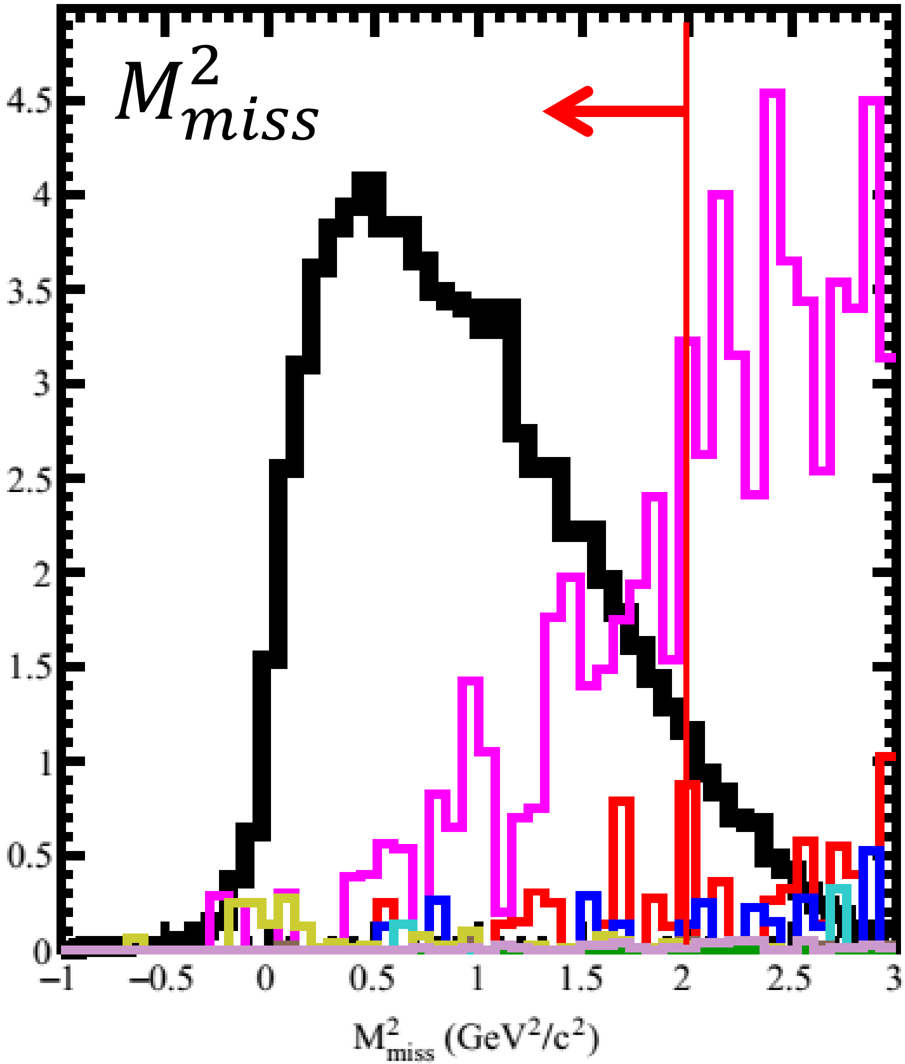
- charged b→c
- neutral b→c
- $e^+e^- \rightarrow c\bar{c}$
- $e^+e^0 \rightarrow q\bar{q}$ (q=u,d,s)
- charged b→ulν
- neutral b→ulν
- charged b→s,d or leptonic
- neutral b→s,d or leptonic

Cuts applied so far

$M_{bc} > 5.27$

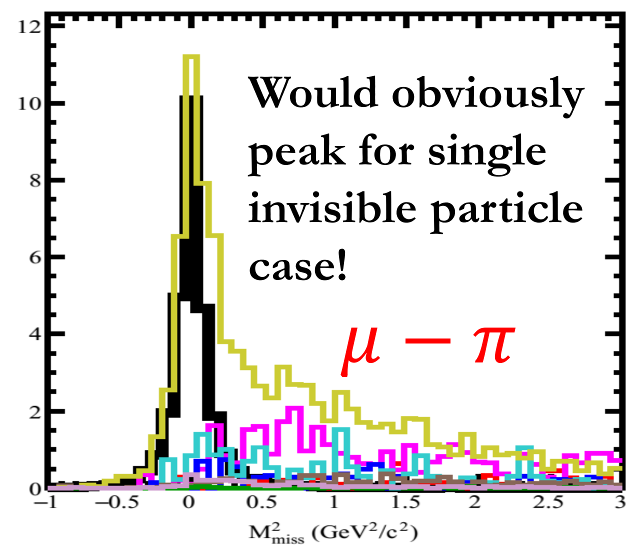
Variables in the case of $\mu - e$ mode

- $M^2_{miss}(\text{ideal}) \equiv [P_{Bsig} - P_\ell - P_{SP}]^2$



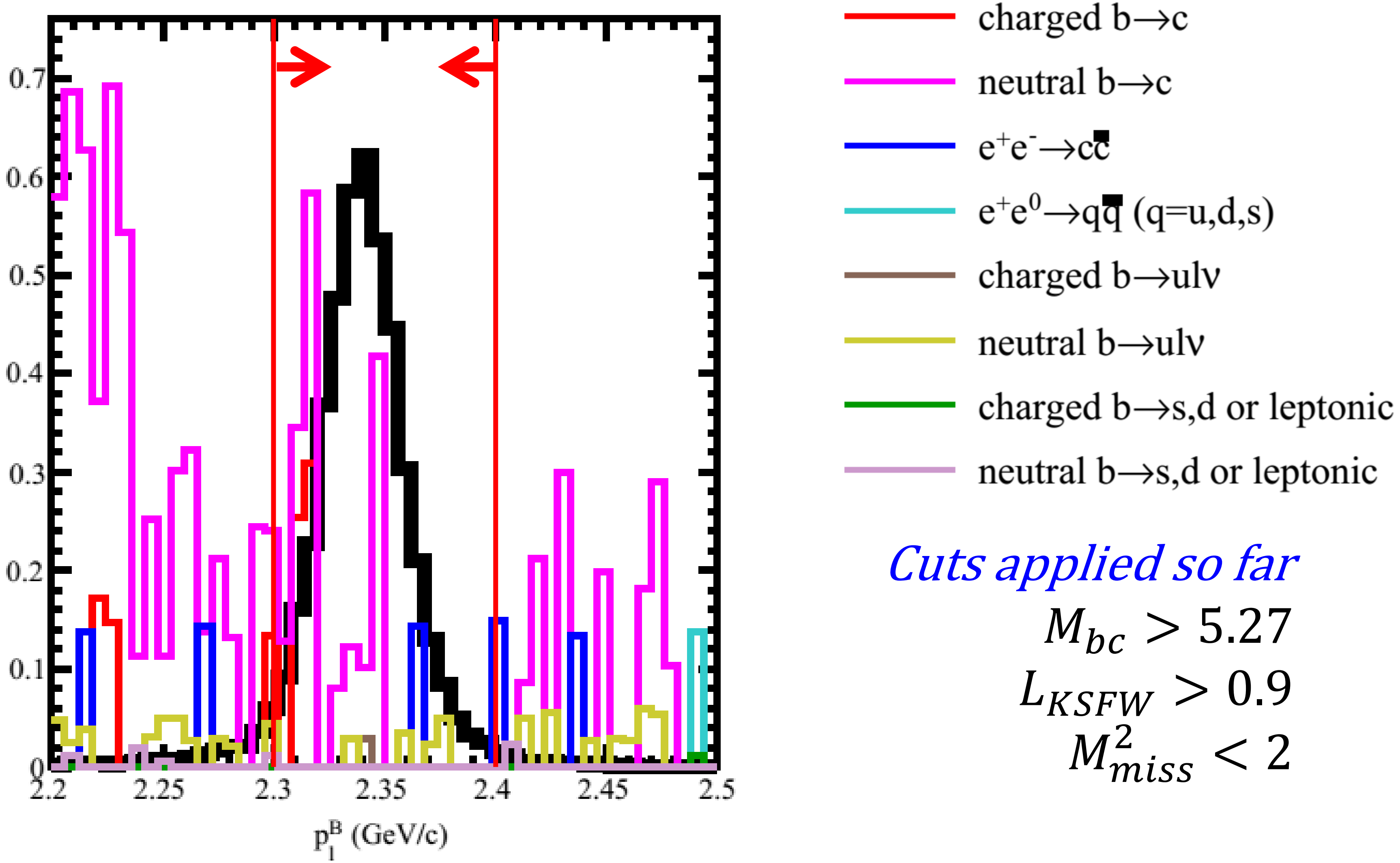
charged b→c
neutral b→c
e⁺e⁻→cc̄
e⁺e⁰→qq̄ (q=u,d,s)
charged b→ulν
neutral b→ulν
charged b→s,d or leptonic
neutral b→s,d or leptonic

Cuts applied so far
$M_{bc} > 5.27$; $L_{KSFW} > 0.9$



Variables in the case of $\mu - e$ mode

- p_ℓ^B



Cuts applied so far

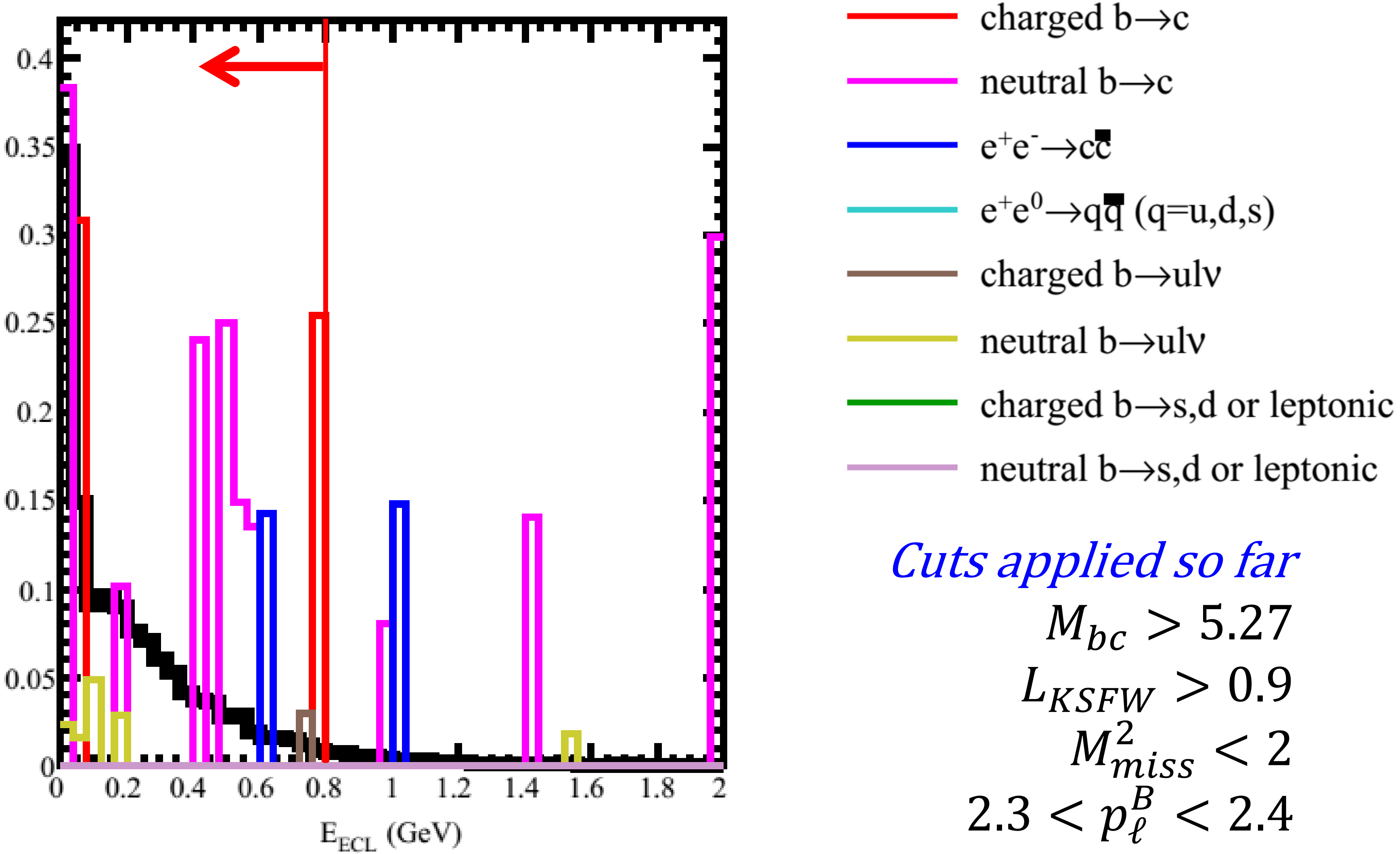
$M_{bc} > 5.27$

$L_{KSFW} > 0.9$

$M^2_{miss} < 2$

Variables in the case of $\mu - e$ mode

- E_{ECL}: sum of E not associated with B_{tag} nor PL nor SP



Cuts applied so far

$M_{bc} > 5.27$

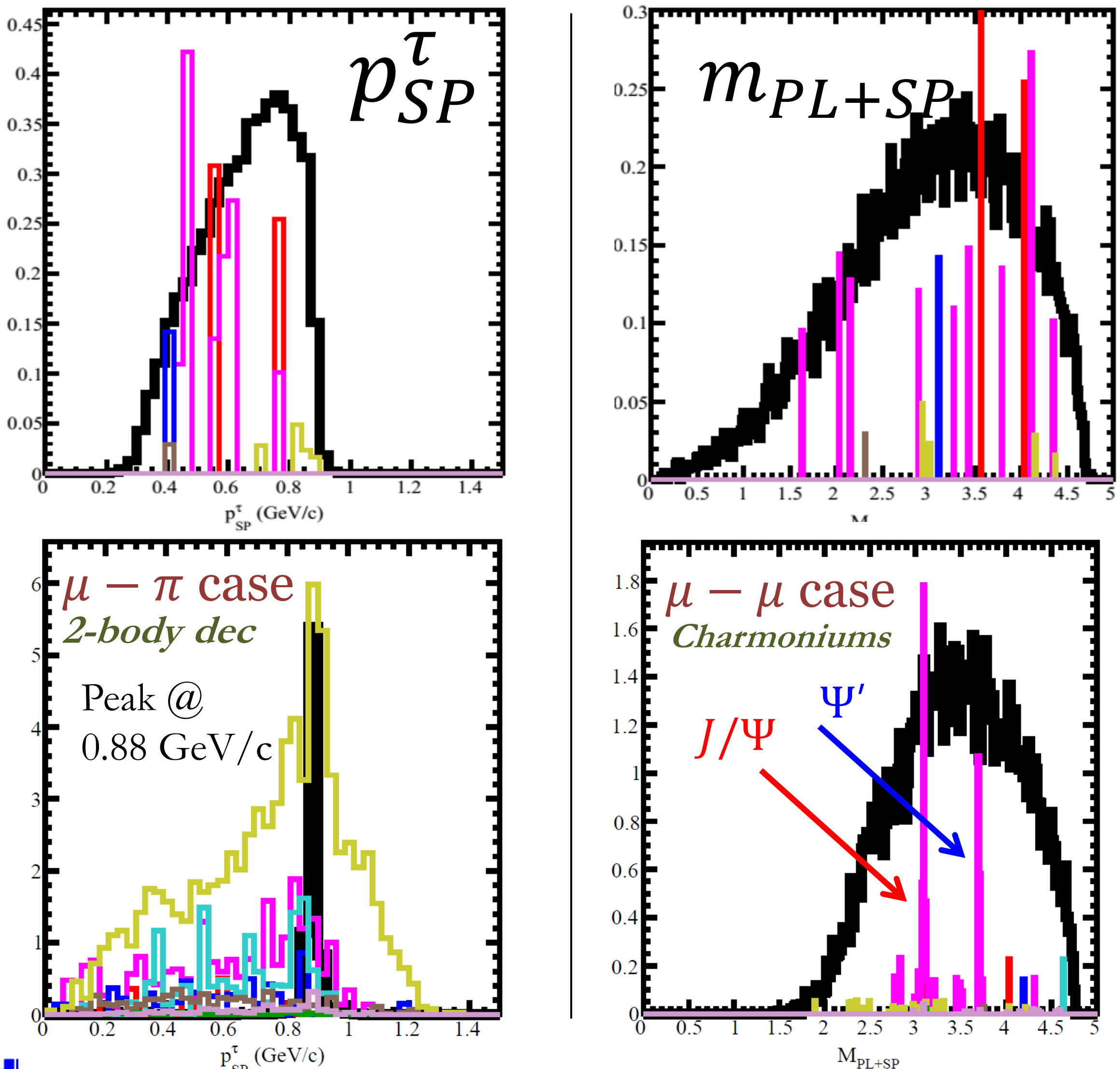
$L_{KSFW} > 0.9$

$M^2_{miss} < 2$

$2.3 < p^B_\ell < 2.4$

Variables in the case of $\mu - e$ mode

- The rest of variables



charged b→c
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e⁺e⁻→cc̄
e⁺e⁰→qq̄ (q=u,d,s)
charged b→ulν
neutral b→ulν
charged b→s,d or leptonic
neutral b→s,d or leptonic

Cuts applied so far

$M_{bc} > 5.27$

$L_{KSFW} > 0.9$

$M_{miss}^2 < 2$

$2.3 < p_{\ell}^{B} < 2.4$

$E_{ECL} < 0.8$

Variables in the case of $\mu - e$ mode

- U.L. expectation by counting method
  - Assumptions:
    - 50% uncertainty on $N_{background}$
    - 10% uncertainty on ϵ_{sig}
    - ~ expected N_{bkg} observed
  - Comments:
    - $\mu - e$ mode only!
    - ~3% continuum BG expected from MC

Cuts applied so far

$M_{bc} > 5.27$

$L_{KSFW} > 0.9$

$M^2_{miss} < 2$

$2.3 < p^B_\ell < 2.4$

$E_{ECL} < 0.8$

ϵ_{SIG}	N_{bkg}	$B(B \to \mu\tau)$
0.011%	4.2	$< 2.6 \times 10^{-5}$(90% $C.L.$)

$< 2.2 \times 10^{-5}$(BaBar's using 6 τ decays)

I guess I have some hope!

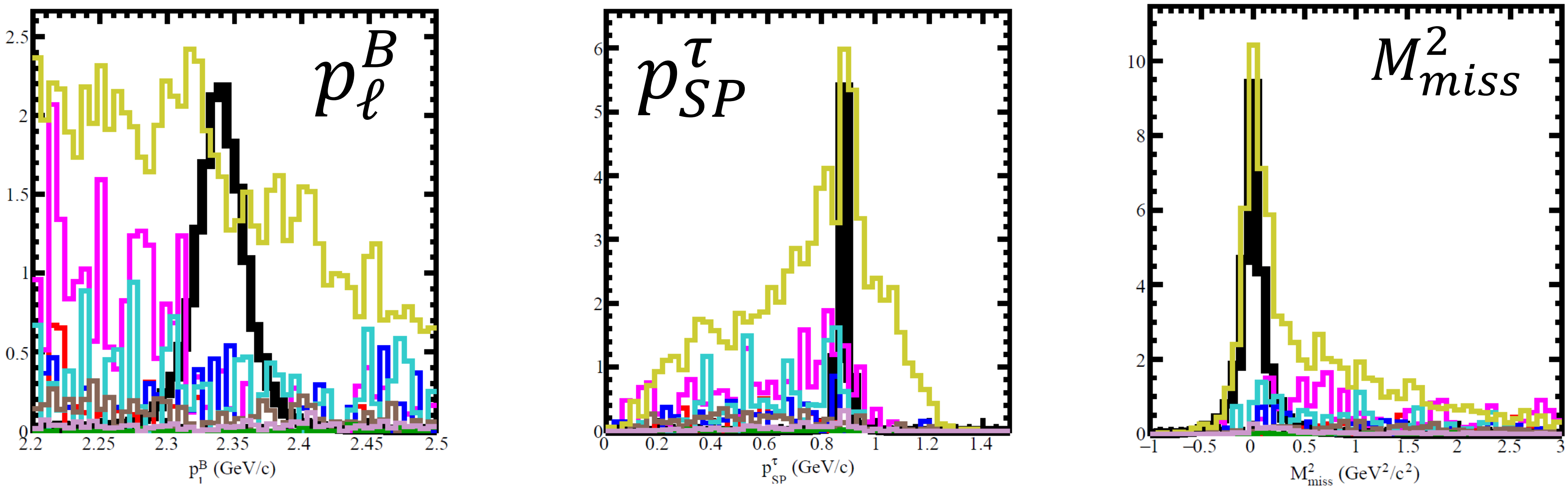
Variables used in this Analysis

Normal level: $\tau \to \pi\nu$

Variables in the case of $\mu - \pi$ mode

Cuts
$M_{bc} > 5.27$
$L_{KSFW} > 0.9$
$E_{ECL} < 0.8$

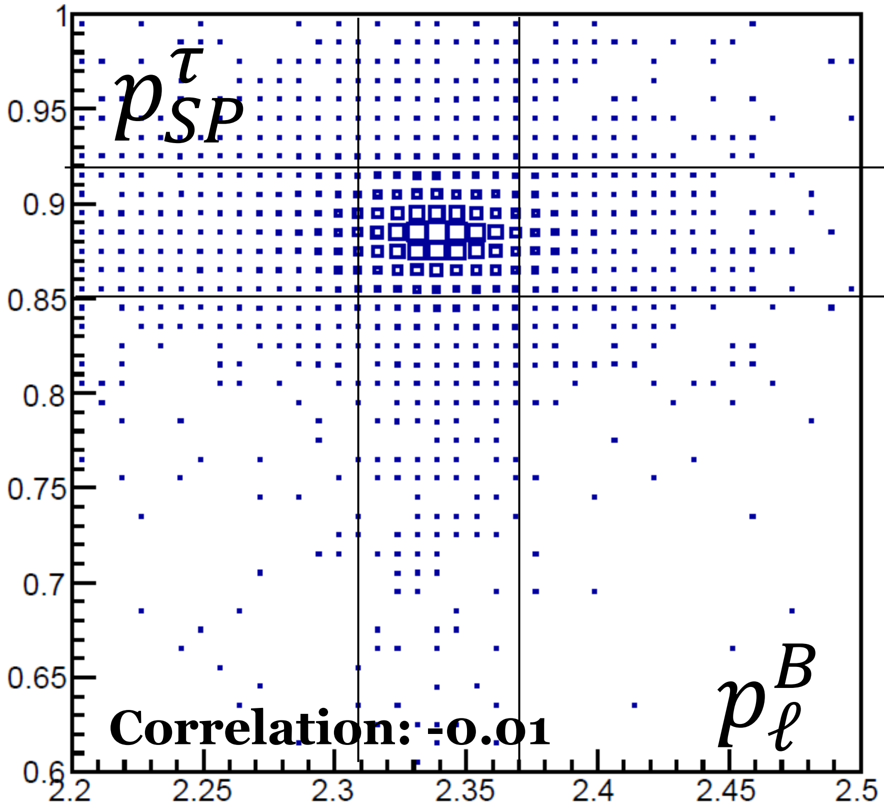
The gold BG = neutral $b \to u\ell\nu$



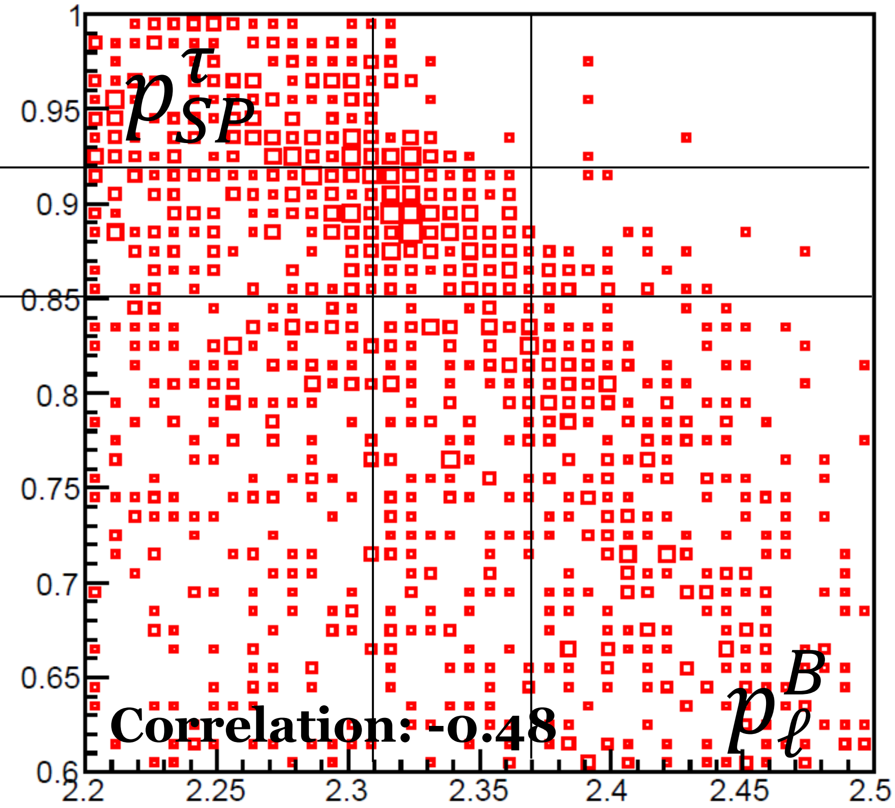
Variables in the case of $\mu - \pi$ mode

Cuts
$M_{bc} > 5.27$
$L_{KSFW} > 0.9$
$E_{ECL} < 0.8$

Signal MC



Neutral $b \to u\ell\nu$



Variables in the case of $\mu - \pi$ mode

Cuts

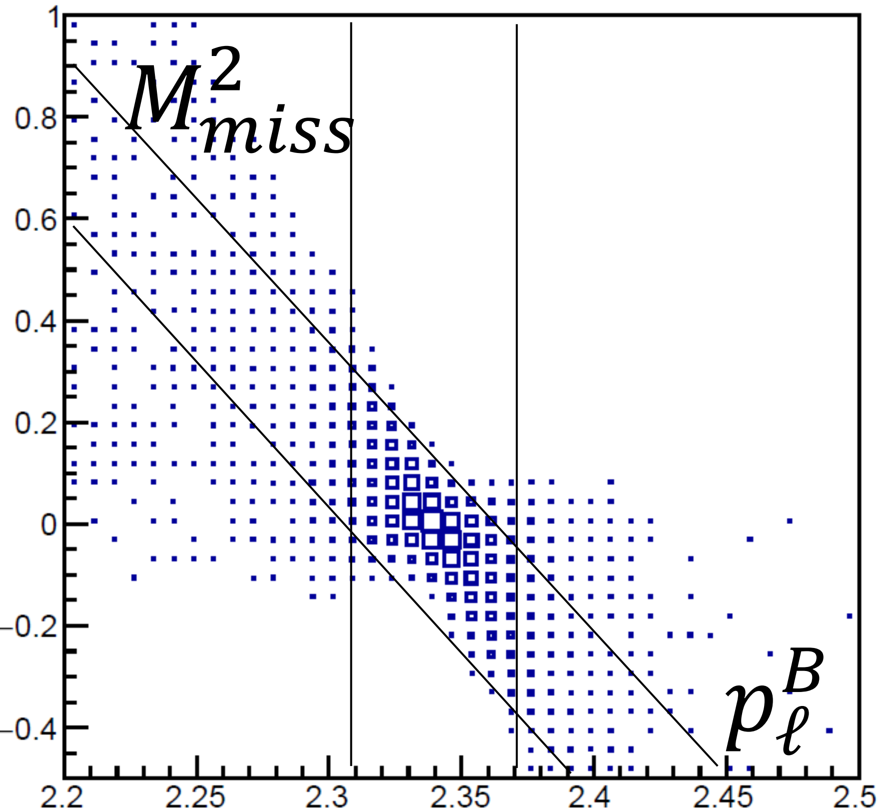
$M_{bc} > 5.27$

$L_{KSFW} > 0.9$

$E_{ECL} < 0.8$

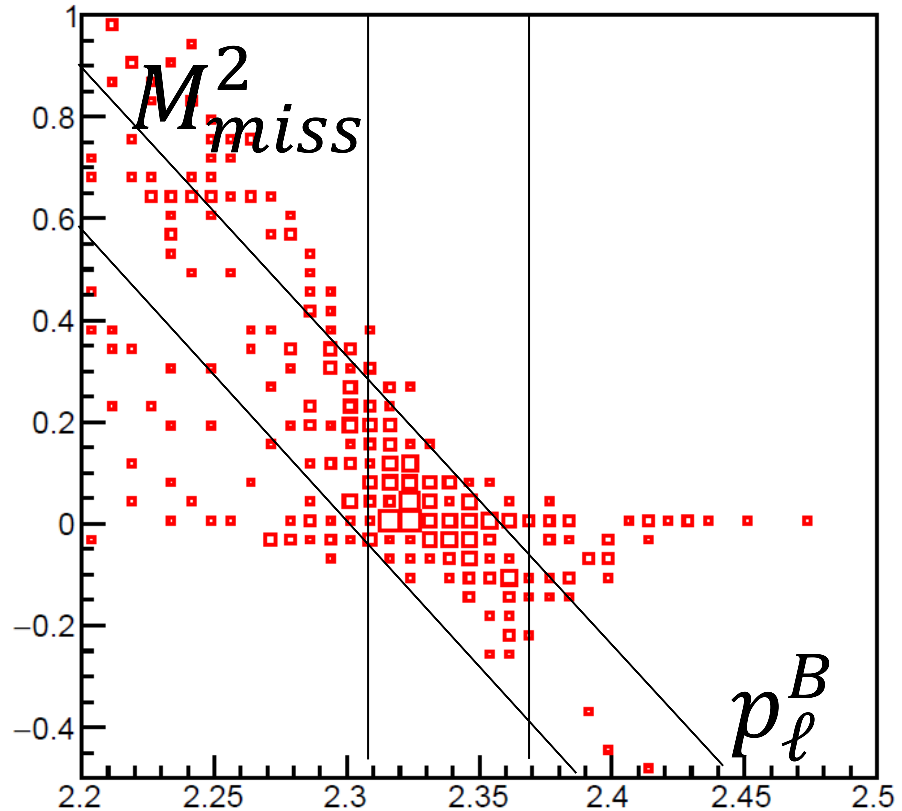
$0.85 < p_{SP}^{\tau} < 0.92$

Signal MC



Correlation: -0.77

Neutral $b \to u\ell\nu$

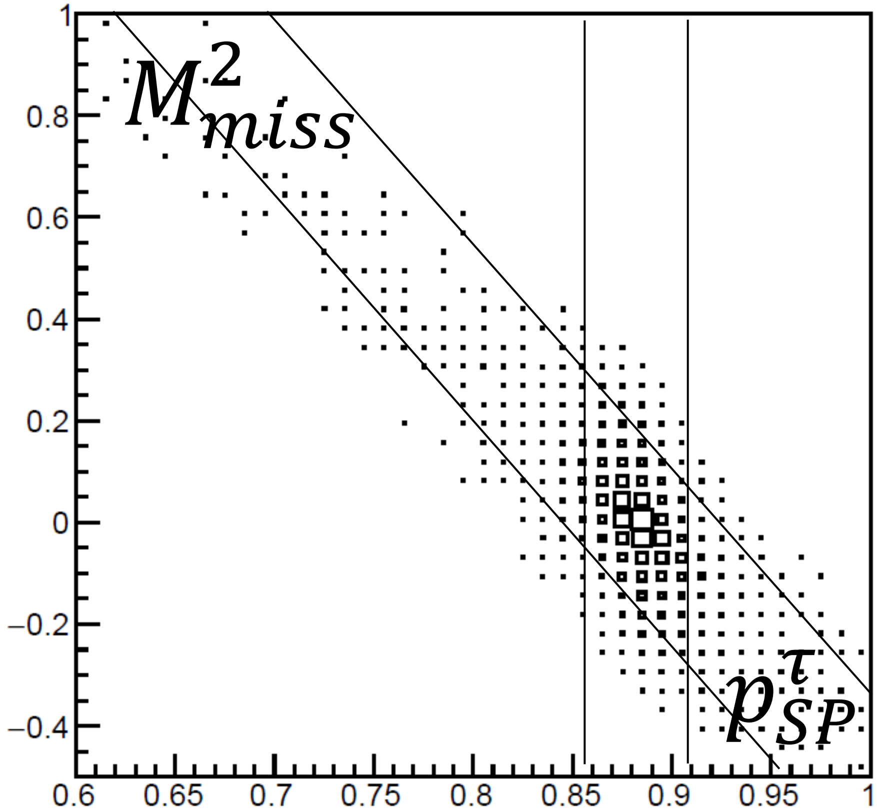


Correlation: -0.74

Variables in the case of $\mu - \pi$ mode

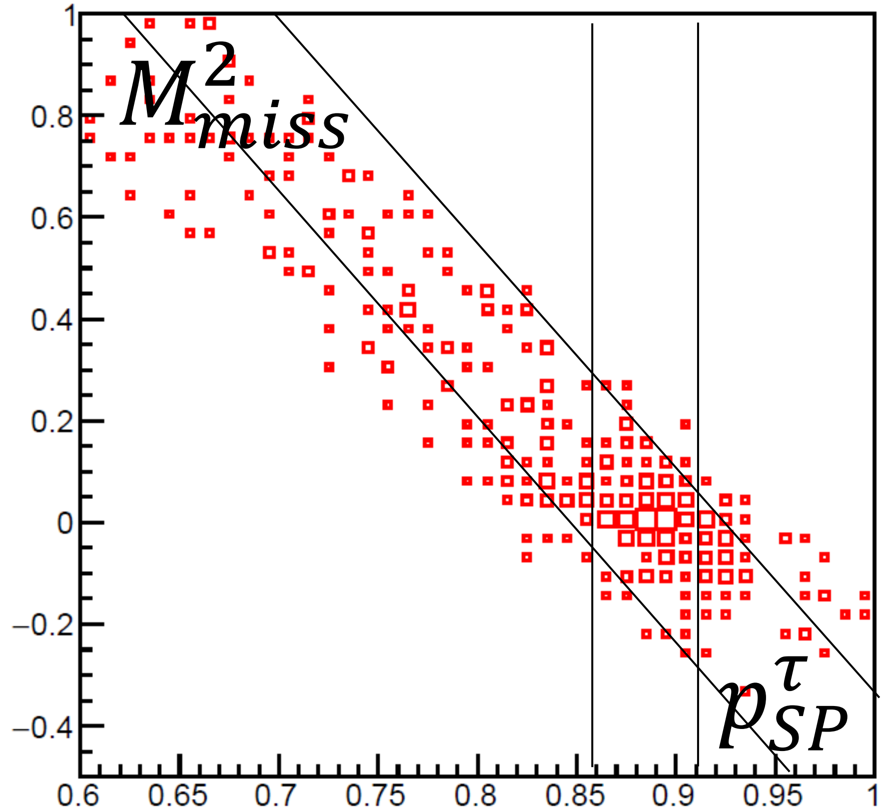
Cuts
$M_{bc} > 5.27$
$L_{KSFW} > 0.9$
$E_{ECL} < 0.8$
$2.31 < p_{\ell}^{B} < 2.37$

Signal MC



Correlation: -0.66

Neutral $b \to u\ell\nu$



Correlation: -0.92

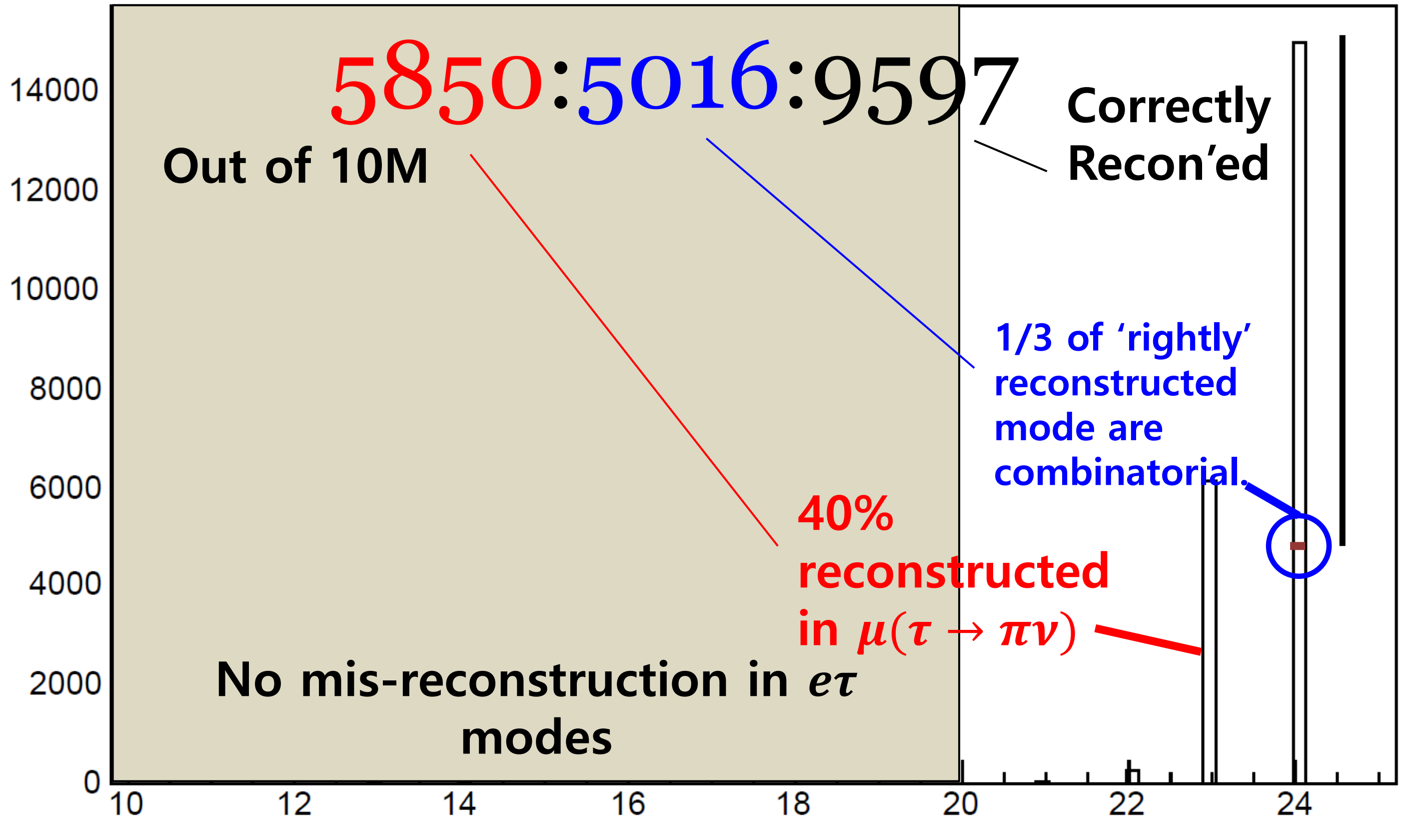
Variables used in this Analysis

Hard level: $\tau \to \rho\nu$

Variables in the case of $\mu - \rho$ mode

Cuts
$M_{bc} > 5.27$
$L_{KSFW} > 0.9$
$E_{ECL} < 0.8$

What this signal MC plot says is…



Currently working on to reduce these mis-reconstructed and combinatorial BGs.

Variables in the case of $\mu - \rho$ mode

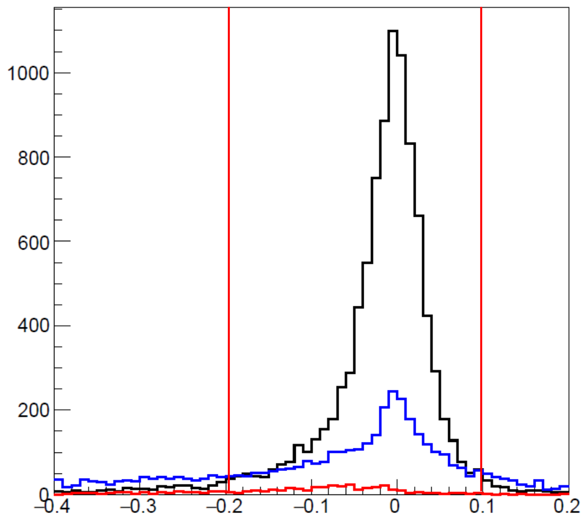
Cuts
$M_{bc} > 5.27$
$L_{KSFW} > 0.9$
$E_{ECL} < 0.8$

What this plot says is…

Requiring more than 0 mdst_pi0 formed of good clusters

Reconstructed in $\mu\tau(\pi\nu)$ combinatorial

443(-93%):5016:9597



$-0.2 < \min(\Delta E_\tau) < 0.1$

310:2934(-42%):9122

Currently working on to reduce these mis-reconstructed and combinatorial BGs.

Variables in the case of $\mu - \rho$ mode

Cuts
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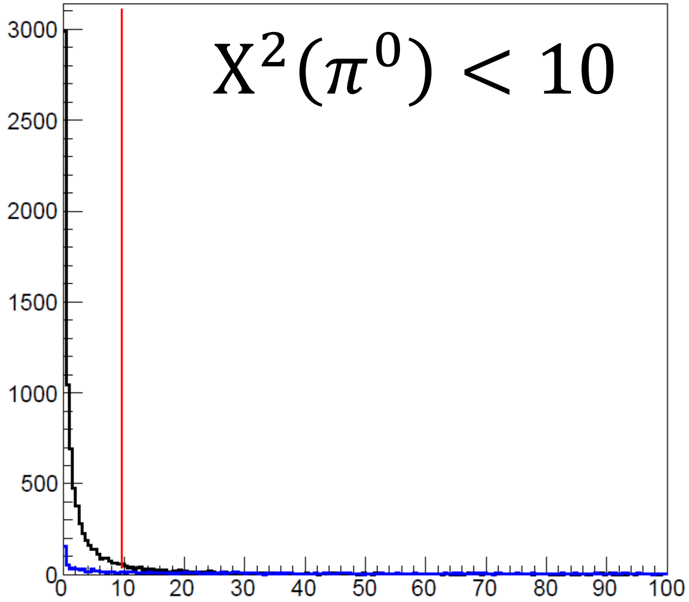
$E_{ECL} < 0.8$

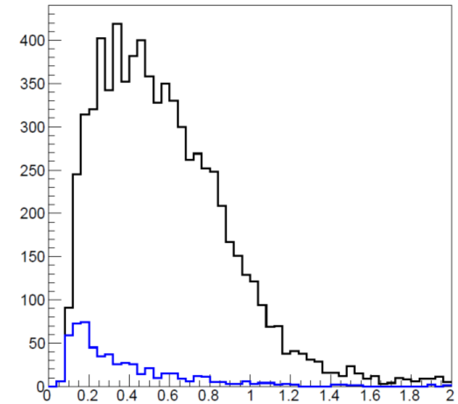
More than 1 π^0
$-0.2 < \min(\Delta E_\tau) < 0.1$

310:2934:9122

Reconstructed in $\mu\tau(\pi\nu)$ combinatorial



310:576(-80%):7406(-19%)



Currently working on to reduce these mis-reconstructed and combinatorial BGs.

Variables in the case of $\mu - \rho$ mode

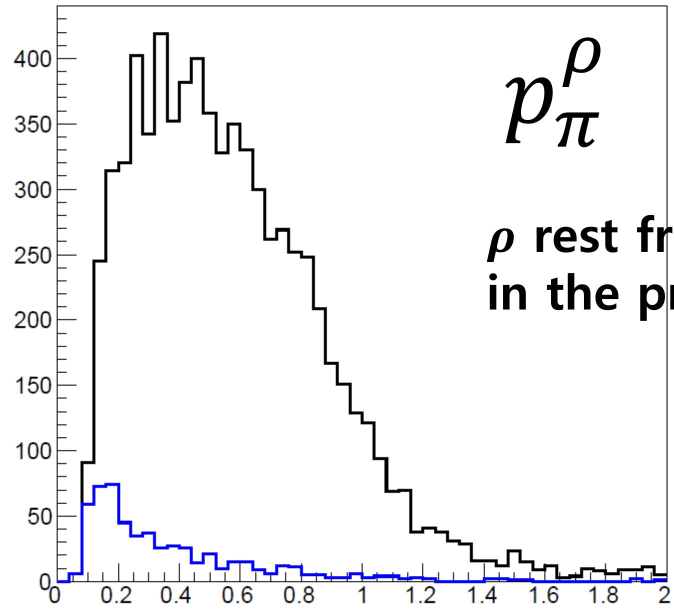
Cuts
$M_{bc} > 5.27$
$L_{KSFW} > 0.9$
$E_{ECL} < 0.8$

More than 1 π^0
$-0.2 < \min(\Delta E_\tau) < 0.1$

310(-95%):576(-91%):7406(-26%)

Reconstructed in $\mu\tau(\pi\nu)$ combinatorial

More handles in hand…



ρ rest frame obtained as in the previous procedure.

+ E9/E25: 3x3 vs 5x5 ECL energy deposit for the γs from the π^0

Currently working on to reduce these mis-reconstructed and combinatorial BGs.

Summary and Plans

- Reconstruction of events and variables for l-tau hadronic tagging study is prepared.
- A very naïve cut and count method on one of the mode makes the future look promising.
- While the $u\ell\nu$ BG look dangerous for $\tau \to \pi\nu$ sub-decay modes, it is planned to get over it by using the resonance difference in p_{SP}^{τ}.
- Reducing mis-reconstructed signal MC in the $\tau \to \rho\nu$ channel is going on.
  - Combination of the conditions mentioned in the last section on the ρ meson selection will bring improvements.
- Optimization expected to be carried out on E_{ECL} variable
  - The momentums and the M_{miss}^2 will be fitted on random toy samples and the mean of the resulting U.L.(90%) on B.F. will be the estimator.