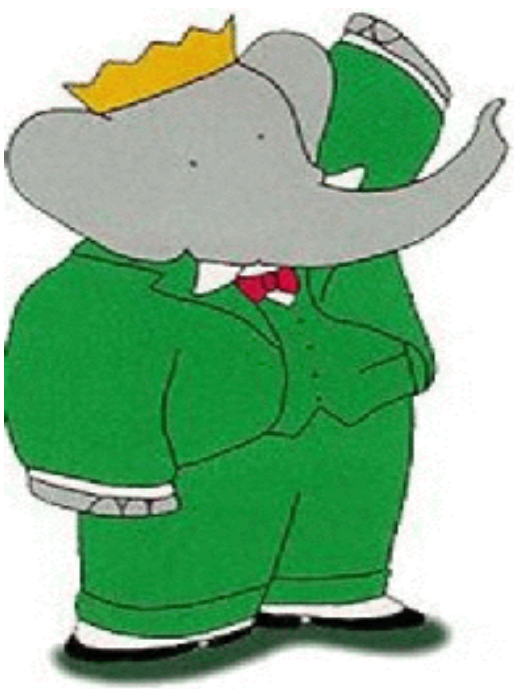
Search for the rare decay $B^+ \rightarrow K^+\tau^+\tau^-$ at BaBar

Canadian Association of Physicists
June 16th, 2014



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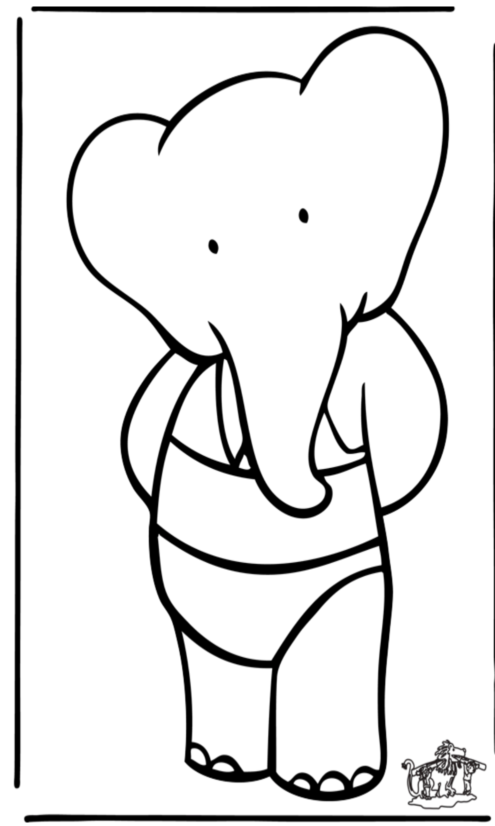
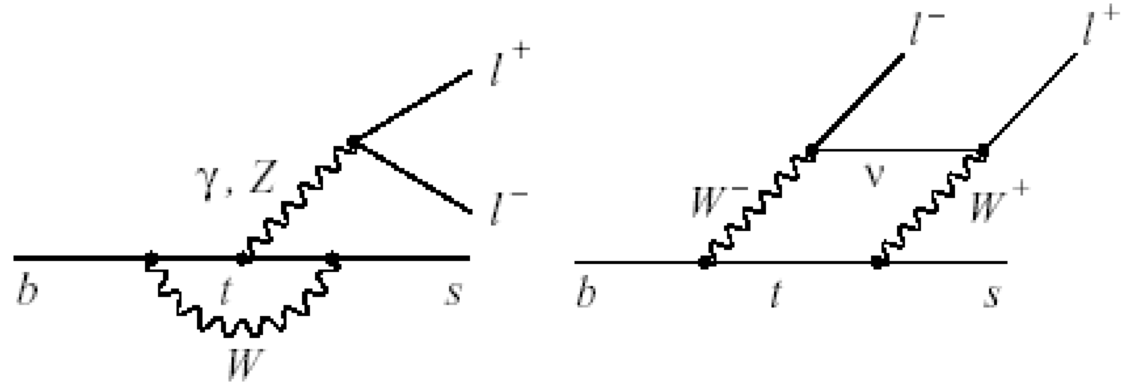
Outline

- $B^+ \rightarrow K^+\tau^+\tau^-$ Theoretical Motivation
- BaBar Analysis Details
- Signal selection
- Background Estimate
- Expected Results and sensitivity



$B^+ \rightarrow K^+\ell^+\ell^-$:Electroweak FCNC

b→s l^+l^- **:**



C_7, C_9 (vector) , and C_{10} (axial).
Observables: branching fraction, A_{CP}, A_{FB}.

$$H_{eff} = \frac{4G_F}{\sqrt{2}} \sum_i C_i(\mu, M) O_i$$

Operator Matrix Elements
Encode long-distance contributions, calculated by heavy quark expansion in powers of m_b or SCET.

Wilson Coefficients
calculated perturbatively, describe short-distance physics

New Physics can alter physical observables.

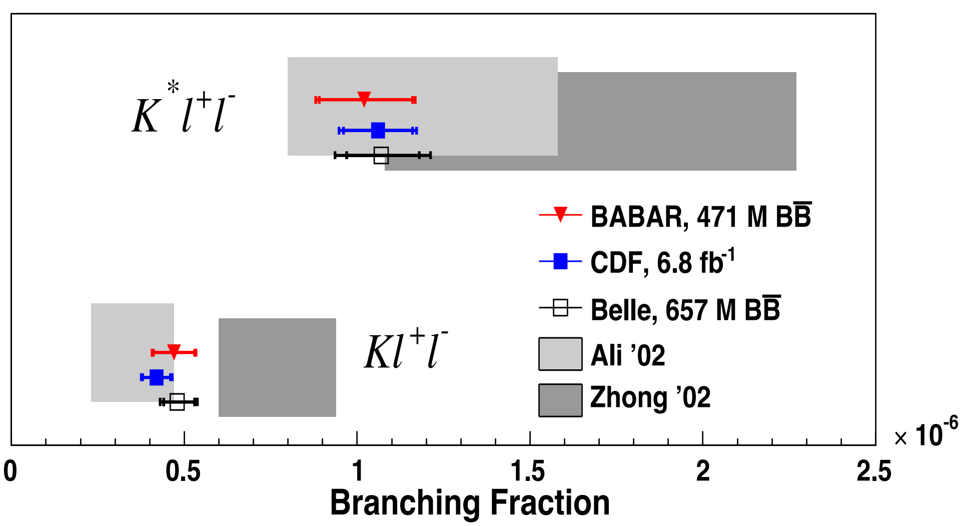
$B^+ \rightarrow K^+\ell^+\ell^-$:

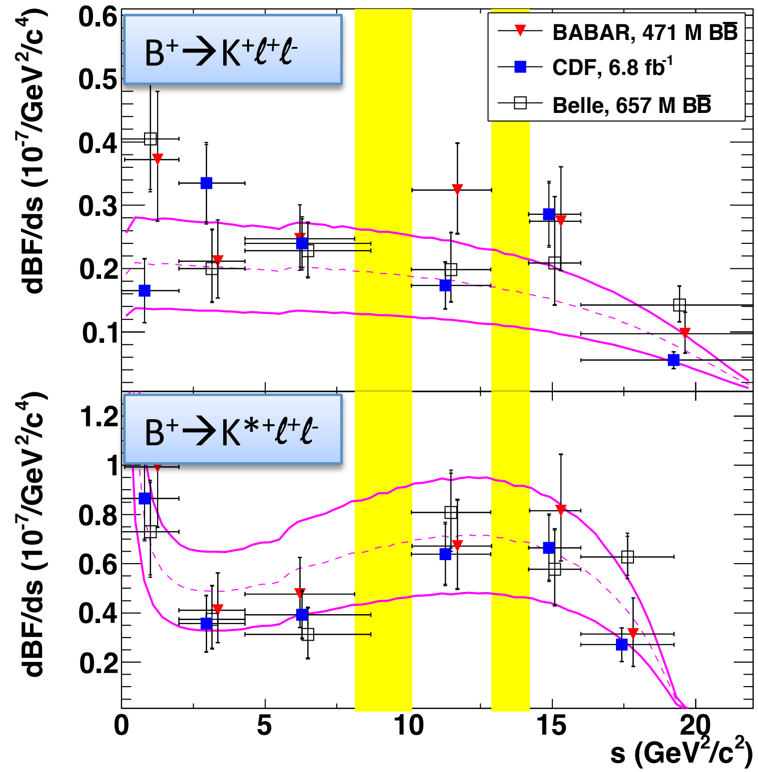
- $B \rightarrow K^+ \ell^+\ell^-$, where ℓ =e or μ.

FCNC process with branching fraction of $O(10^{-6})$.

- BaBar results: Consistent with SM

Phys. Rev. D **86**, 032012





▼ *BABAR 471 M BB*

■ CDF 6.8 fb^{-1} PRL 107, 201802 (2011)

□ Belle 657 *M BB* PRL 103, 171801 (2009)

● LHCb 0.37 fb^{-1} arXiv:1112.3515 (2012)

— SM-based predictions

Ball & Zwicky, PRD71, 014015(2005), PRD71, 014029(2005); Ali et al., PRD 66, 034002 (2002).

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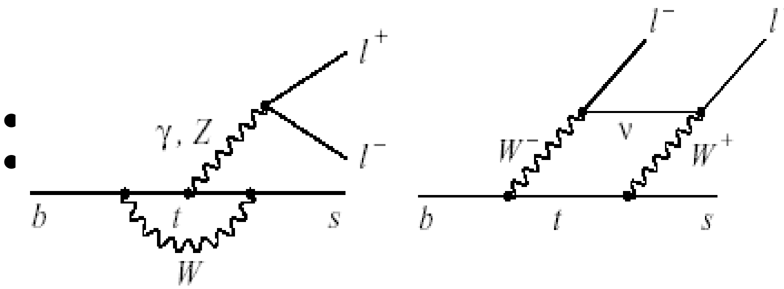
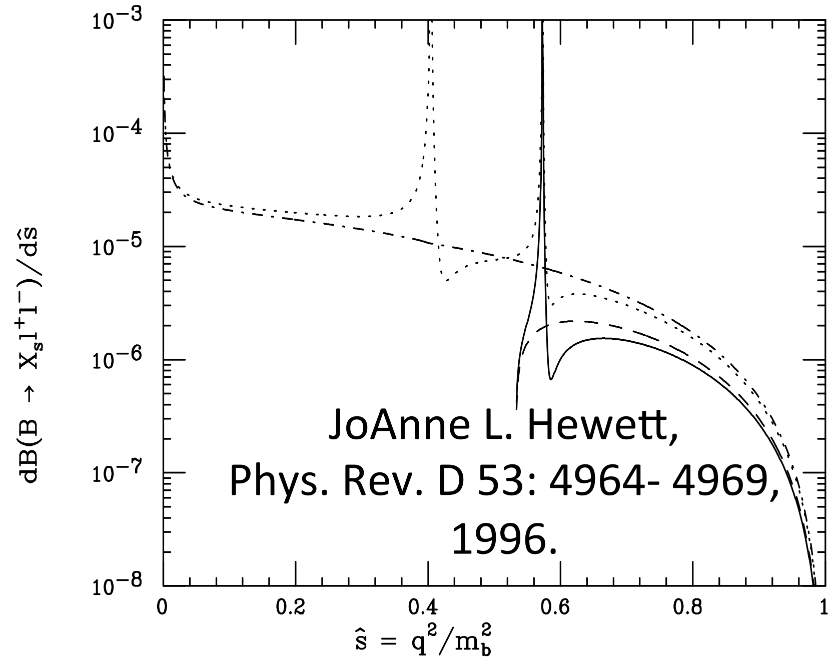
$B^+ \rightarrow K^+\tau^+\tau^-$:

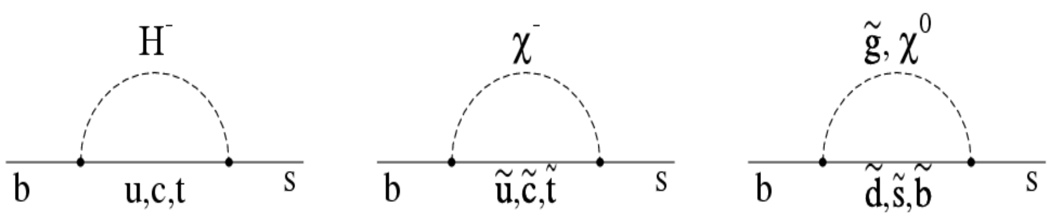


- Third generation extension of $B \rightarrow K^+ \ell^+ \ell^-$.

ℓ	$4x \le \hat{s} \le 1$	$0.6 \le \hat{s} \le 1$
e	1.2×10^{-5}	8.5×10^{-7}
μ	1.0×10^{-5}	8.5×10^{-7}
τ	5.4×10^{-7}	4.3×10^{-7}



- New physics could enter the loop and alter the branching fraction



- No long distance contribution from $J/\psi \rightarrow \tau^+\tau^-$.

$B(\psi(2S) \rightarrow \tau^+\tau^-) = 3.0 \times 10^{-4}$

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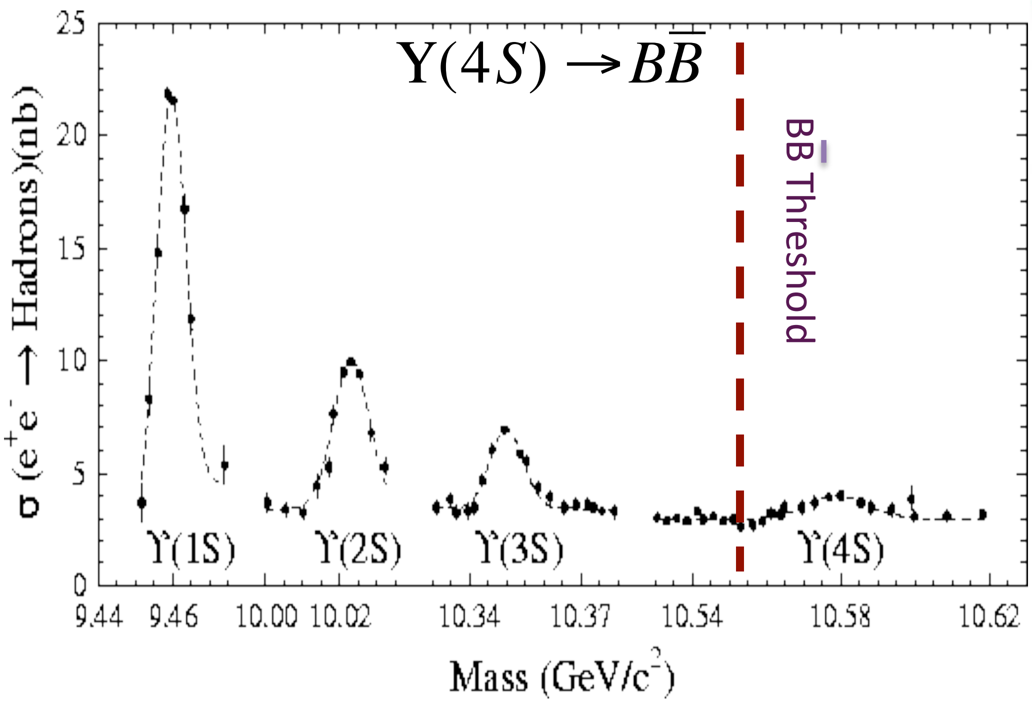
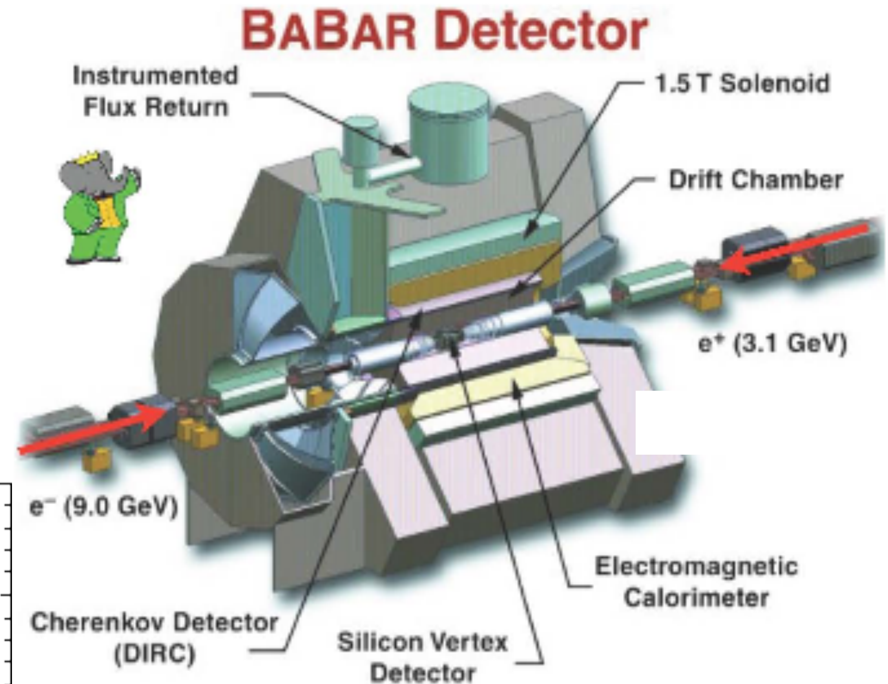
BaBar Experiment:

•Located at SLAC National Accelerator Laboratory

•e+e- collisions at CM energy of 10.58 GeV ~ mass of Υ(4S) .





Data Collection: 1999 to 2008

Total integrated luminosity, at the Υ(4S) resonance, of 429 fb^{-1}.

471 million $B\overline{B}$ pairs.

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Analysis Tools:

- Full BaBar dataset: 429 fb^{-1}.
  - Data, in the region of interest, is blinded until analysis is finalized.
- Signal Monte Carlo:
  - Dedicated MC samples

  where $B^+ \to K^+\tau^+\tau^-$ governed by Ali Model (Phys Rev D **61** , 074024)

Background Monte Carlo

Five types:

B^+B^-, $B^0\bar{B}^0$, $c\bar{c}$, $q\bar{q}$, $\tau^+\tau^-$

$\Upsilon(4S) \to B\bar{B}$ occurs, but B does not decay via $B^+ \to K^+\tau^+\tau^-$ (B^+B^-, $B^0\bar{B}^0$)

No $\Upsilon(4S)$ formed, $e^+e^- \to \ell^+\ell^-$ or $q\bar{q}$ ($c\bar{c}$, $q\bar{q}$, $\tau^+\tau^-$)

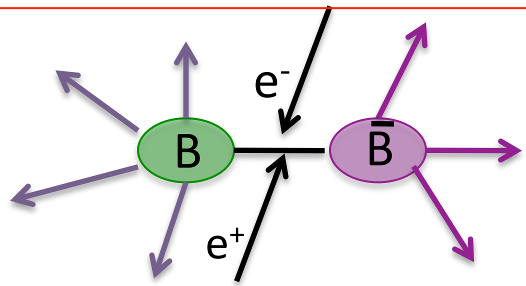
$B^+ \to K^+\tau^+\tau^-$: Consider only leptonic final states.

Mode	τ decay
Electron	$\tau^+ \to e^+\bar{\nu}_e\nu_\tau$, $\tau^- \to e^-\bar{\nu}_e\nu_\tau$,
Muon	$\tau^+ \to \mu^+\bar{\nu}_\mu\nu_\tau$, , $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$
Electron-Muon	$\tau^+ \to \mu^+\bar{\nu}_\mu\nu_\tau$, $\tau^- \to e^-\bar{\nu}_e\nu_\tau$

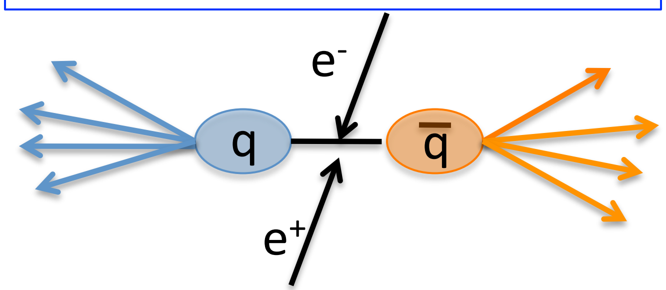
Hadronic B_{tag} Reconstruction:

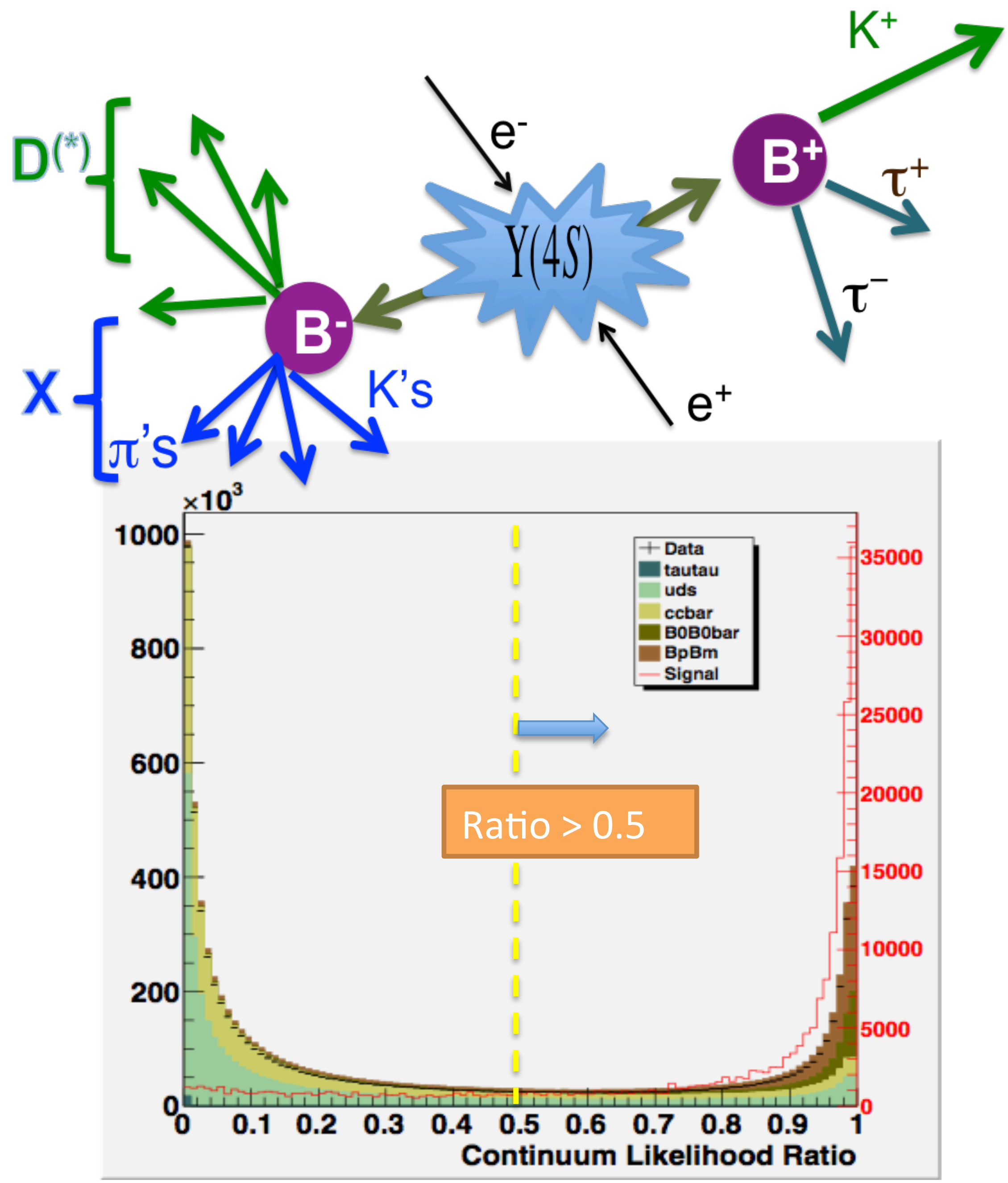
- Reconstruct first B, B_{tag}, from hadronic modes, using B → D+X.
- The remaining tracks and clusters are attributed to B_{sig}

Isotropic $B\bar{B}$ events



Jet-like continuum events



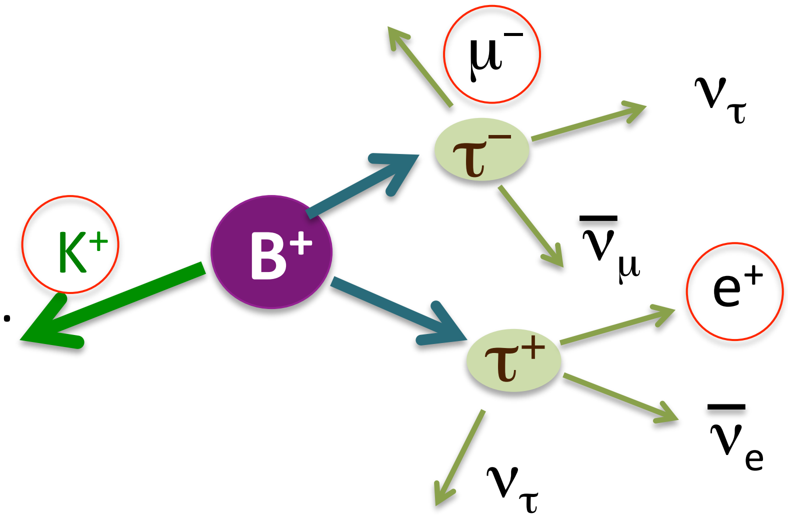


Signal Selection: B_{sig} side

- E_{miss}>0.
  - $E_{miss} = p_{\Upsilon} - p_{Btag} - p_{tracks} - p_{clusters}$.
- Q_{tot}=-Q_{Btag}.
- Exactly 3 tracks, passing

Particle Identification (PID)

for one Kaon and two leptons.

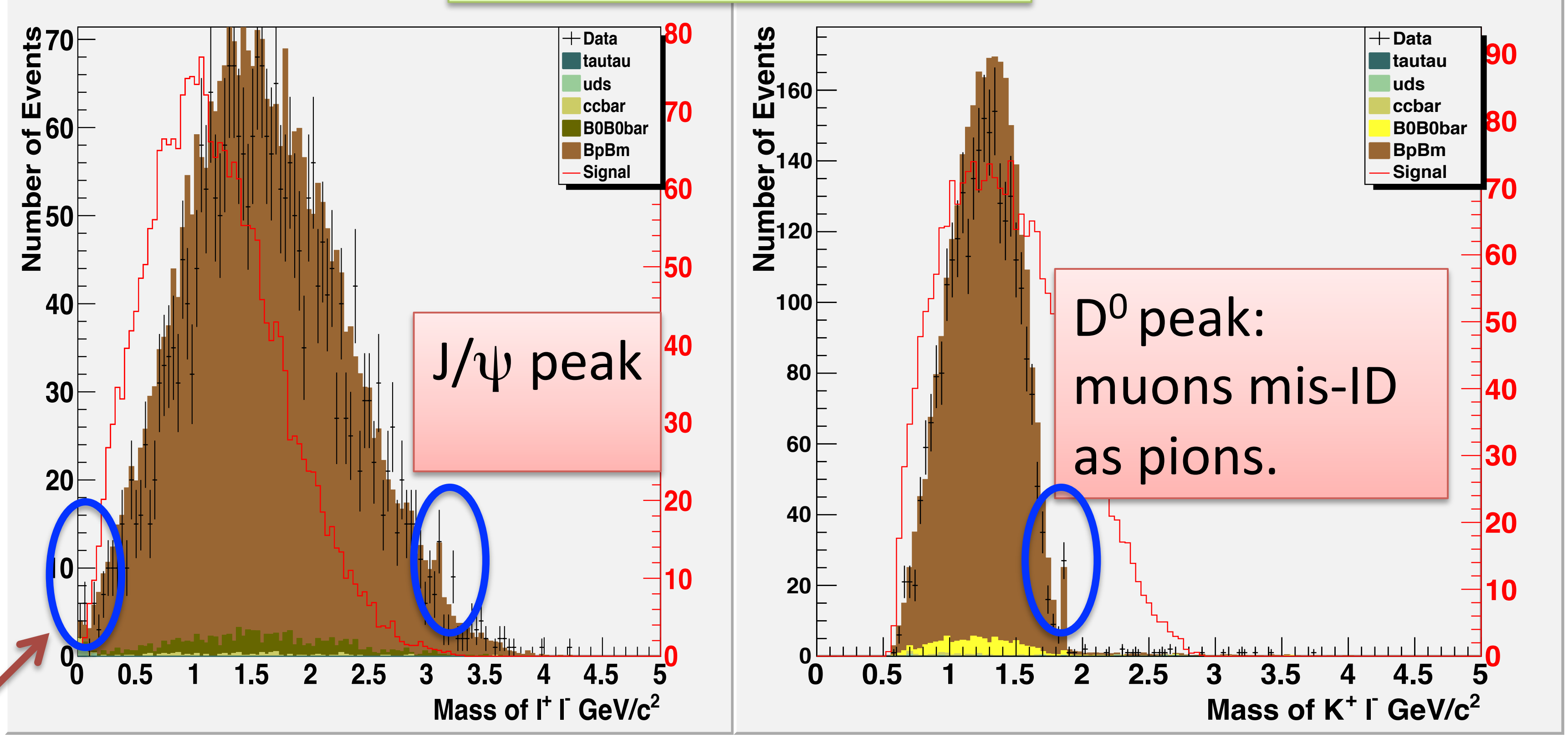


- π^0 veto
  - Any 2 clusters with E>30 MeV, E_{sum}>200 MeV and 0.1<M_{sum}<0.16 GeV.

Look at mass combinations of tracks at this point to identify potential backgrounds.

Signal Selection:

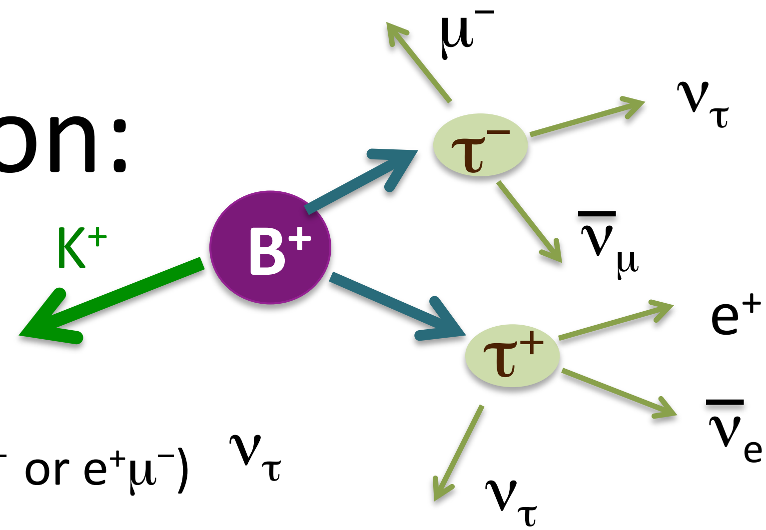
Leptonic Modes:



Photon conversions

O~ 50 events

Signal Selection:

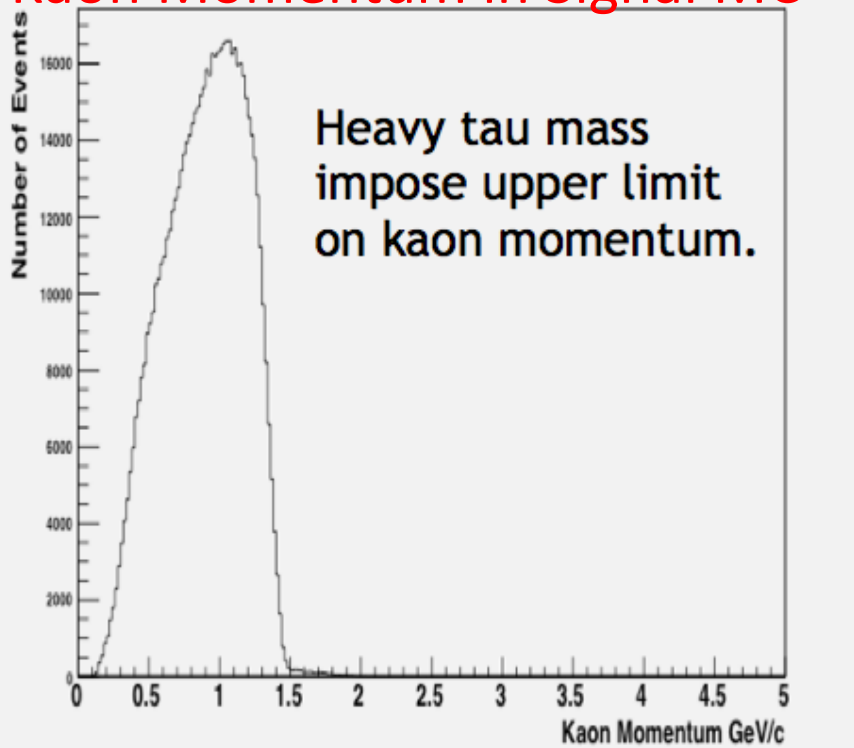


- Exactly three tracks.
- One kaon: Q_k=-Q_{btag}
- Two Oppositely charged Leptons (e^+e^- or $\mu^+\mu^-$ or $e^+\mu^-$)
- π^0 veto
  - Any 2 clusters with E>30 MeV, 0.1<lateral moment<0.8, E_{sum}>200 MeV and 0.1<M_{sum}<0.16 GeV.
- J/ψ veto
  - Sum of 2 leptons does not lie 3.00<M_{l+l-}<3.194 GeV.
- Photon conversions veto
  - Require sum of e^+ with any other oppositely charged track has a mass >50 MeV.
- D^0 veto
  - Require sum of Kaon with any oppositely charged lepton does not lie within the mass region 1.80<M_{K+l-}<1.90 GeV.

S_B Cut:

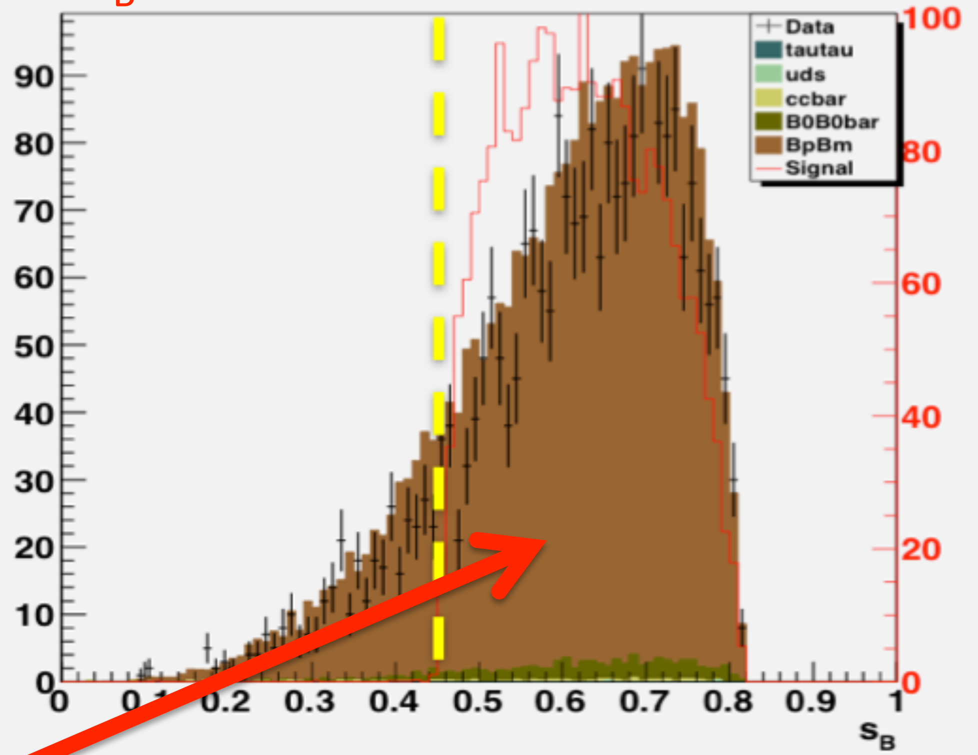
$$s_B = \frac{q^2}{m_B^2} = \frac{p_{Bsig}^2 - p_K^2}{m_B^2}$$

Kaon Momentum in Signal MC



Heavy tau mass impose upper limit on kaon momentum.

s_B

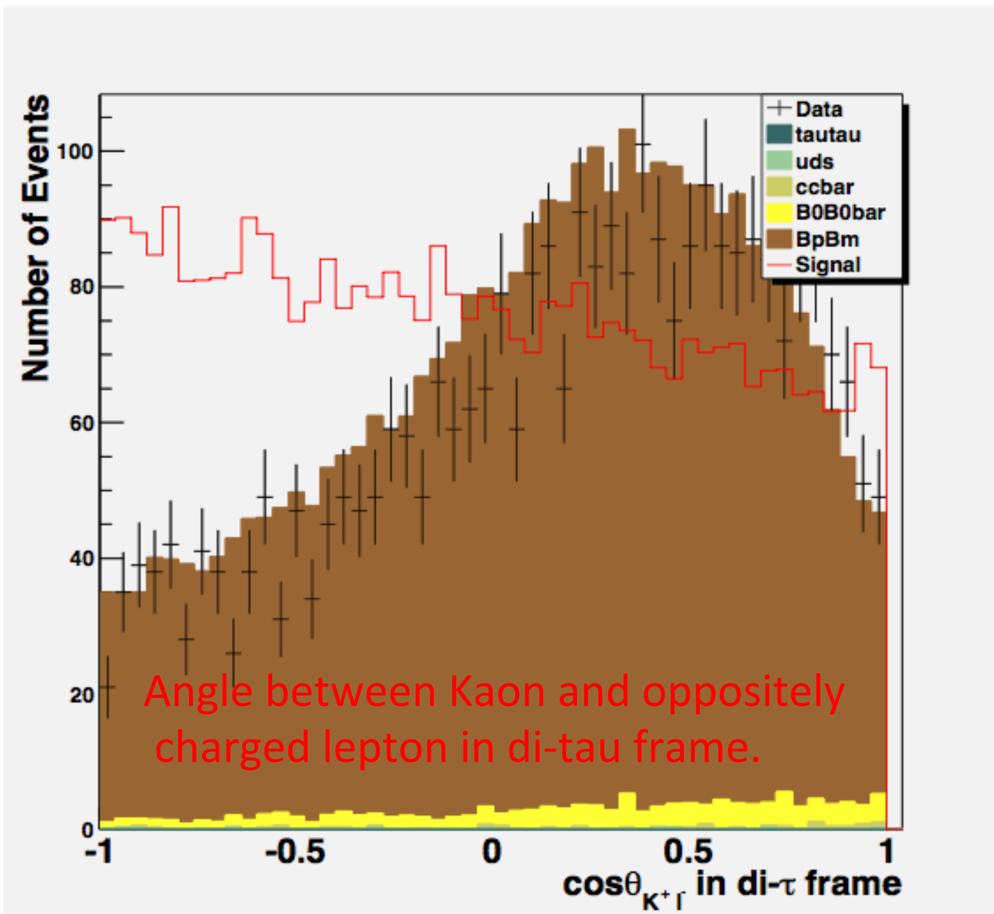


Large number of B+B- events surviving signal cuts

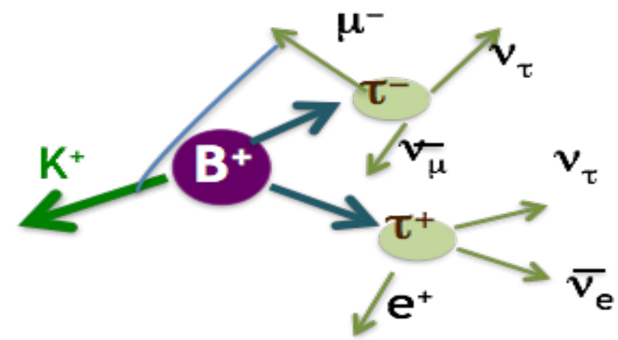
$s_B > 0.45$

Signal Selection: Dominant Background

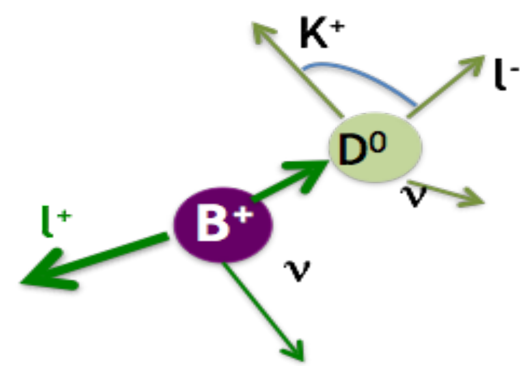
Use TMVA to suppress dominant backgrounds using a set of discriminating variables.



Signal event:



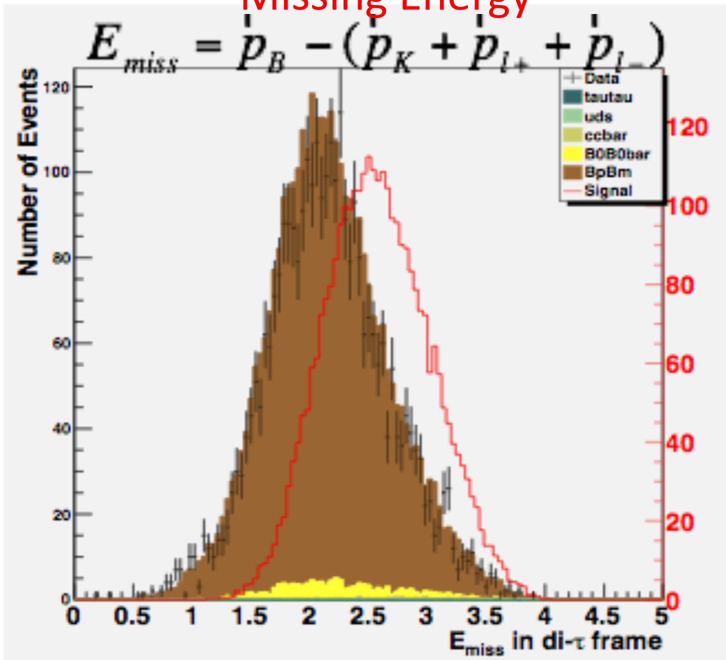
Background event:



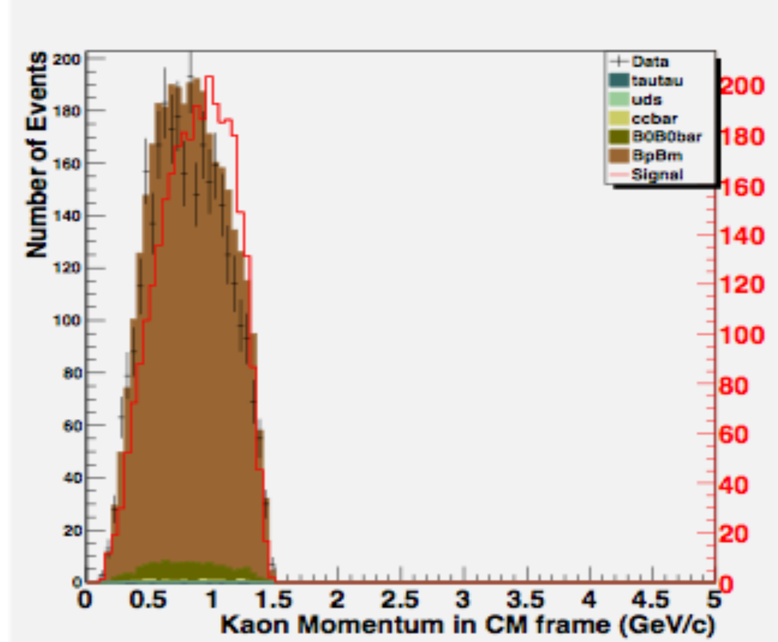
di-tau frame defined as the frame recoiling against the Kaon

Signal Selection: Dominant Background

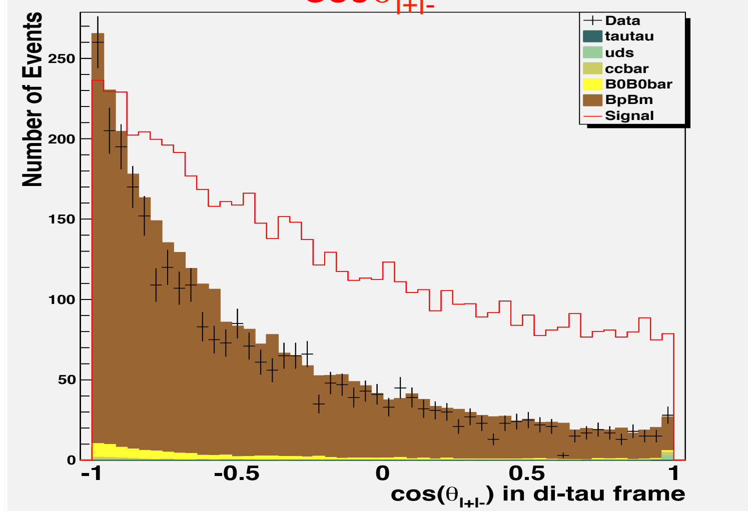
Missing Energy



Kaon Momentum



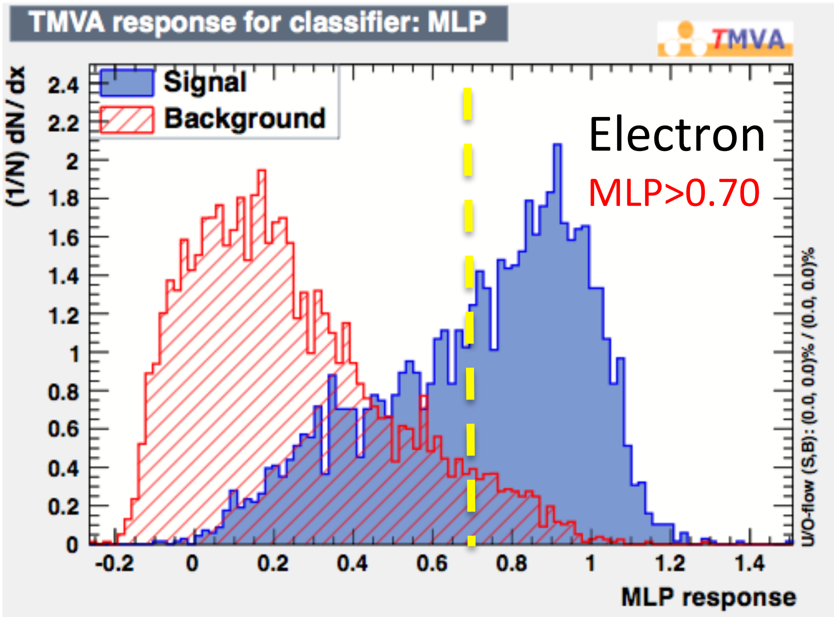
$\cos\theta_{l+l-}$

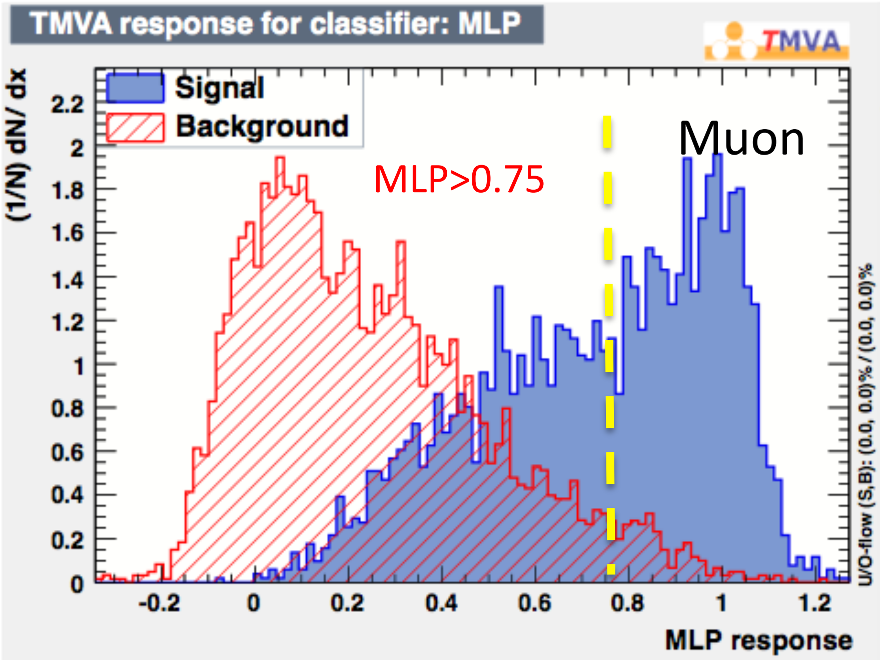


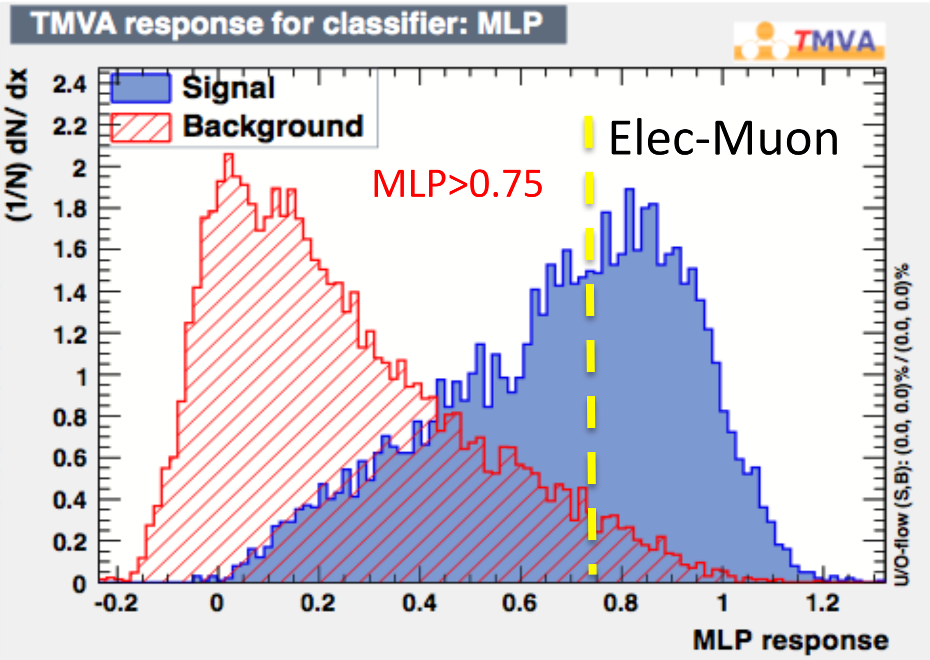
9 Input variables:

- 3 calorimeter
- 2 Kinematic
- 4 angular

TMVA Cut:


TMVA response for classifier: MLP
TMVA
Signal
Background
Electron
MLP>0.70
(1/N) dN/ dx
MLP response
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

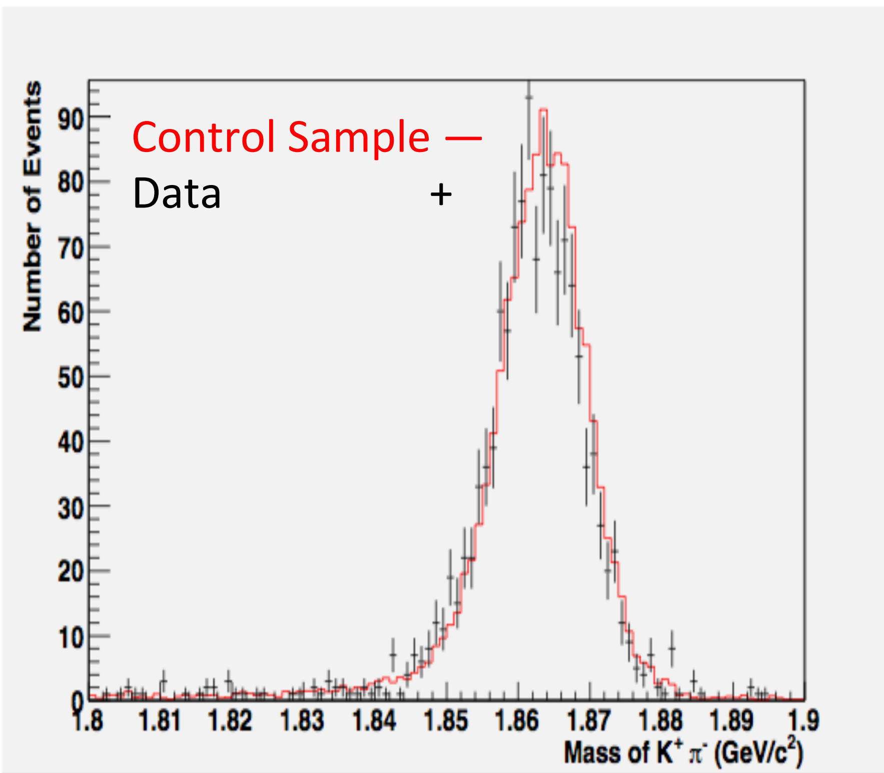

TMVA response for classifier: MLP
TMVA
Signal
Background
Muon
MLP>0.75
(1/N) dN/ dx
MLP response
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

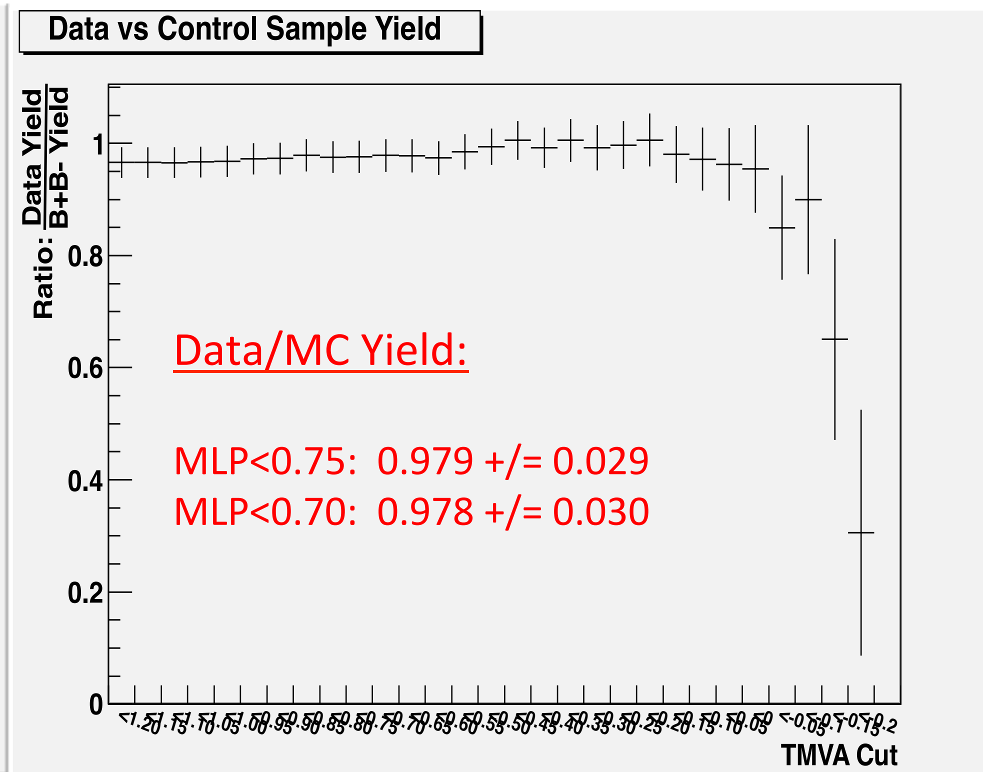

TMVA response for classifier: MLP
TMVA
Signal
Background
Elec-Muon
MLP>0.75
(1/N) dN/ dx
MLP response
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

Control Study:

$B^+ \rightarrow \bar{D}^0 l^+ \nu$ $\bar{D}^0 \rightarrow K^+ \pi^-$

- Need to verify data-MC agreement after TMVA cut.
- Reverse TMVA cut on control sample in increments of 0.05 .



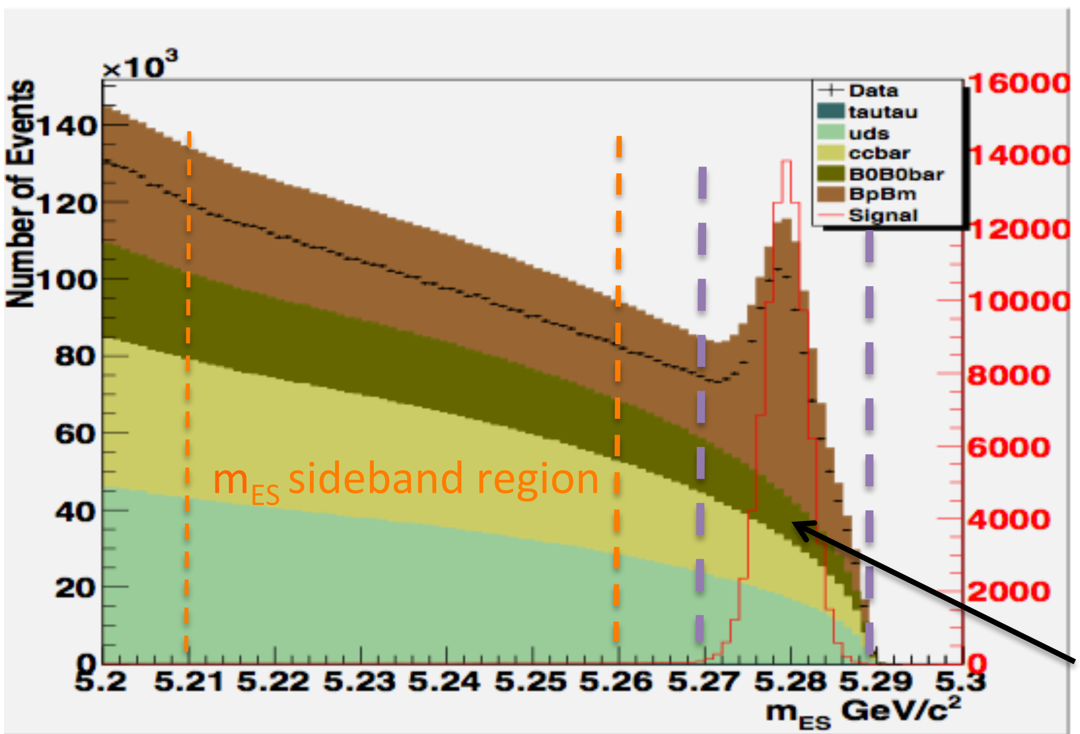


Good agreement between data and MC

Background Estimate: m_{ES} sideband substitution

Two types of background:

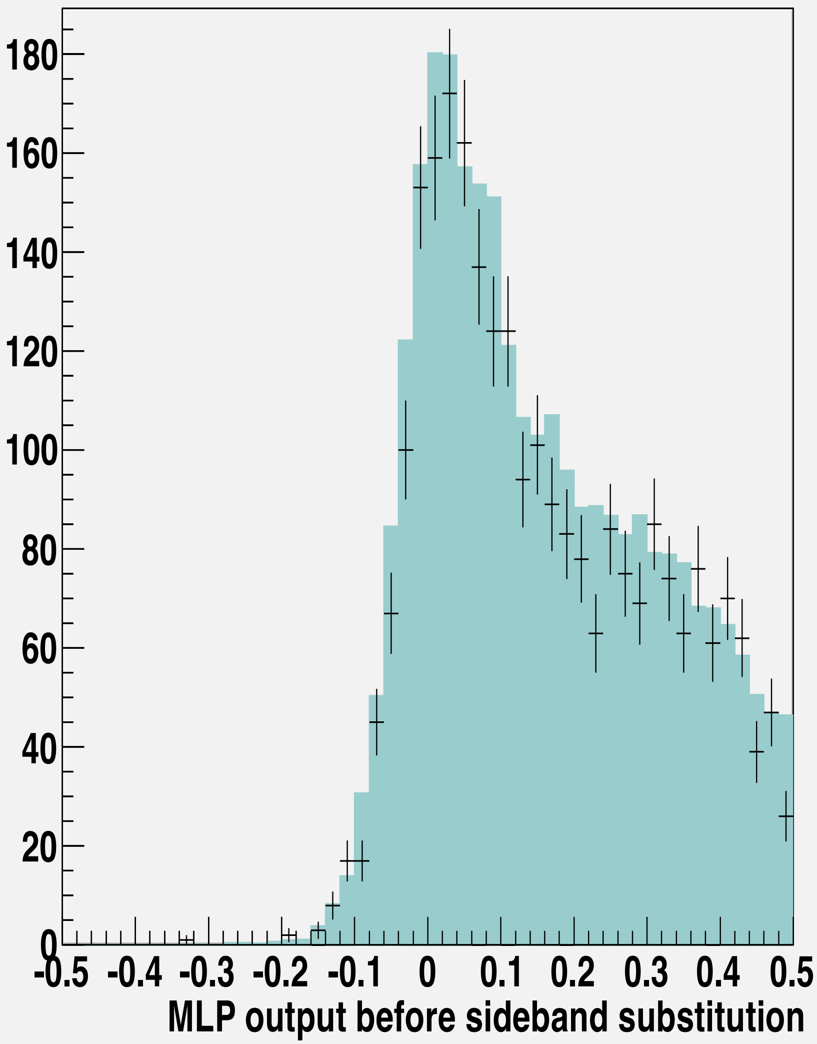
- Combinatorial background: cc, $\tau^+\tau^-$, $q\bar{q}$, and mis-reconstructed $B\bar{B}$.
- Peaking background: Properly reconstructed $B\bar{B}$.



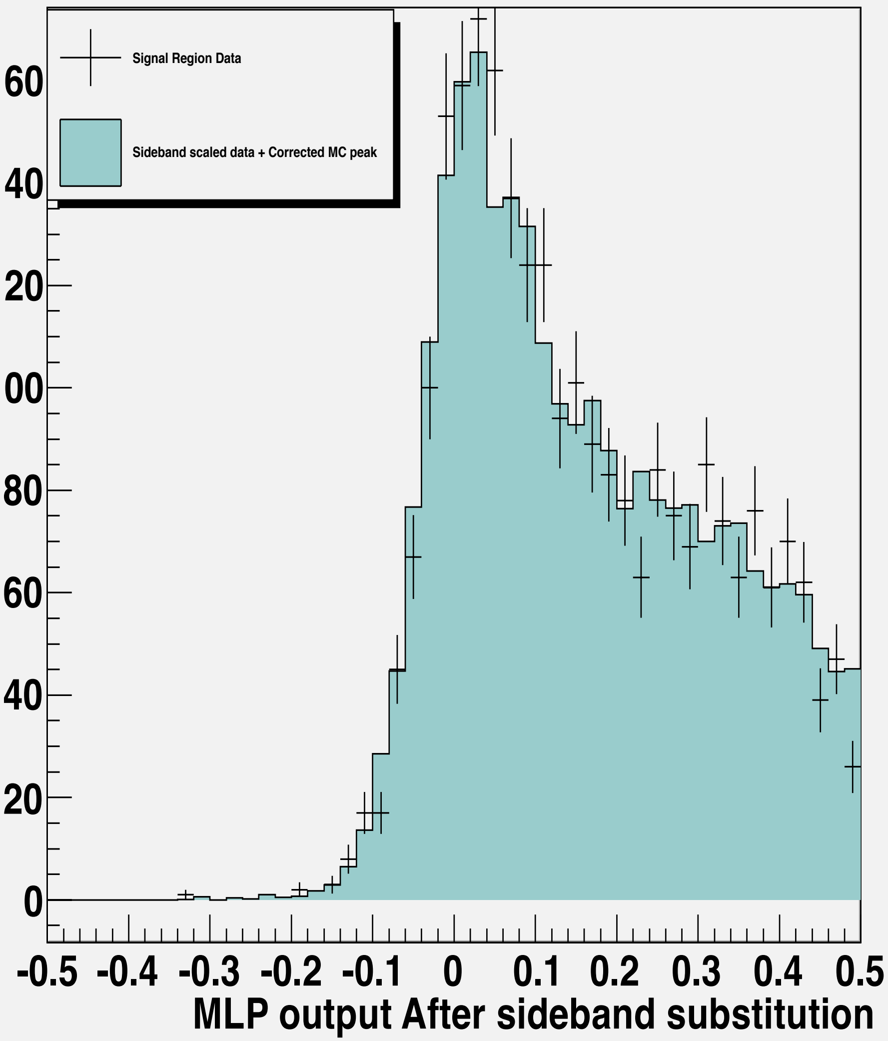
- Estimate combinatorial background using data in m_{ES} sideband region.
- Correct peaking background to match peaking data component.

Unblinded Data in MLP<0.5:

Before m_{ES} sideband substitution:



After m_{ES} sideband substitution:



Systematic Errors

Source	Estimate
Theoretical Uncertainty	~2-3%
B_{tag} Yield	~3-5%
Kaon PID	~2-4%
Lepton PID	~5-7%
π^0 Reconstruction	~3%
Background BFs	~2-3%
TMVA Cut	~9%

Compare signal efficiency between signal MC generated with BALL model and phasepace.

Vary the shape of the combinatorial m_{ES} (continuum instead of mis-charged $B\bar{B}$)

Data-MC comparison using information from PID performance plots.

Apply π^0 reconstruction on control sample and calculate the difference in relative efficiency

Vary background BFs by their PDG uncertainty and determine the difference in bkg estimate.

Use TMVA output in TMVA sideband region: MLP<0.5 to estimate data-MC difference

Expected Sensitivity

Systematic Errors are NOT included.

Mode	Signal Efficiency (x 10^{-6})	Non-Peaking Bkg	Peaking Bkg	Central Limit (x 10^{-4})	Upper Limit (x 10^{-4})
Electron	11.2 ± 1.8	4.44 ± 0.83	37.4 ± 1.9	0.38	20.1
Muon	11.5 ± 1.9	4.75 ± 0.87	21.9 ± 1.6	0.69	18.5
Elec-Muon	21.2 ± 2.5	6.82 ± 1.0	47.5 ± 2.3	0.70	12.1
Combined	---	----	----	0.64	8.26

Limits calculated assuming $N_{obs} \sim N_{bkg}$.

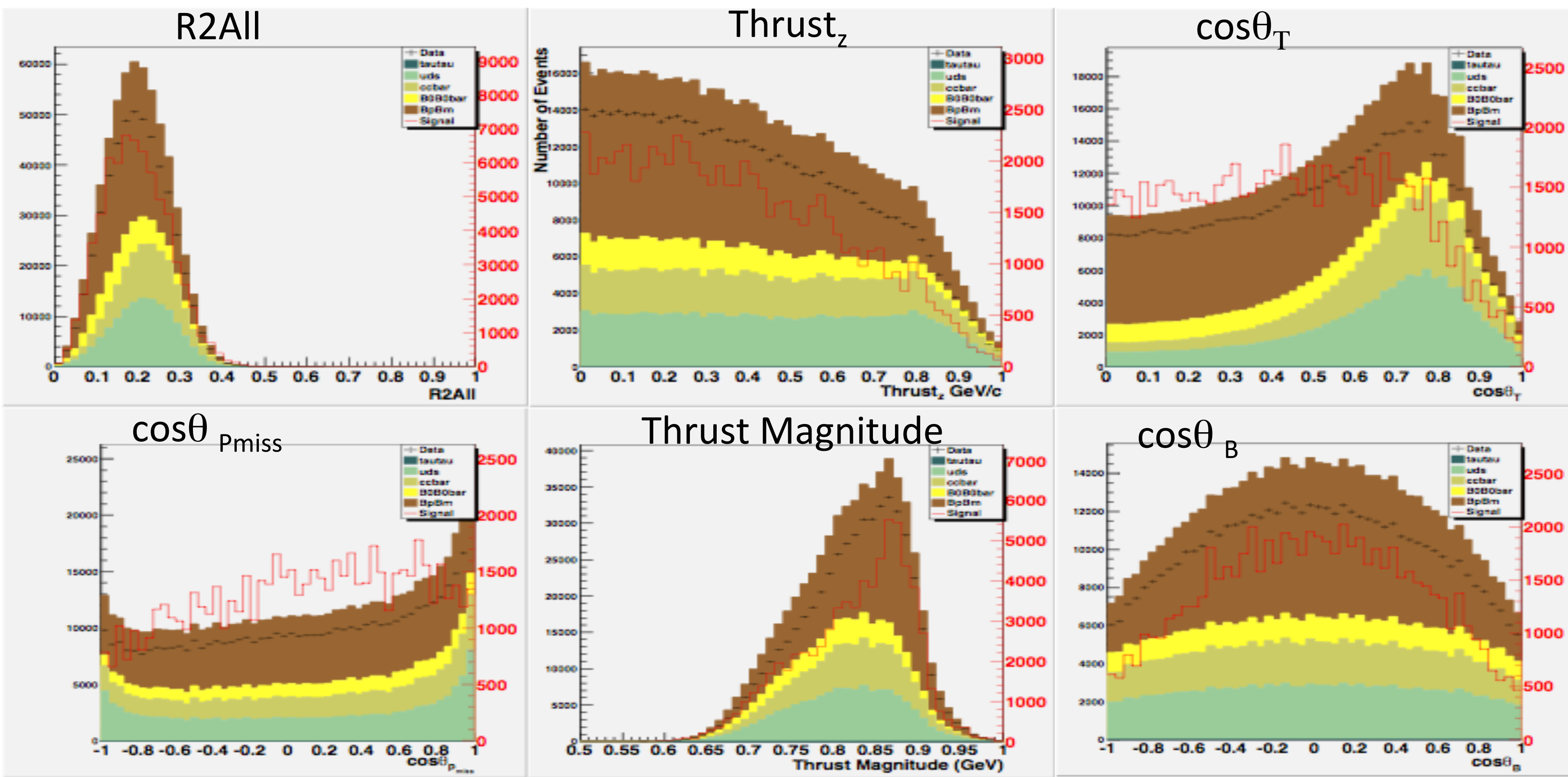
Conclusion

- $B^+ \rightarrow K^+\tau^+\tau^-$: FCNC process, stringent test of the Standard Model.
- Current expected sensitivity of $0(10^{-4})$.
- Analysis to be published in the upcoming year (after finalizing systematics.)

BACK UP SLIDES

Signal Selection: B_{tag} Side

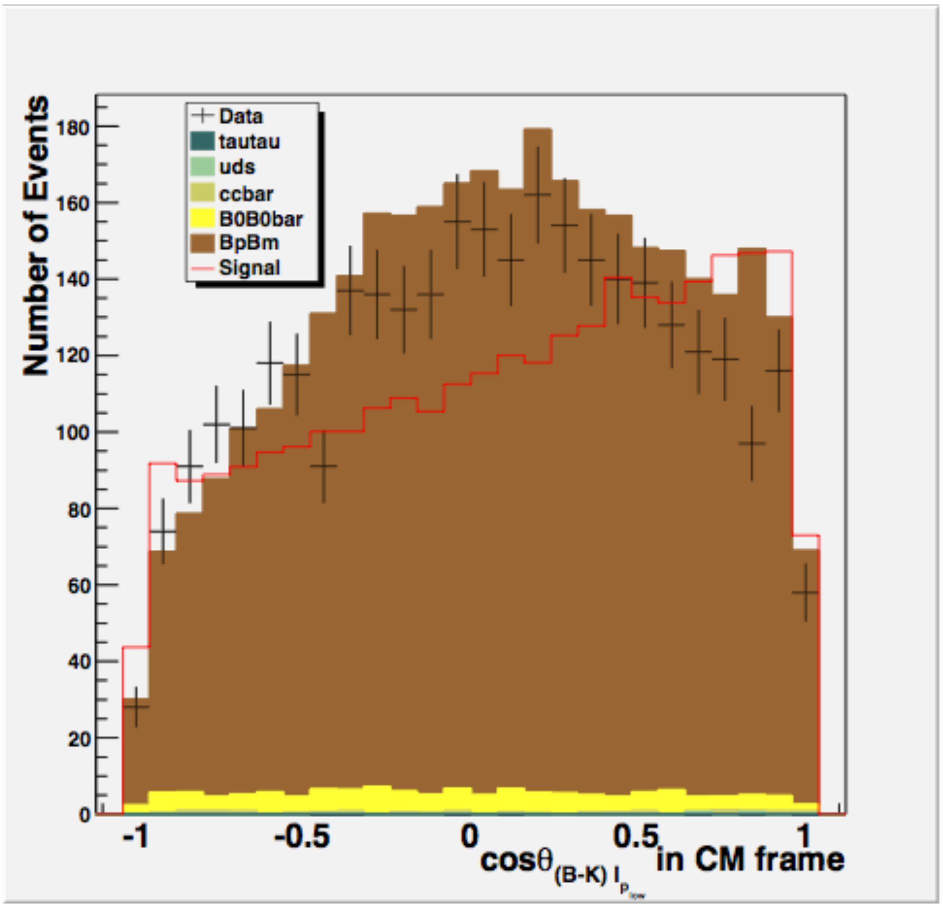
Continuum likelihood suppression using event shape variables .



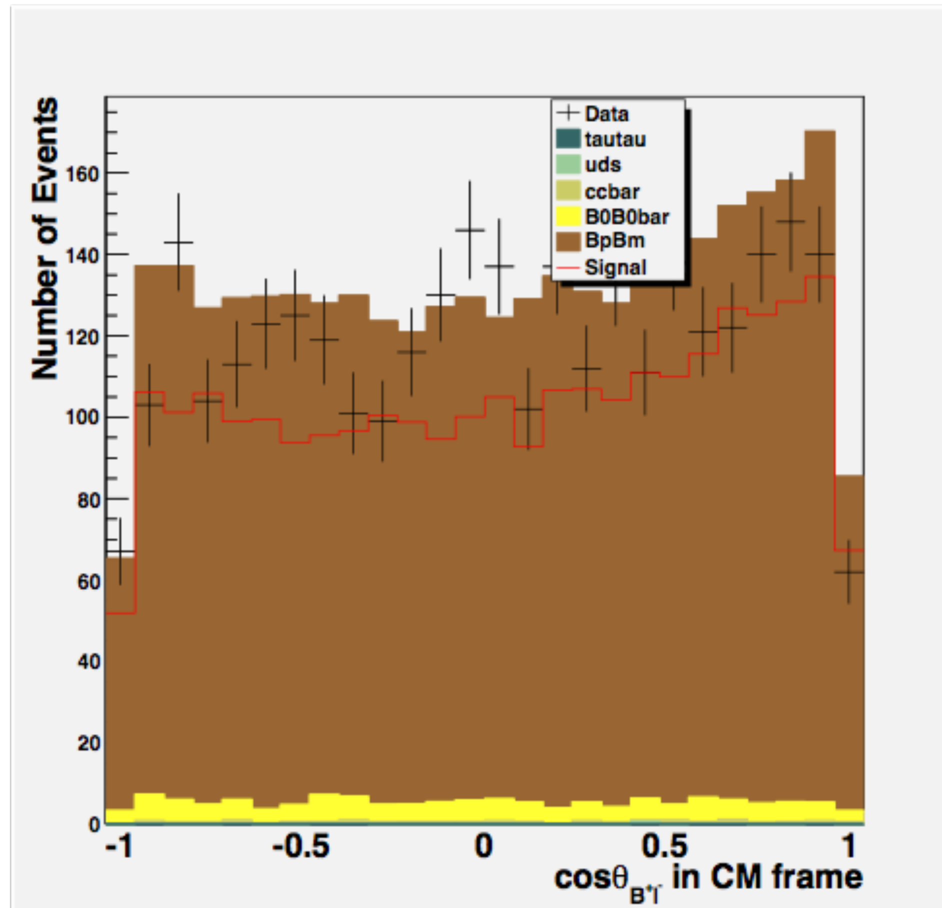
 SIgnal BF of 0.1

Discriminating variables

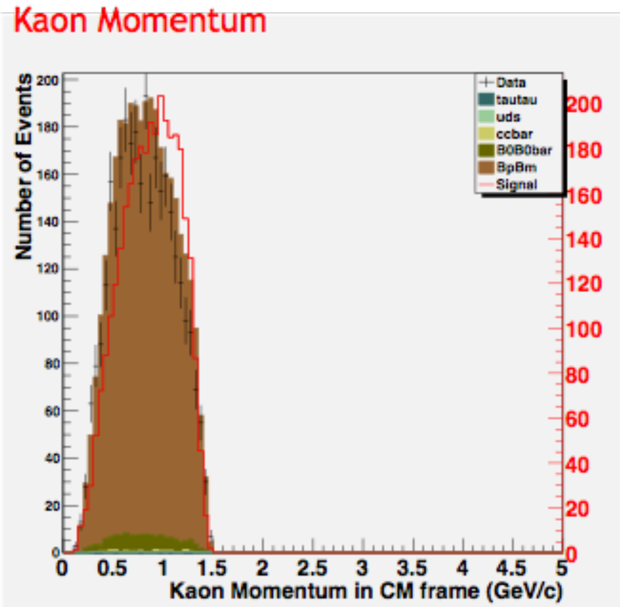
Angle between Vector Recoiling against the Kaon and low momentum lepton in CM frame.

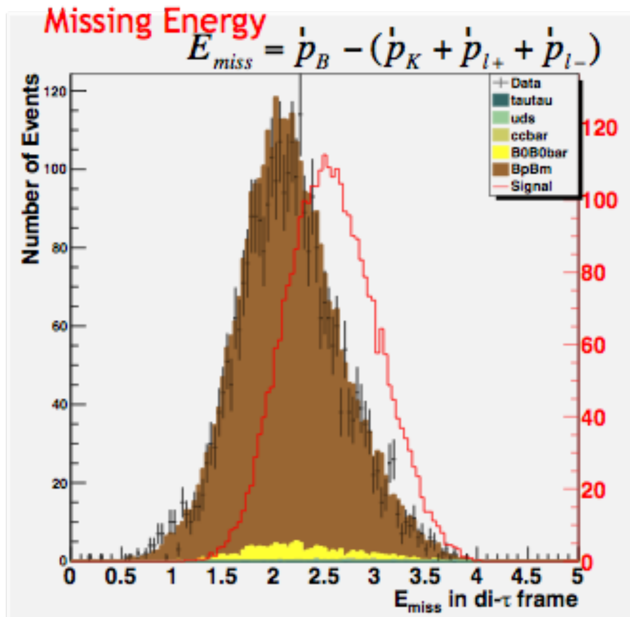


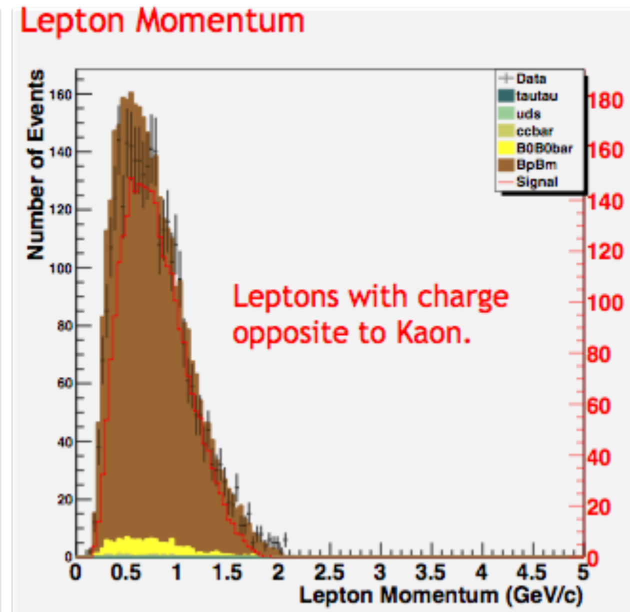
Angle between Bsig and oppositely charged lepton in CM frame.

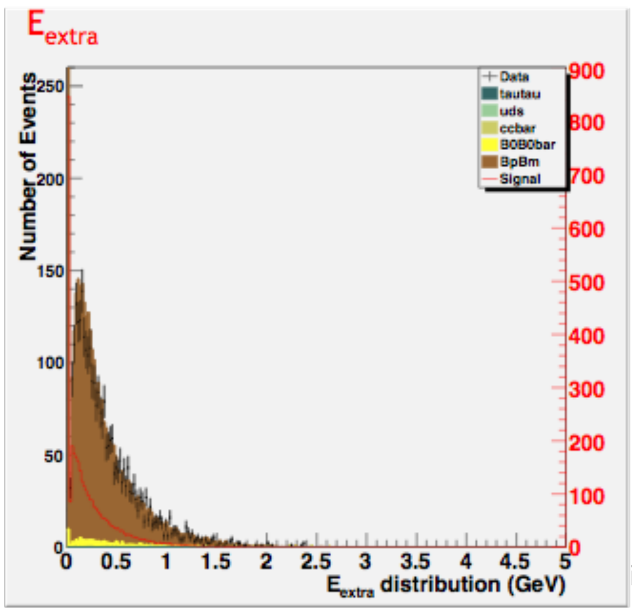


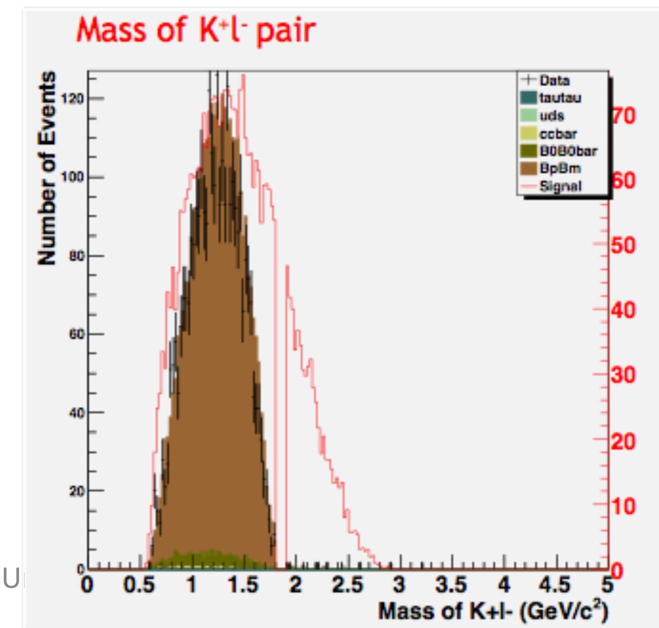
Discriminating variables:











Background Estimate: mES sideband subsitution

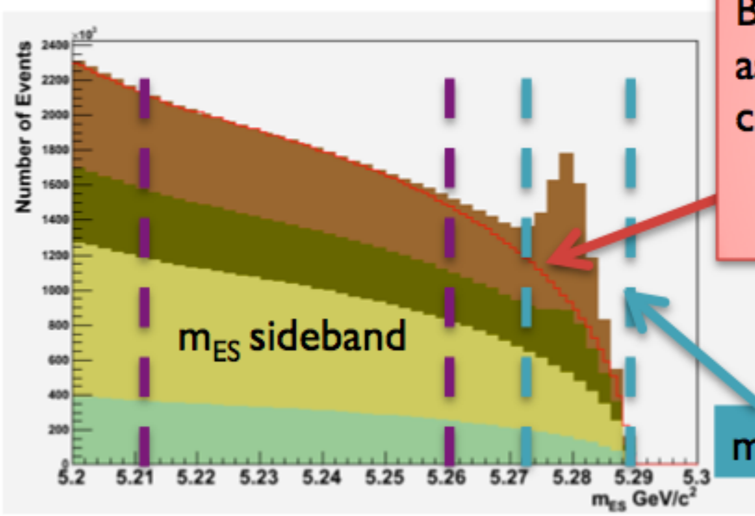
Two types of background:

- Combinatorial background: $c\bar{c}$, $\tau^+\tau^-$, uds, and mis-reconstructed $B\bar{B}$.
- Peaking background: Properly reconstructed BB.

Combinatorial background is determined using data in the sideband m_{ES} region.
Sideband data is scaled by a cumulative Ratio :

R= Number of MC combinatorial events in m_{ES} signal region / Number of events in the m_{ES} sideband region

$$R = \frac{\text{Number of MC combinatorial events in } m_{ES} \text{ signal region}}{\text{Number of events in the } m_{ES} \text{ sideband region}}$$

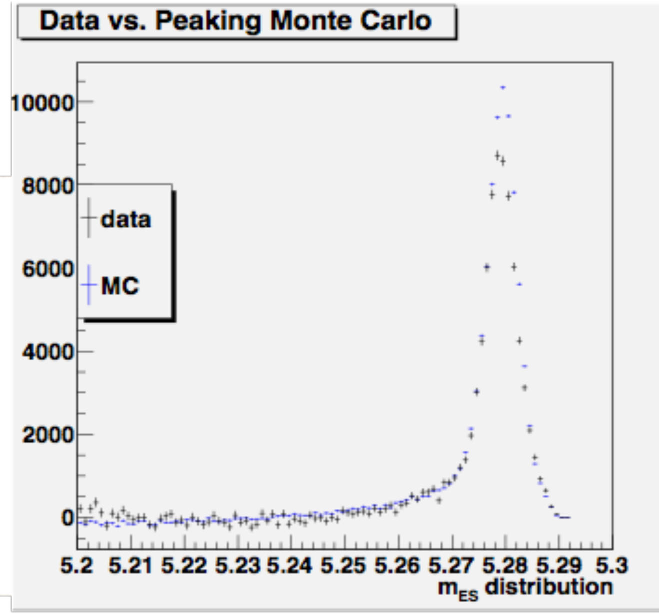


B+B- MC combinatorial component is assumed to be the same as B^0B^0 for charged modes:

$$R_{B^0\bar{B}^0} = \frac{N^{signal}_{B^0\bar{B}^0}}{N^{sideband}_{B^0\bar{B}^0}}$$

m_{ES} signal

m_{ES} sideband substitution:



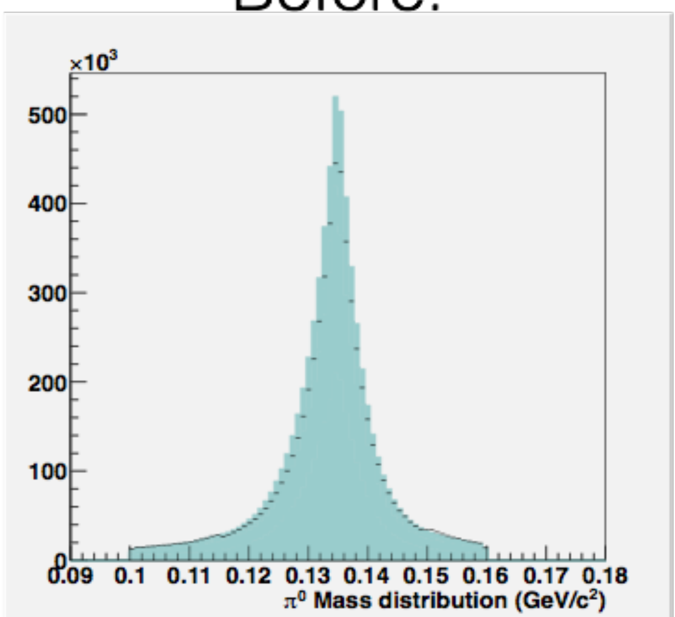
Two types of background:

- Combinatorial background: cc, $\tau^+\tau^-$,uds, and mis-reconstructed $B\bar{B}$.
- Peaking background: Properly reconstructed BB.

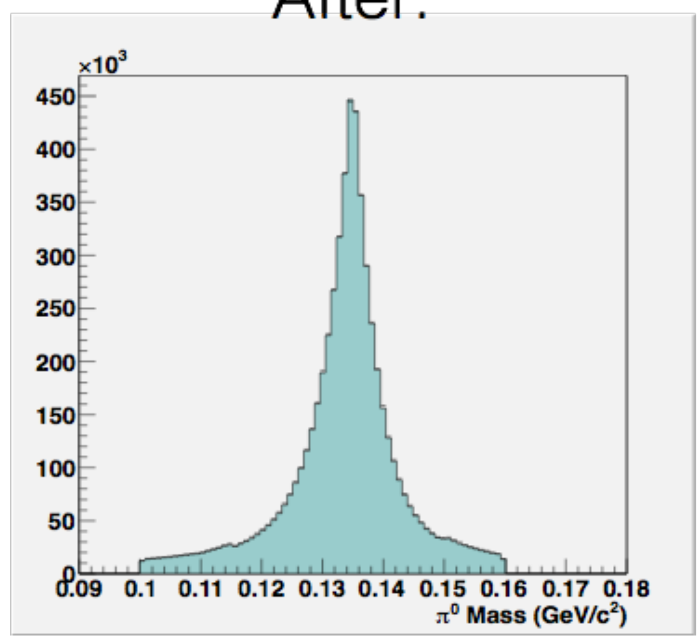
Peaking component is estimated using B^+B^- or B^0B^0 MC, depending on the charge of the signal mode.
Peaking component of B^+B^- or B^0B^0 is isolated and scaled by a correction factor, CF, to match the peaking data.

$$CF = \frac{N_{data}}{N_{B\bar{B}}}$$

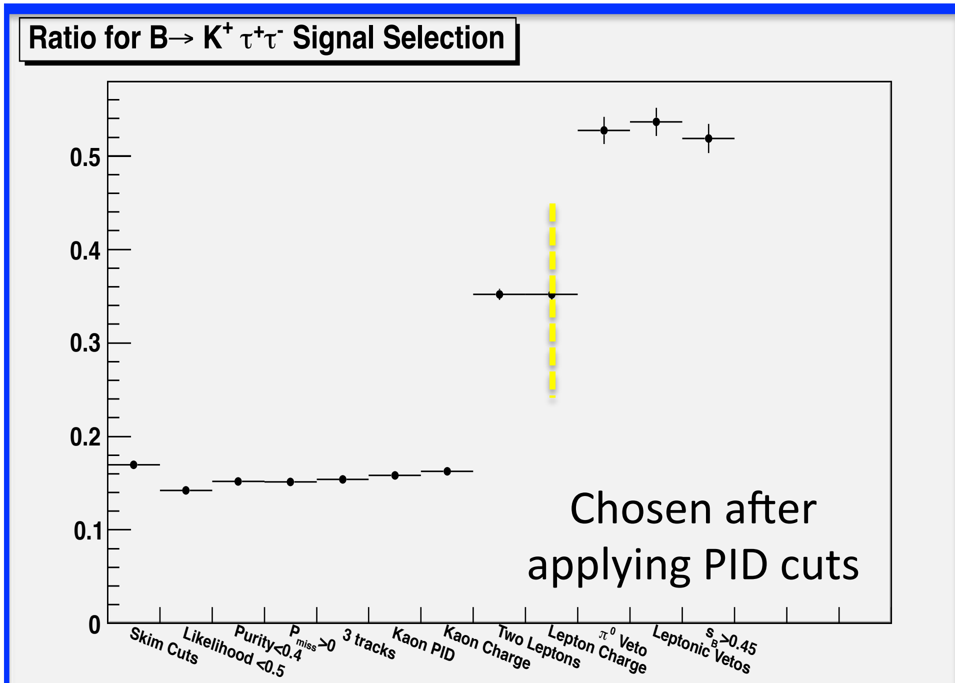
Before:

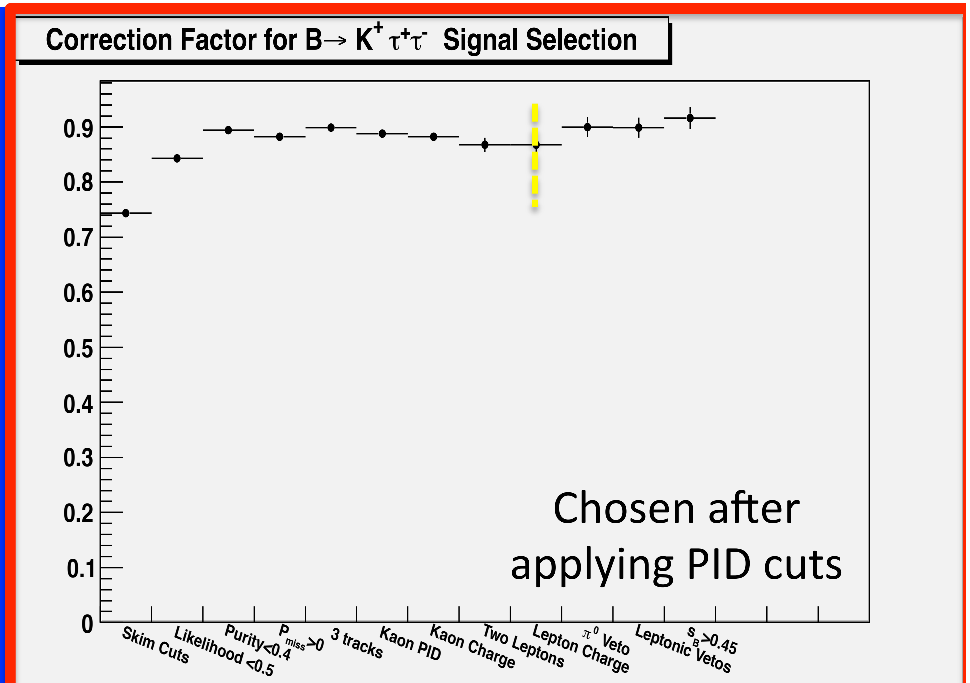


After:



Ratio and Correction Factor



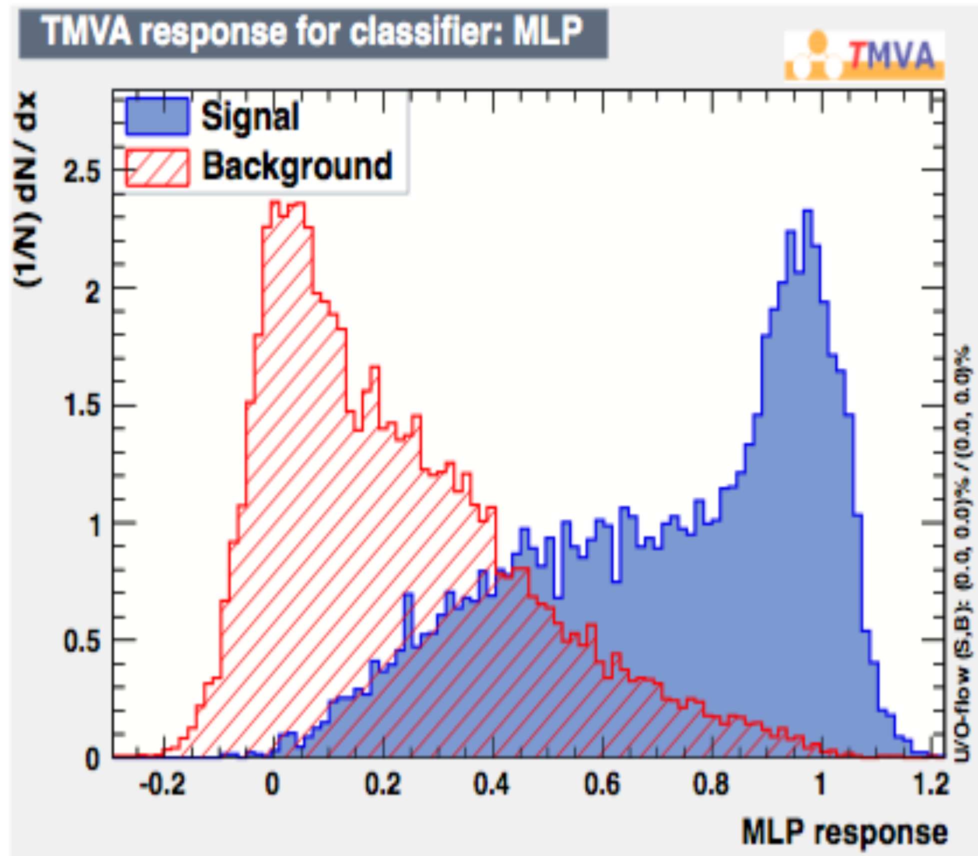


Ratio used to scale sideband data and estimate non-peaking background.
0.352 +/-0.006

Correction factor used to correct differences between Monte Carlo peaking background and peaking data.
0.868 +/-0.012

TMVA: Neural Network

- Use a Neural Network to separate between signal and background.
- 9 Input variables: 5 calorimeter and 4 angular.
- Both signal and background samples are randomly split in half for training and testing.



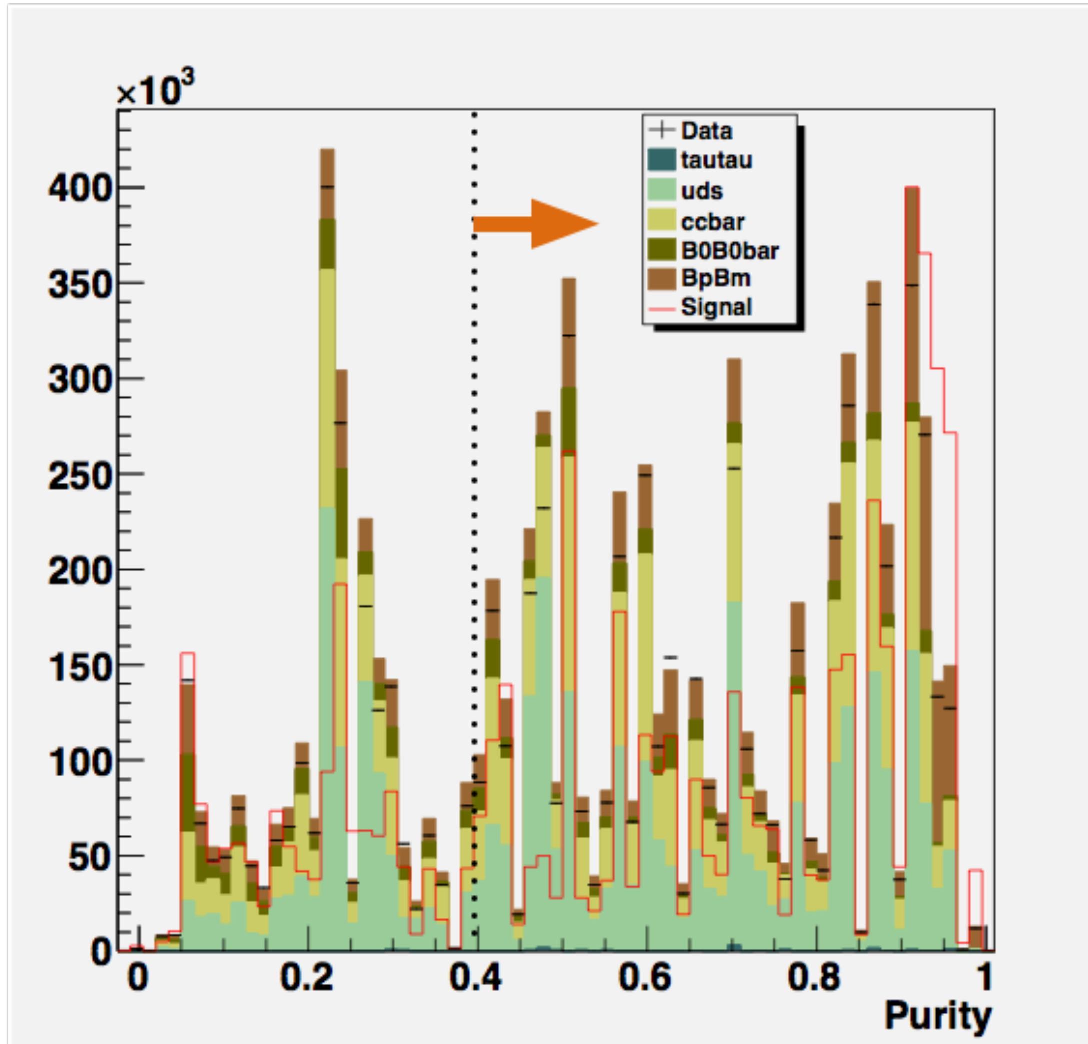
Signal Selection: B_{tag} side

<u>Purity:</u>

Fraction of properly reconstructed Btag's within a decay mode.

For each decay mode, the daughter *tracks* of the Btag are truth-matched:

- The number of pions, kaons, and Ks0 is determined for each mode.
- This number is compared with the actual number of each particle type originating from the Btag according to MC truth.

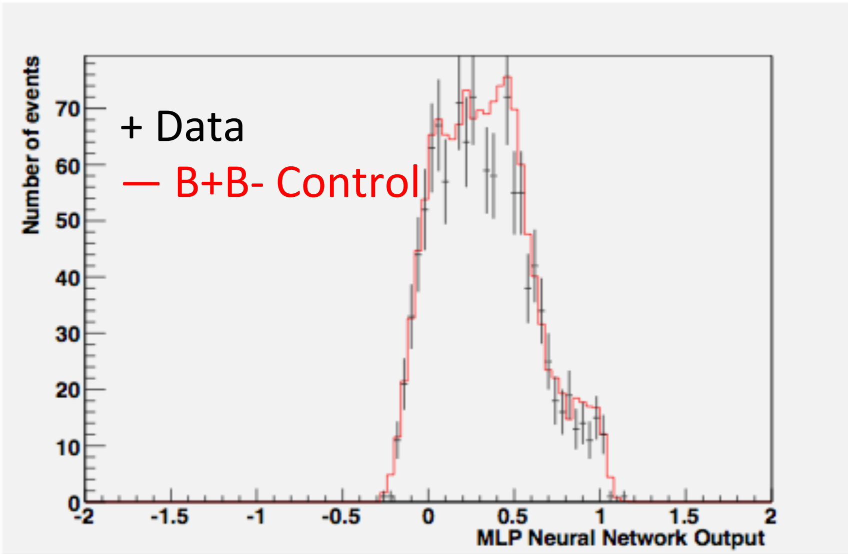


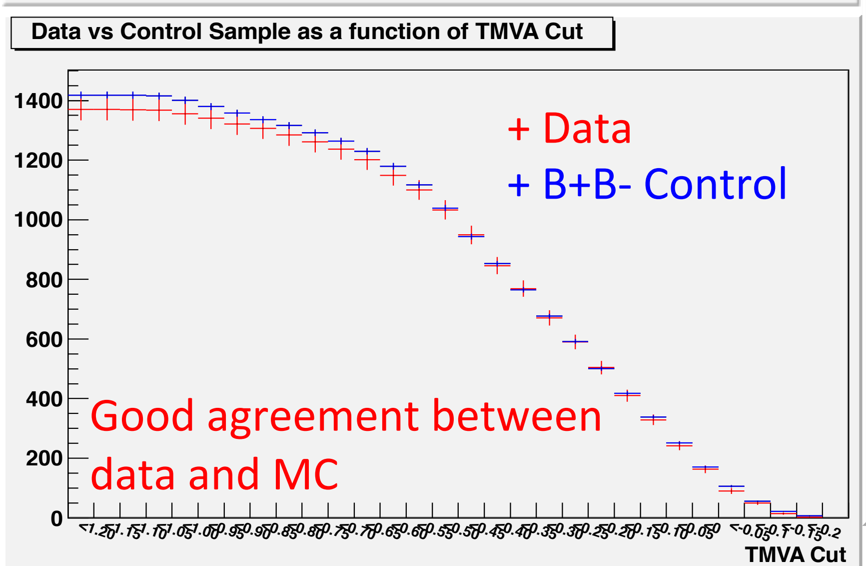
5

Generic Signal BF 10^(-1)

Control Study:

$B^+ \rightarrow \bar{D}^0 l^+ \nu$ $\bar{D}^0 \rightarrow K^+ l^- \nu$





Apply TMVA on control and data sample, and then reverse TMVA Cut in increments of 0.05.