Search for Fully Leptonic B Decays at Babar

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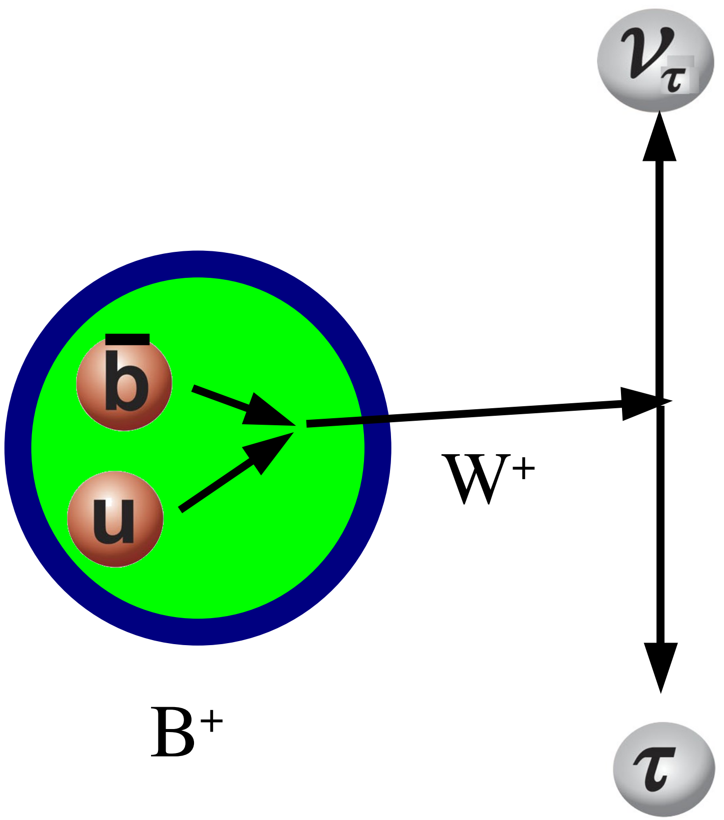
Outline

- Motivation
- Standard Model Predictions & New physics
- Experimental Procedure
- Systematics
- Numerical Results
- Branching fraction and upper limit
- Future Outlook

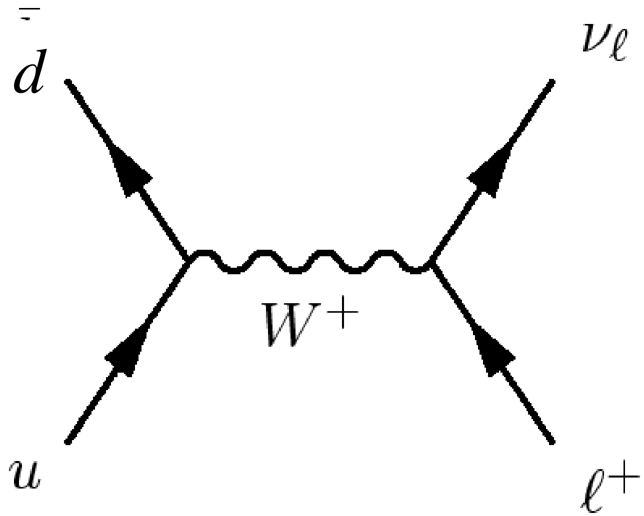
What are we looking for & why?

$B^+ \rightarrow \ell^+ \nu_\ell (\ell = e, \mu, \tau)$



- Rare Decays
- Test of Standard Model
- Measure wave function overlap of quarks
- Weak Interaction Probe
- New physics could contribute as well

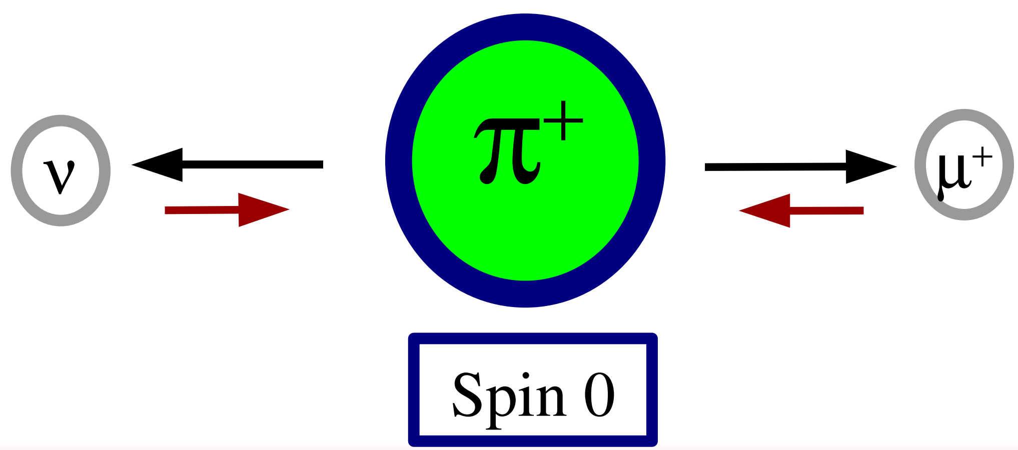
Already know a familiar decay



$$\mathcal{B}(\pi^+ \to \ell^+ \nu_\ell) = \frac{G_F^2 m_\pi}{8\pi} m_\ell^2 \left(1 - \frac{m_\ell^2}{m_\pi^2}\right)^2 f_\pi^2 \tau_\pi$$

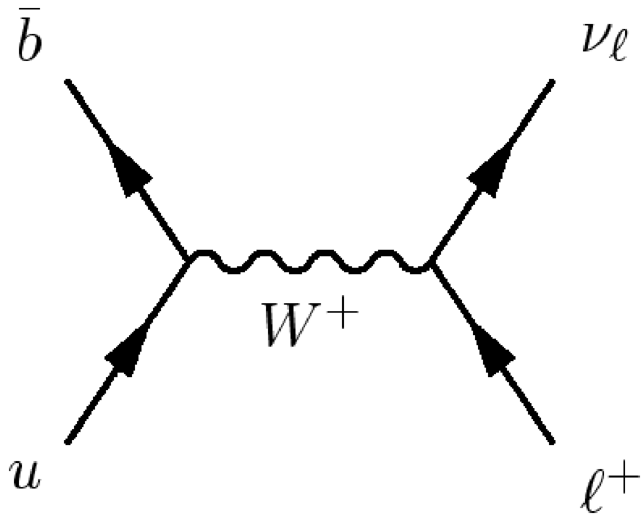
$$\text{Helicity} = \vec{p} \cdot \vec{S}$$

Weak force couples to negative helicity ν



Must be negative helicity, easier with more mass

Analogous to our target



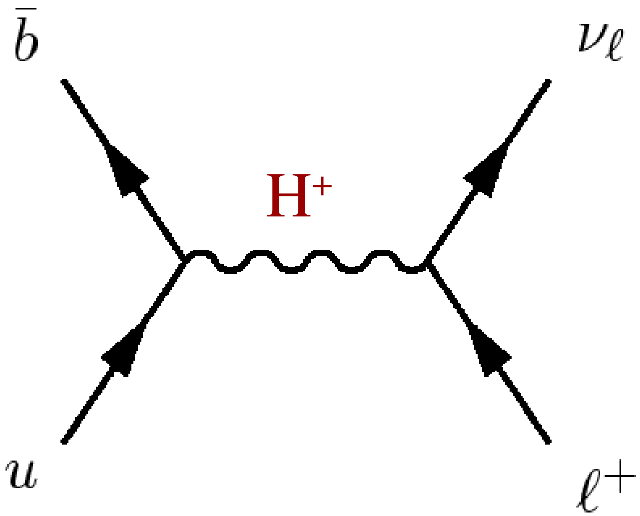
$$\mathcal{B}(B^+\to\ell^+\nu_\ell)=\frac{G_F^2\, m_B}{8\pi}\, m_\ell^2\left(1-\frac{m_\ell^2}{m_B^2}\right)^2 f_B^2\, |V_{ub}|^2\, \tau_B$$

Calculate from branching fraction (f_B^2)

- Helicity suppresses the BFs of the light leptons
- SM Prediction
  - $|V_{ub}|$ = $(4.39 \pm 0.54)\times 10^{-3}$ (PRL **96**:22180)
  - f_B = 0.189 ± 0.027 GeV (CKM Fitter) – Test lattice QCD

	$B^+\to e^+\nu_e$	$B^+\to\mu^+\nu_\mu$	$B^+\to\tau^+\nu_\tau$
SM Prediction	$(1.7\pm0.4)\times10^{-11}$	$(7.1\pm1.6)\times10^{-7}$	$(1.6\pm0.4)\times10^{-4}$
Experimental Values	$<9.8\times10^{-7}$	$<1.7\times10^{-6}$	$(1.4\pm0.4)\times10^{-4}$

Potential New Physics



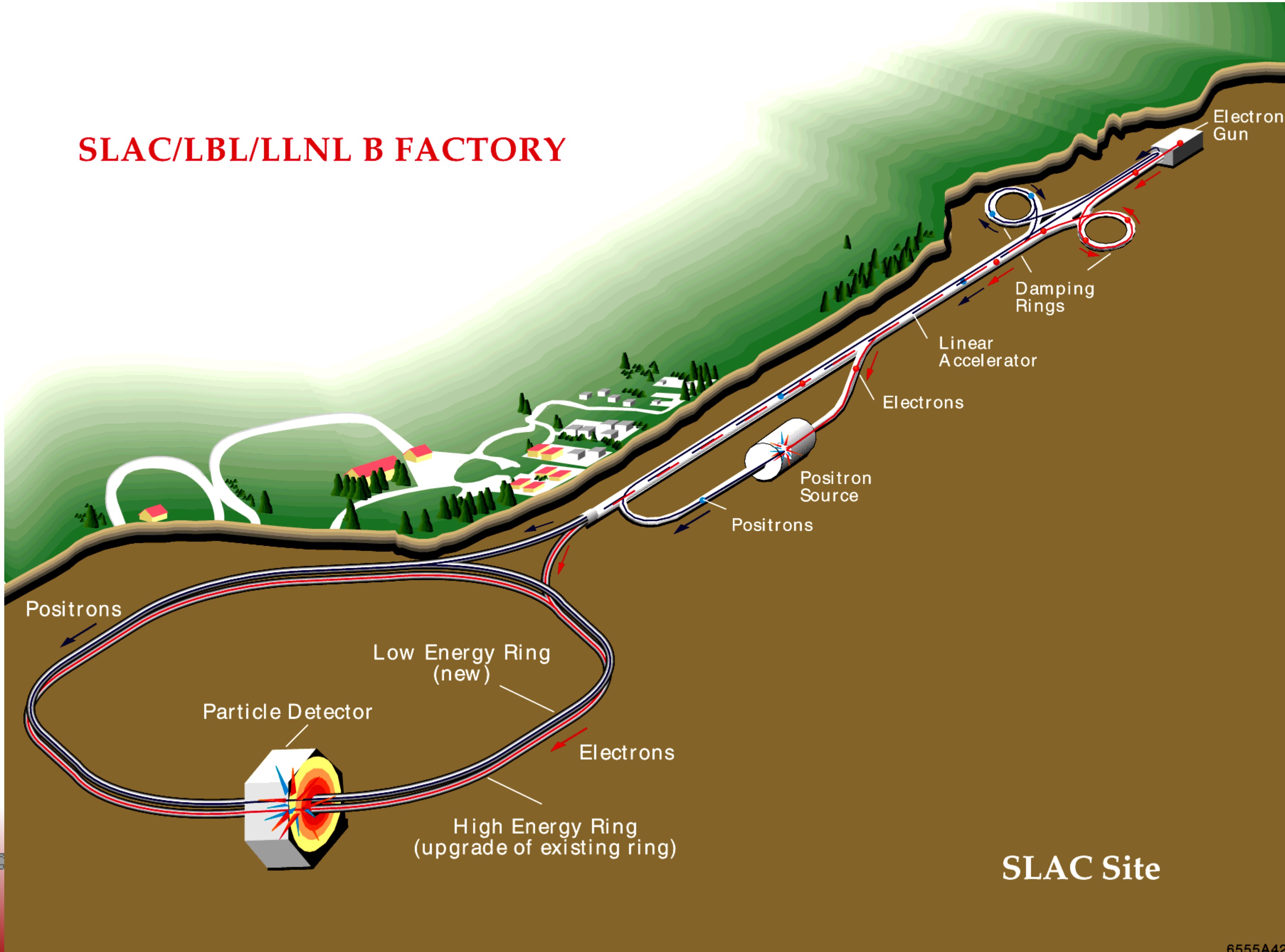
- Charged Higgs boson, from the Two-Higgs Doublet Model (2HDM) can modify BF

$$\mathcal{B}(B^+ \to \ell^+ \nu_\ell) = \mathcal{B}(B^+ \to \ell^+ \nu_\ell)_{SM} \times \left| 1 - \tan^2\beta \frac{m_{B^+}^2}{m_{H^+}^2} \right|^2$$

The ratio of VEVs for the u and d type Higgs bosons ($\tan^2\beta$)

Charged Higgs Mass ($m_{H^+}^2$)

Stanford Linear Accelerator Center

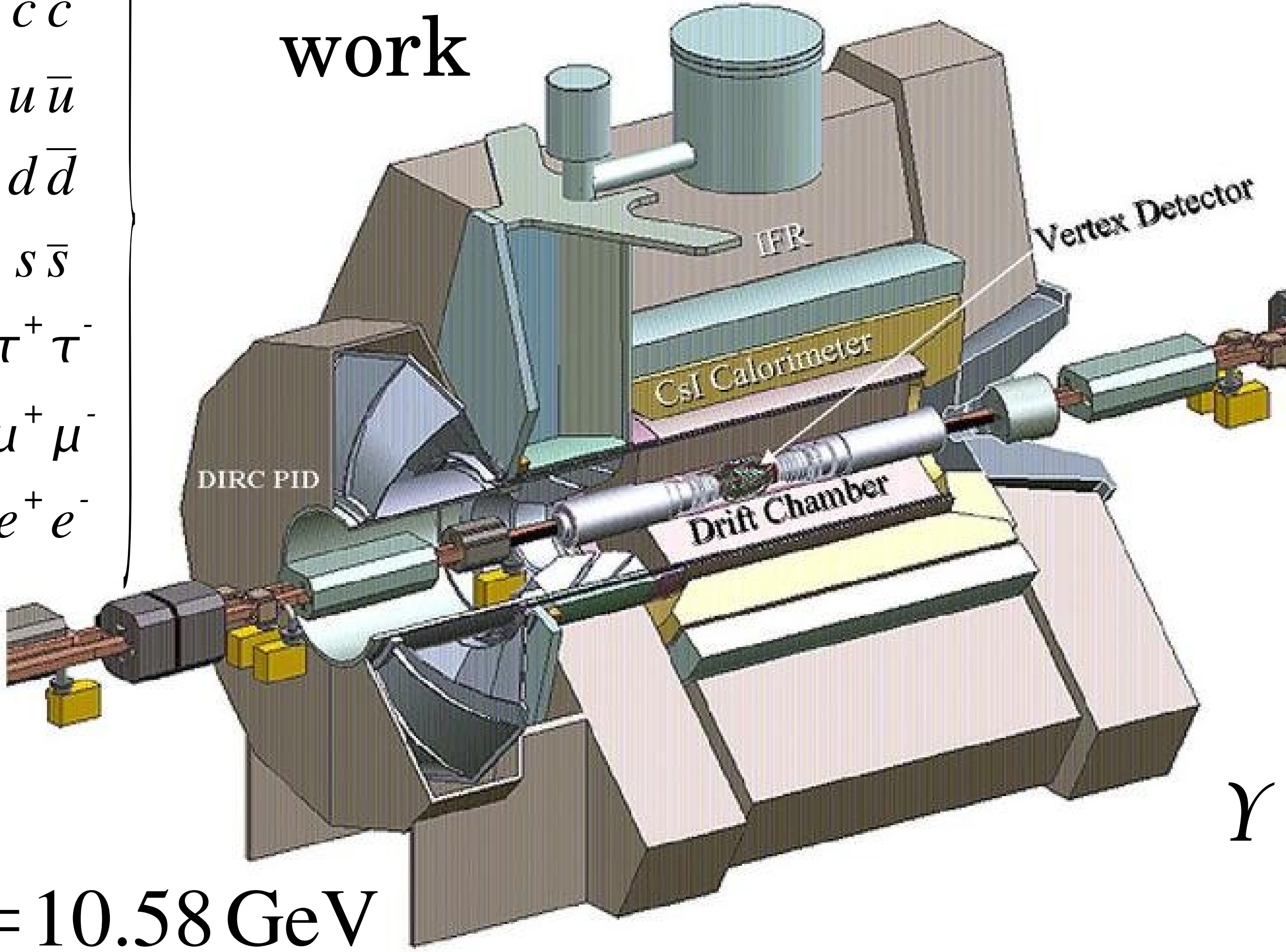


BaBar

$$e^+e^- \to \begin{Bmatrix} \Upsilon(4S) \\ c\bar{c} \\ u\bar{u} \\ d\bar{d} \\ s\bar{s} \\ \tau^+\tau^- \\ \mu^+\mu^- \\ e^+e^- \end{Bmatrix}$$

Use 459×10^6 $\Upsilon(4S)$ decays in this work

e^-



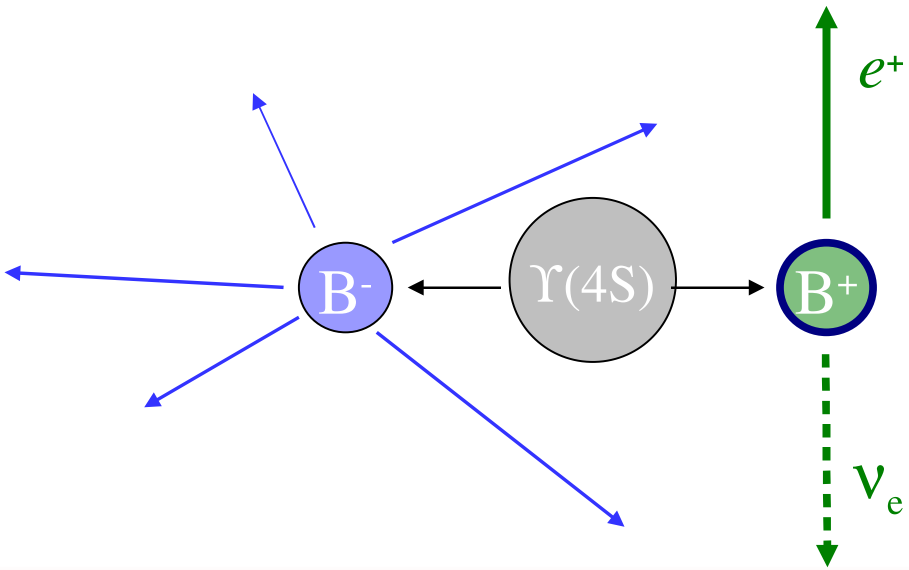
e^+

$$m_{\Upsilon(4S)} = 10.58\,\text{GeV}$$

$$\Upsilon(4S) \to \begin{Bmatrix} B^+B^- \\ B^0\overline{B^0} \end{Bmatrix}$$

Reasons for Tag

- Problem: Neutrinos undetectable
- Solution: Reduce the number of unknowns by reconstructing one "tag" B in a well understood set of decay channels



Semileptonic Tag Reconstruction

$$Tag\ B^- \to D^0 \ell^- \overline{\nu}_\ell X\ (\ell = e\ or\ \mu)$$

$$D^0 \to K^- \pi^+$$

$$D^0 \to K^- \pi^+ \pi^- \pi^+$$

$$D^0 \to K^- \pi^+ \pi^0$$

$$D^0 \to K^0_S \pi^- \pi^+ (K^0_S \to \pi^+ \pi^-)$$

$$\mathcal{B}(B^- \to D^0 \ell^- \overline{\nu}_\ell X) \approx 20\,\%$$

First search for
$B \to \mu\nu$, $B \to e\nu$
using this tag

- Pioneered by Babar
- Reconstruct tag side assuming ν is only missing particle
- X = nothing, γ or π^0 from higher mass charm state
- This yields lower purity
- Higher efficiency
  - ~1% vs. ~0.2%

Complementary Methods

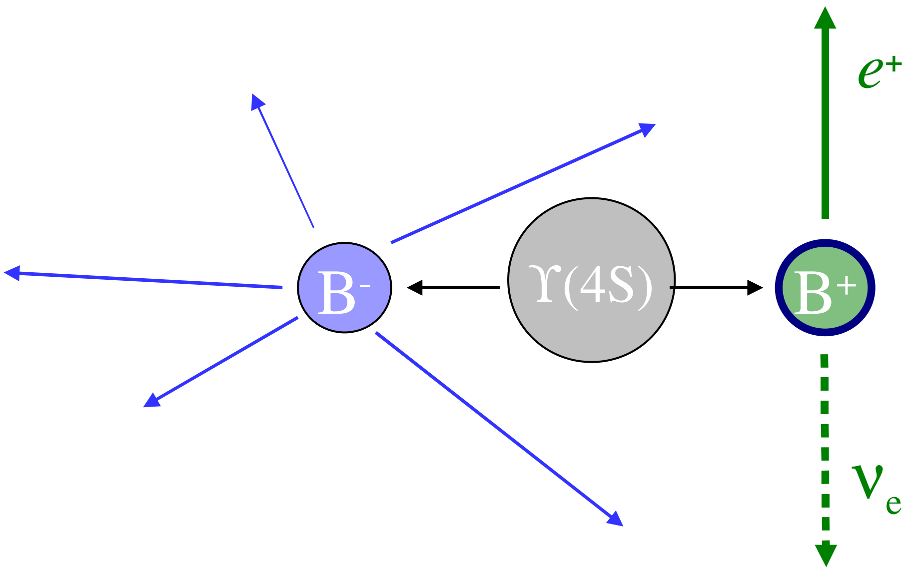
- No tags (Inclusive), not applicable to $B \to \tau\nu$
  - Find highest momentum lepton, make a B with the rest of the event. High background, best limits
- Hadronic tags
  - Reconstruct Tag B using fully hadronic modes
  - Fully reconstruct tag B
  - Branching Fraction ≈ 10%
- Double statistical power in combination

Measurements thus far

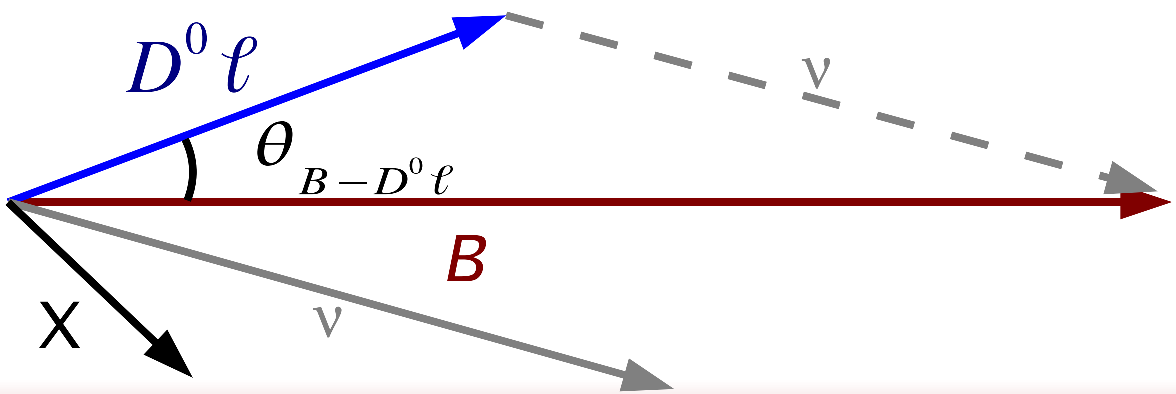
PDG Values [1]		$< 9.8 \times 10^{-7}$	$< 1.7 \times 10^{-6}$	$(1.4 \pm 0.4) \times 10^{-4}$
Inclusive Meas.	*BABAR* [9]	-	$< 1.3 \times 10^{-6}$	N/A
	Belle [10]	$< 9.8 \times 10^{-7}$	$< 1.7 \times 10^{-6}$	N/A
Hadronic	*BABAR*	$< 5.2 \times 10^{-6}$ [11]	$< 5.6 \times 10^{-6}$ [11]	$(1.8^{+1.0}_{-0.9}) \times 10^{-4}$[12]
Tag Meas.	Belle	-	-	$(1.8 \pm 0.7) \times 10^{-4}$ [13]
Semilep.	*BABAR*	This Talk	This Talk	This Talk
Tag Meas.	Belle [14]	-	-	$(1.65^{+0.38+0.35}_{-0.37-0.37}) \times 10^{-4}$

[9] arXiv:0807.4187 [10] *Phys. Lett.* **B647**:67-73 [11] arXiv:0801.0697
[12] *Phys. Rev.* **D77**:011107 [13] *Phys Rev. Lett.* **97**:251802 [14] arXiv:0809.3834

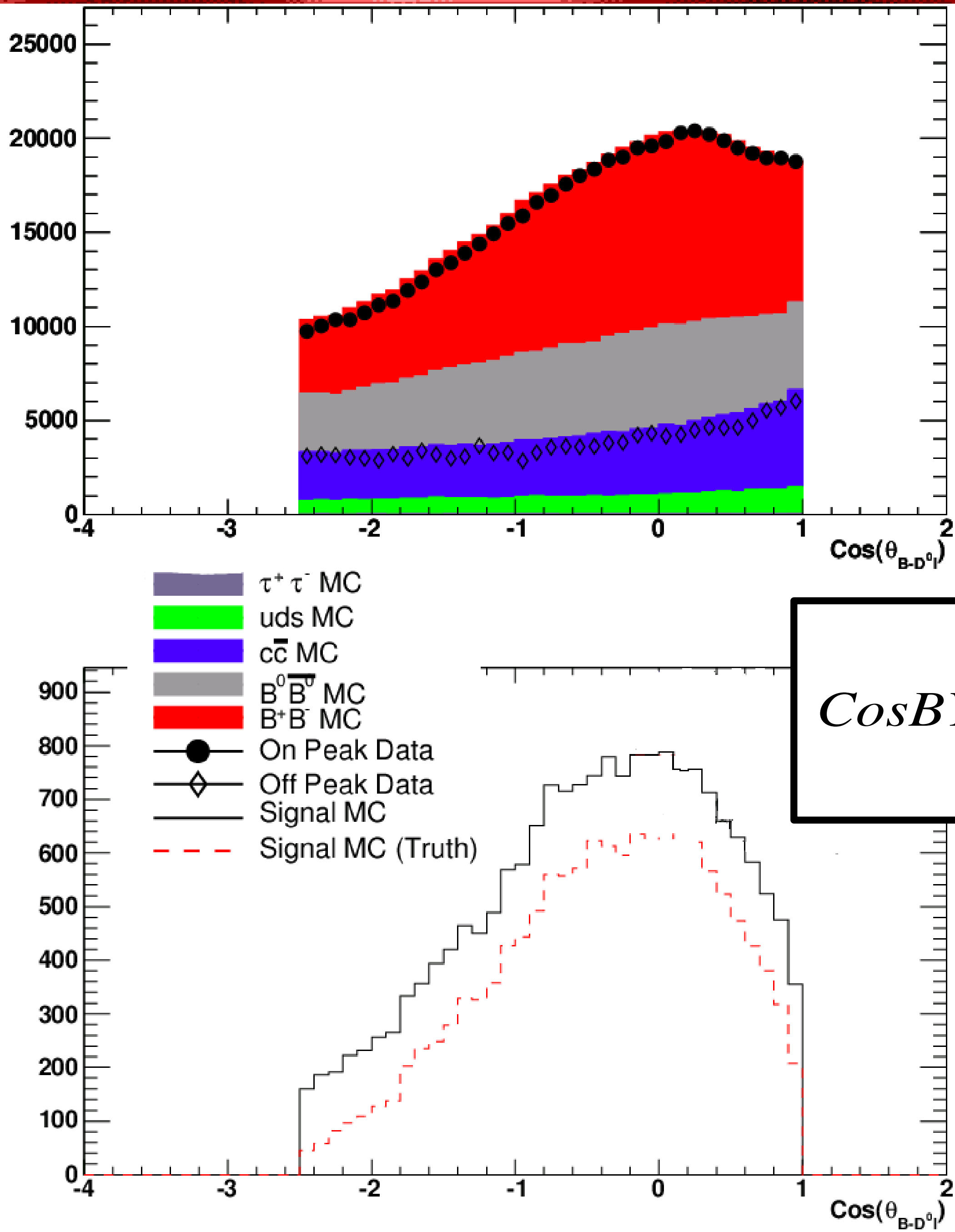
Tag B Kinematics: CosBY



- Tag ν prevents meas. CM frame
- Use beam info to calculate angle between B and $D^0 l$



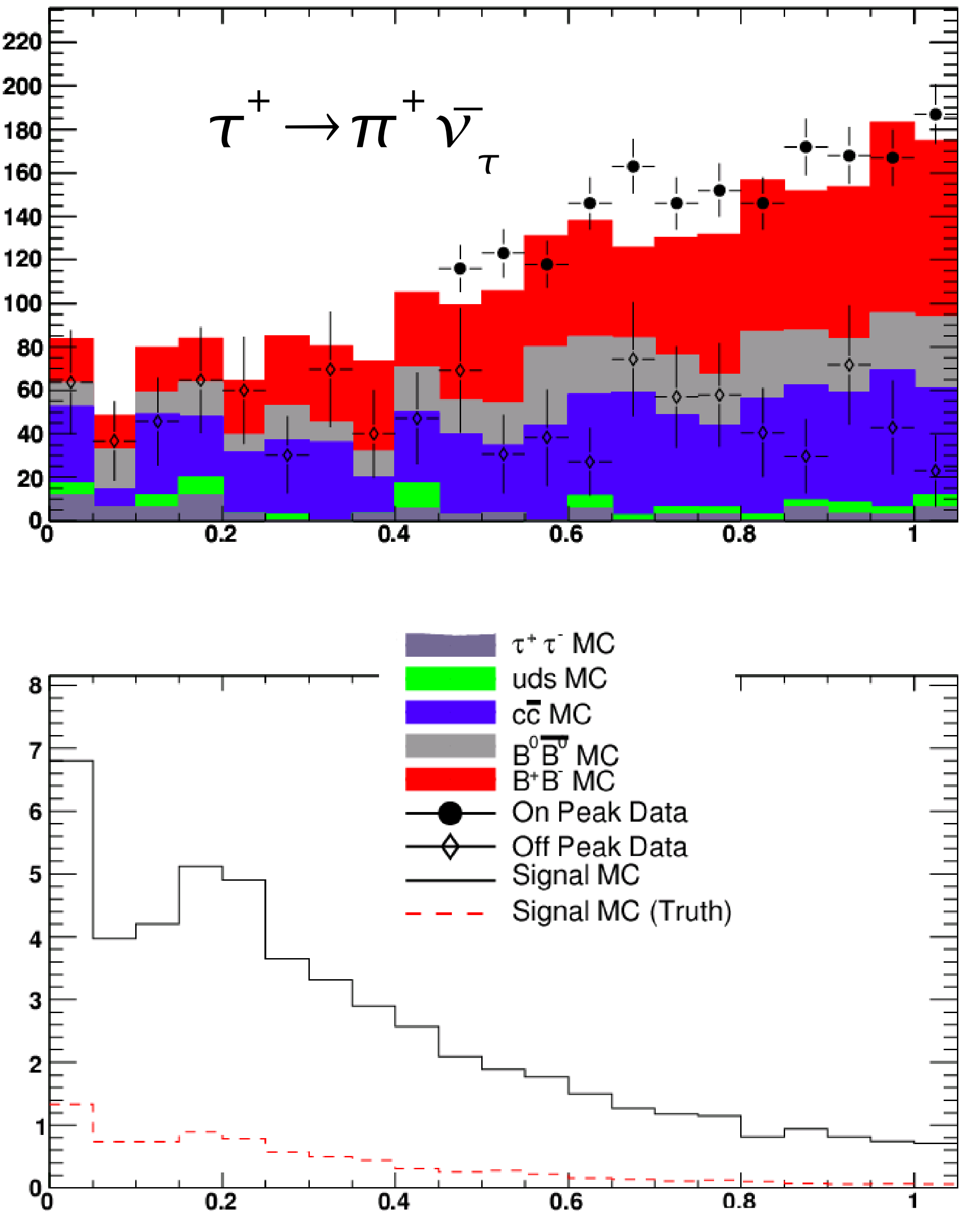
Tag B Kinematics: CosBY



- Presence of X causes values < -1

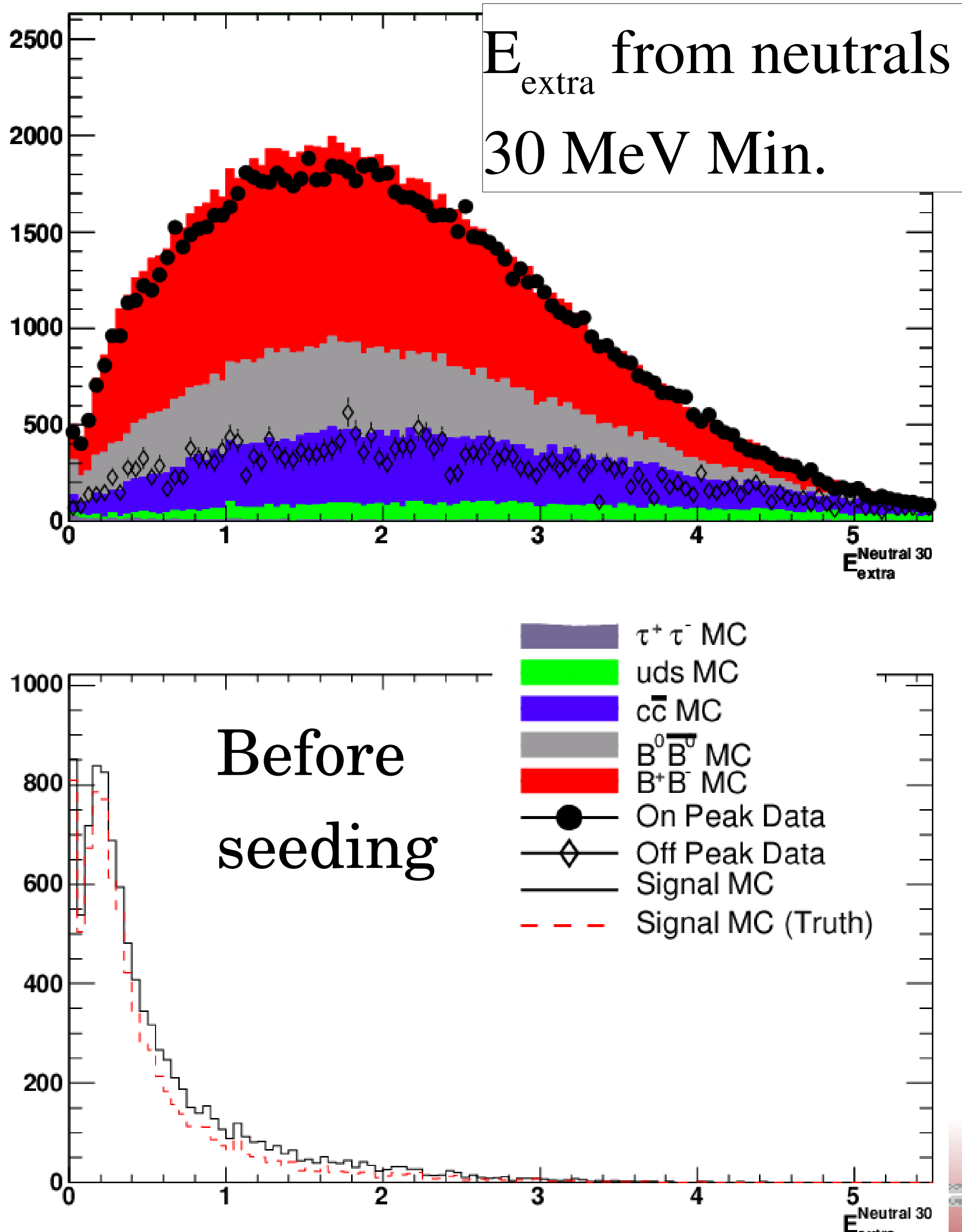
$$CosBY \equiv \cos(\theta_{B-D^0\ell}) = \frac{2E_B E_{D^0\ell} - m_B^2 - m_{D^0\ell}^2}{2|\vec{p}_B||\vec{p}_{D^0\ell}|}$$

Tag B Kinematics: E_{extra}



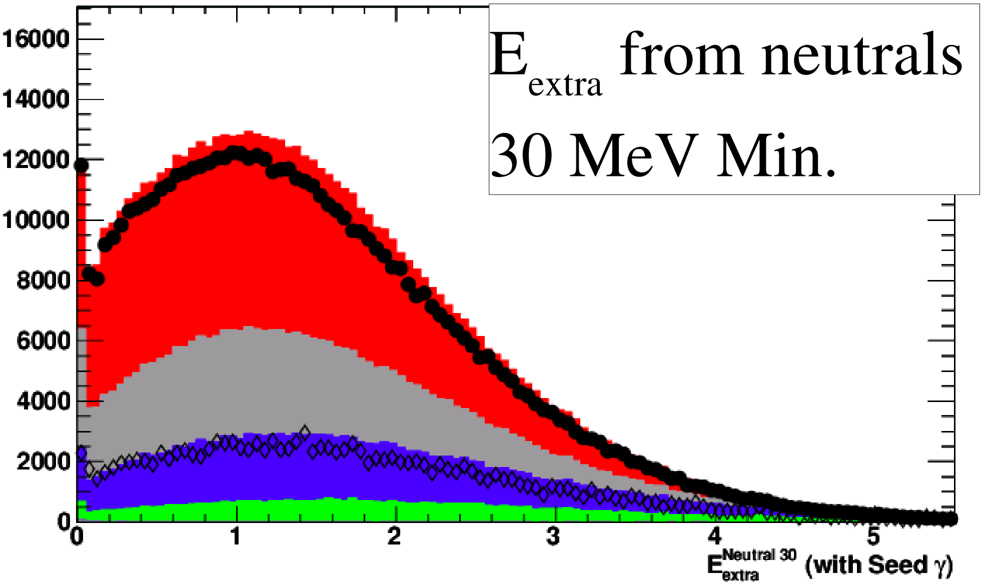
- E_{extra} = all energy after both B's are reconstructed.
  - Should be zero for an ideal, fully reconstructed, event.
- "Blind" signal region until analysis selection is complete

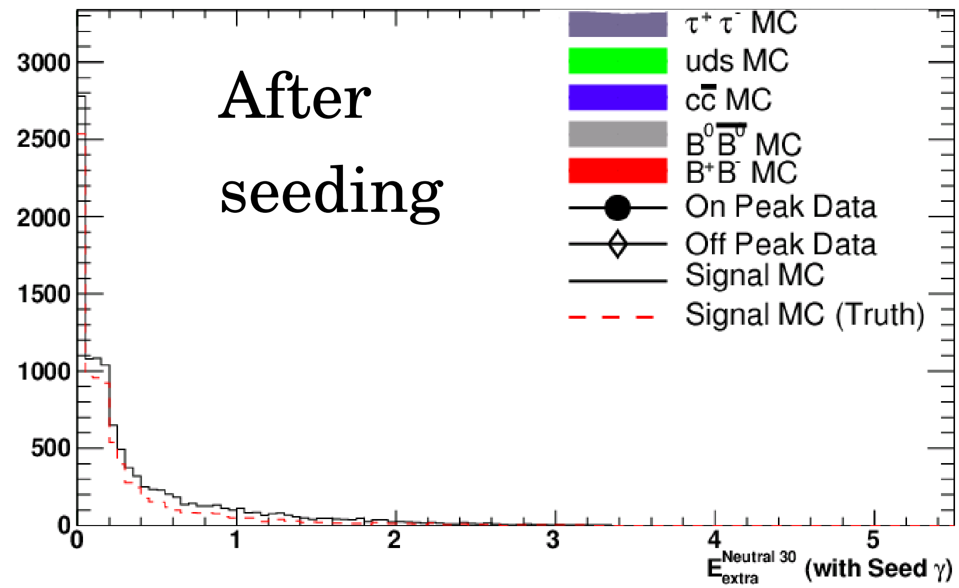
Seeding Method



- Remove a “seed” γ from other variables and combine with the tag D^0
  - $E_\gamma^* < 300$ MeV
  - Recalculate relevant variables.
  - If the new CosBY is closer to 1, keep new configuration.

Seeding Comparison





- Remove a "seed" γ from other variables and combine with the tag D^0
  - $E_\gamma^* < 300$ MeV
  - Recalculate relevant variables.
  - If the new CosBY is closer to 1, keep new configuration.

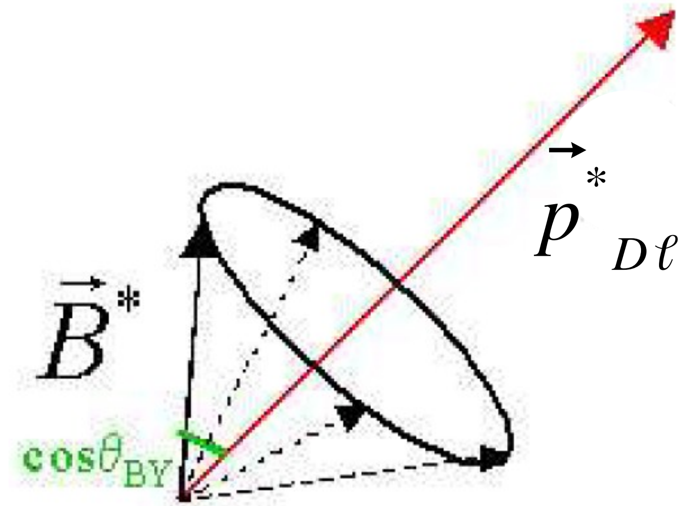
Signal Side Reconstruction

$B^+ \to \tau^+ \nu$
- $\to e^+ \nu \bar{\nu}$
- $\to \mu^+ \nu \bar{\nu}$
- $\to \pi^+ \nu$
- $\to \rho^+ \nu$
  - $\to \pi^+ \pi^0$
- $\to a_1^+ \nu$
  - $\to \pi^+ \pi^- \pi^+$

$B^+ \to \mu^+ \nu$

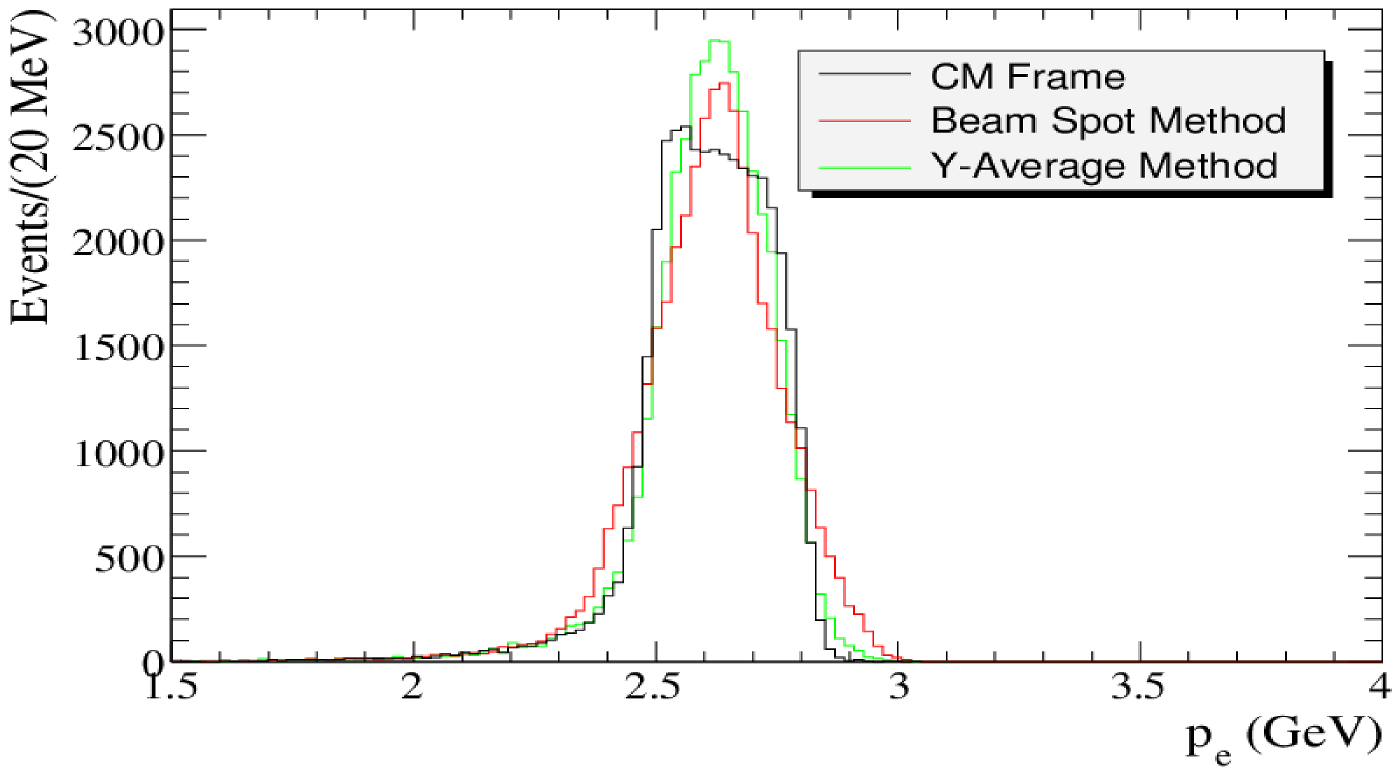
$B^+ \to e^+ \nu$

- Calculate $|\vec{p}_\ell|$ at several points around BY cone
- $|\vec{p}\,'_\ell|$ = average of all results



- Use $|\vec{p}\,'_\ell|$ for separation
  - Two body $\Rightarrow |\vec{p}\,'_\ell| \approx \frac{m_B}{2} = 2.64\,\text{GeV}$
  - $|\vec{p}\,'_e| \leqslant 2.25\,\text{GeV} \Rightarrow \tau^+ \to e^+ \nu \bar{\nu}$
  - $|\vec{p}\,'_\mu| \leqslant 2.30\,\text{GeV} \Rightarrow \tau^+ \to \mu^+ \nu \bar{\nu}$

Example: $B^+ \rightarrow e^+ \nu_e$

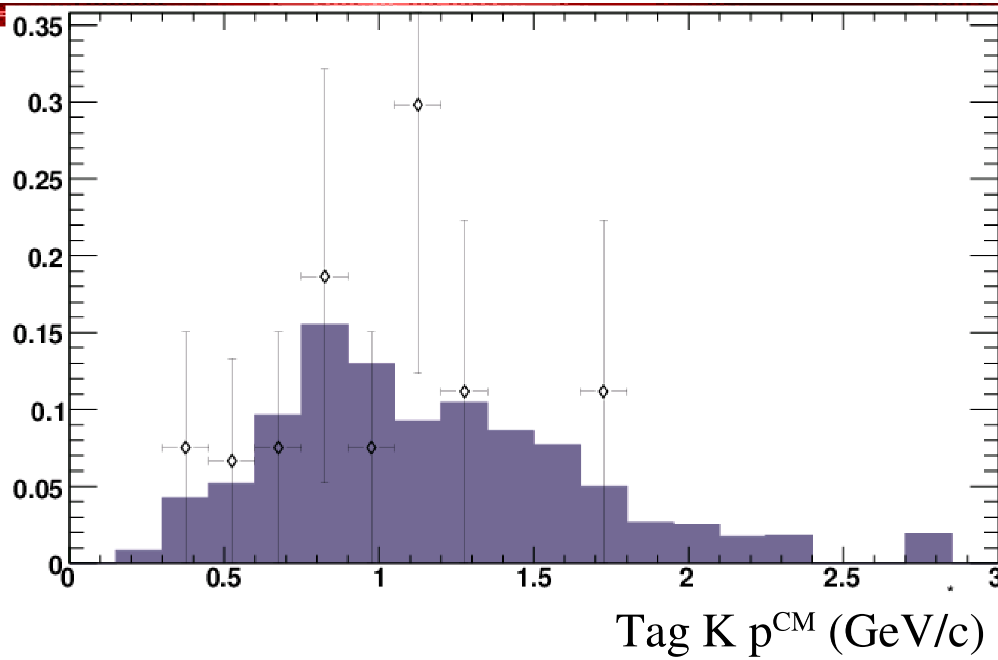


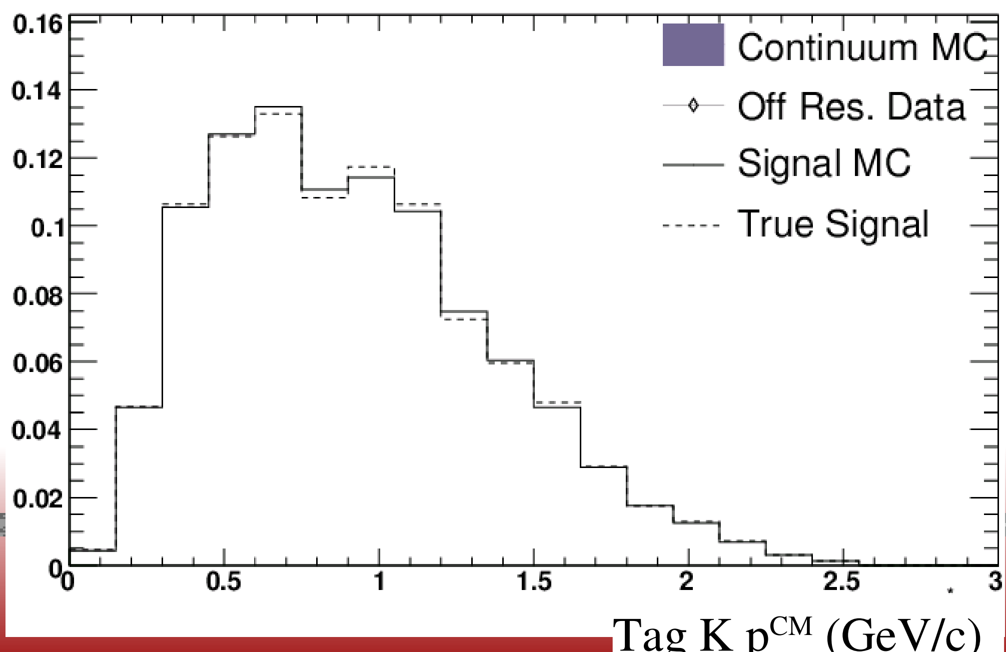
- Tau decays in flight, daughters smear spectrum

Signal Variables

- Cannot reconstruct B mass, so we use...
  - E_{extra} = all energy after both B's are reconstructed.
  - Momentum of signal lepton in B rest frame (p'_l)
- Remaining variables considered for likelihood ratios (LHRs) composed of probability density functions (PDFs).
  - Separate LHRs for continuum and $B\bar{B}$ background and for each of the 7 signal modes

PDFs for LHRs





- Made after tag cuts
- Normalize histograms of cont. and signal MC to unit area.
- Call height of hist. bin $P_s(x)$ for signal MC and $P_b(x)$ for BG MC
- $$P(x) = \frac{P_s(x)}{P_s(x) + P_b(x)}$$

Selecting PDFs for the LHRs

- We have a large number of PDFs (up to 27)
  - Remove those that are not helpful in the LHRs
- Remove each PDF to see effect on figure of merit (FOM)
- Calculate variation from all PDFs included
- Eliminate PDF if it degrades performance
- Eliminate if physics tells us it should not help (e.g. Tag side variables in $B\bar{B}$ MC).

Cut Optimization

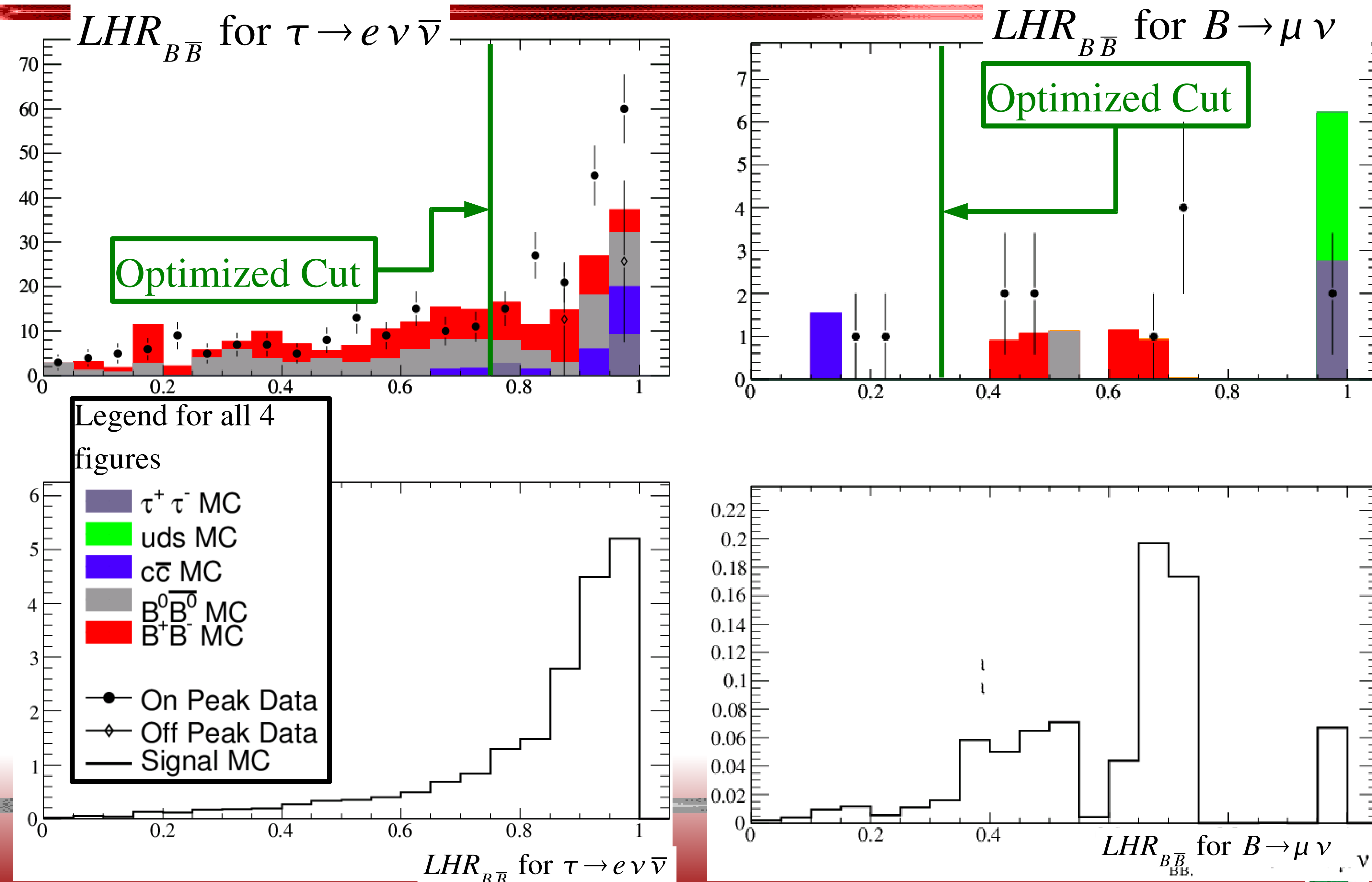
- Maximize Significance for $B\to\tau\nu$
- Maximize Punzi FOM for $B\to e\nu$ and $B\to\mu\nu$

$$\text{Significance} = \frac{N_{sig}}{\sqrt{N_{sig}+N_{BG}}}$$

$$\text{Punzi} = \frac{N_{sig}}{\frac{N_\sigma}{2}+\sqrt{N_{BG}}} \qquad N_\sigma = 3$$

Mode	E_{extra}	$LHR_{B\overline{B}}$	$LHR_{\text{cont.}}$	$p'_{\text{sig}\ \ell}$
$\tau^+ \to e^+\nu_e\overline{\nu}_\tau$	[0,0.24] GeV	[0.74,1]	[0.16,1]	[0.00,2.25] GeV
$\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$	[0,0.24] GeV	[0.14,1]	[0.72,1]	[0.00,2.30] GeV
$\tau^+ \to \pi^+\overline{\nu}_\tau$	[0,0.35] GeV	[0.57,1]	[0.8,1]	-
$\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$	[0,0.24] GeV	[0.97,1]	[0.95,1]	-
$\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$	[0,0.31] GeV	[0.97,1]	[0.93,1]	-
$B^+ \to \mu^+\nu_\mu$	[0,0.72] GeV	[0.33,1]	[0.75,1]	[2.45,2.92] GeV
$B^+ \to e^+\nu_e$	[0,0.57] GeV	[0.00,1]	[0.01,1]	[2.52,3.02] GeV

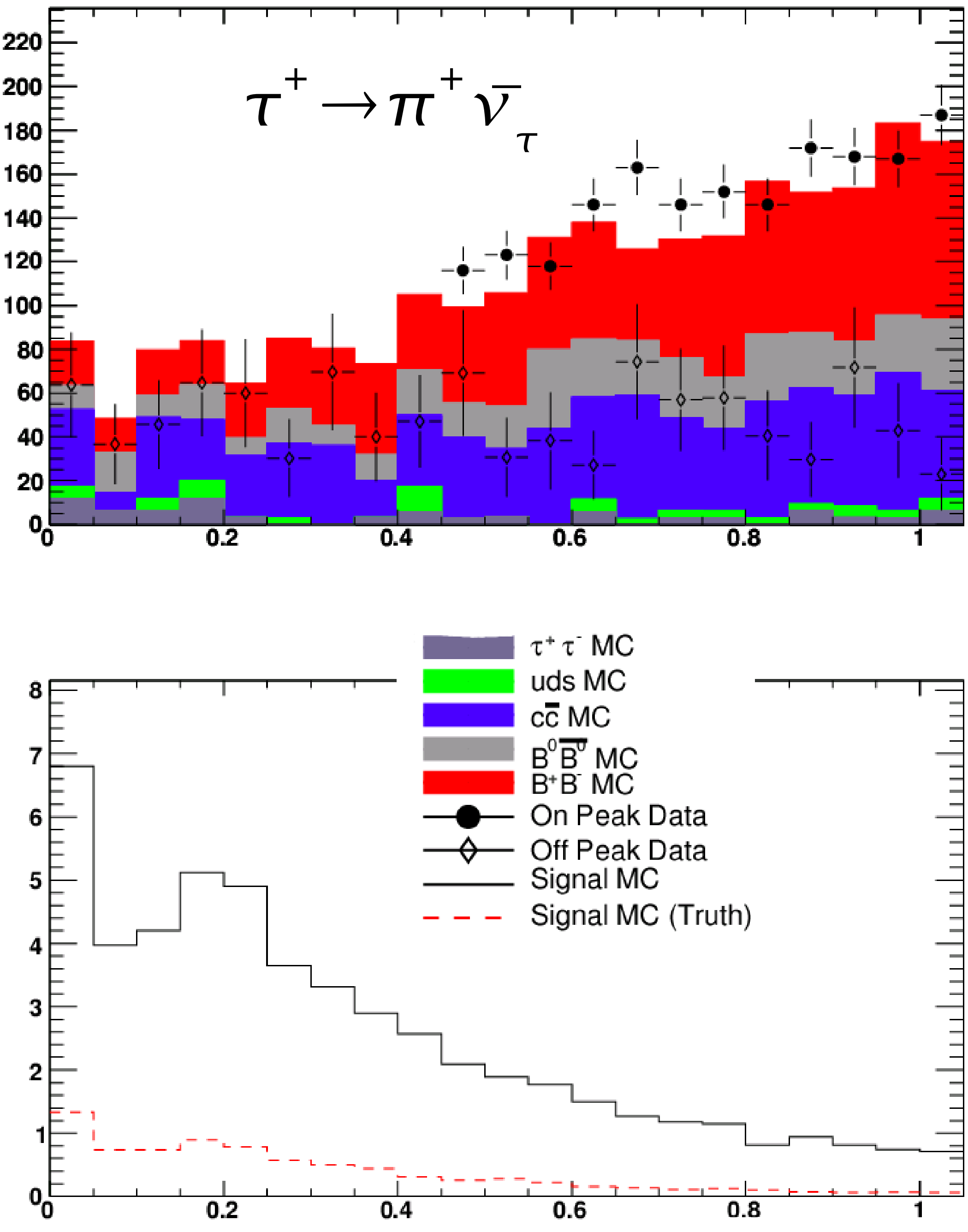
LHR Examples



Signal & Background Predictions

- Need BG prediction to tell if we see signal
- Do not want to us MC alone
- Have several sidebands in data from final selection variables
  - E_{extra}, LHR_{BB}, LHR_{cont}, $p'_{sig\ l}$, D^0 Mass
- Choose one for prediction and cross-check with the others.

Signal & Background Predictions



- Ratio of Sideband to Signal Region in MC (R^{MC})

$$R^{MC} = \frac{N_{MC,Sig}}{N_{MC,SideB}}$$

$$N_{exp,Sig} = N_{data,SideB} \cdot R^{MC}$$

Signal & Background Predictions

- Use E_{extra} for prediction
  - SB defined as $E_{extra} > 0.72$ GeV ($B \rightarrow \mu\nu$)
  - $E_{extra} > 0.6$ GeV (all other modes)
  - Validate with remaining sidebands and MC
- Signal prediction from signal MC sample

Signal Predictions Assuming

$$\mathcal{B}(B^+ \rightarrow \tau^+ \nu) = 1.0 \times 10^{-4}$$

$$\mathcal{B}(B^+ \rightarrow \mu^+ \nu) = 5.0 \times 10^{-7}$$

$$\mathcal{B}(B^+ \rightarrow e^+ \nu) = 1.0 \times 10^{-11}$$

Mode	Signal Prediction
$\tau^+ \rightarrow e^+ \nu_e \overline{\nu}_\tau$	15.14 ± 0.33
$\tau^+ \rightarrow \mu^+ \nu_\mu \overline{\nu}_\tau$	12.09 ± 0.29
$\tau^+ \rightarrow \pi^+ \overline{\nu}_\tau$	18.96 ± 0.37
$\tau^+ \rightarrow \pi^+ \pi^0 \overline{\nu}_\tau$	6.56 ± 0.22
$B^+ \rightarrow \tau^+ \nu_\tau$	53.03 ± 0.63
$B^+ \rightarrow \mu^+ \nu_\mu$	0.74 ± 0.01
$B^+ \rightarrow e^+ \nu_e$	$(1.84 \pm 0.02) \times 10^{-5}$

Background Predictions

Mode	MC Counting	D^0 Mass	E_{extra}	$LHR_{cont.}$	$LHR_{B\overline{B}}$	$p'_{sig\ \ell}$
$\tau^+ \to e^+\nu_e\overline{\nu}_\tau$	98.4 ± 10.8	102.6 ± 15.3	91.4 ± 12.8	127.4 ± 118.8	99.7 ± 17.1	-
$\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$	136.1 ± 11.8	146.1 ± 16.0	137.2 ± 13.3	192.4 ± 48.8	79.3 ± 50.2	-
$\tau^+ \to \pi^+\overline{\nu}_\tau$	212.1 ± 16.8	239.2 ± 20.0	233.0 ± 18.9	228.6 ± 24.8	279.8 ± 80.1	-
$\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$	62.4 ± 9.0	57.7 ± 11.4	59.2 ± 8.8	52.8 ± 11.7	64.7 ± 14.0	-
$B^+ \to \mu^+\nu_\mu$	11.5 ± 5.0	13.9 ± 5.8	15.1 ± 9.9	11.5 ± 7.3	14.8 ± 19.1	12.7 ± 7.6
$B^+ \to e^+\nu_e$	14.6 ± 5.3	13.6 ± 8.5	24.0 ± 11.2	-	-	35.0 ± 17.8

Use E_{extra} SB, cross Check with others

Systematic Errors

$$\mathcal{B}(B^+ \to \ell^+ \nu_\ell) = \frac{N_{\text{obs}} - N_{\text{BG}}}{N_{BB}\varepsilon_{\text{tag}}\varepsilon_{\text{sig}}}$$

1.1%

- Single Tag / Double Tag Studies

- E_{extra} shape in Double Tags
- Tracking Efficiency
- π^0 Selection
- PID Corrections

- Data/MC agreement from sidebands

Tag Efficiency

$\varepsilon_1 = \text{tag efficiency}$

$\varepsilon_2 = \text{efficiency selected second tag}$

$$\varepsilon_1 \equiv \frac{N_{\text{single tags}}}{N_{B^+B^-}}$$

$$\varepsilon_1 \times \varepsilon_2 \equiv \frac{N_{\text{double tags}}}{N_{B^+B^-}} \Rightarrow \varepsilon_2 = \frac{N_{\text{double tags}}}{N_{B^+B^-}} \cdot \frac{N_{B^+B^-}}{N_{\text{single tags}}} = \frac{N_{\text{double tags}}}{N_{\text{single tags}}}$$

- Calculate ε_2 for data and MC, take ratio as systematic correction to tag efficiency
- For all systematics, apply correction to MC and error on corr. as systematic error.

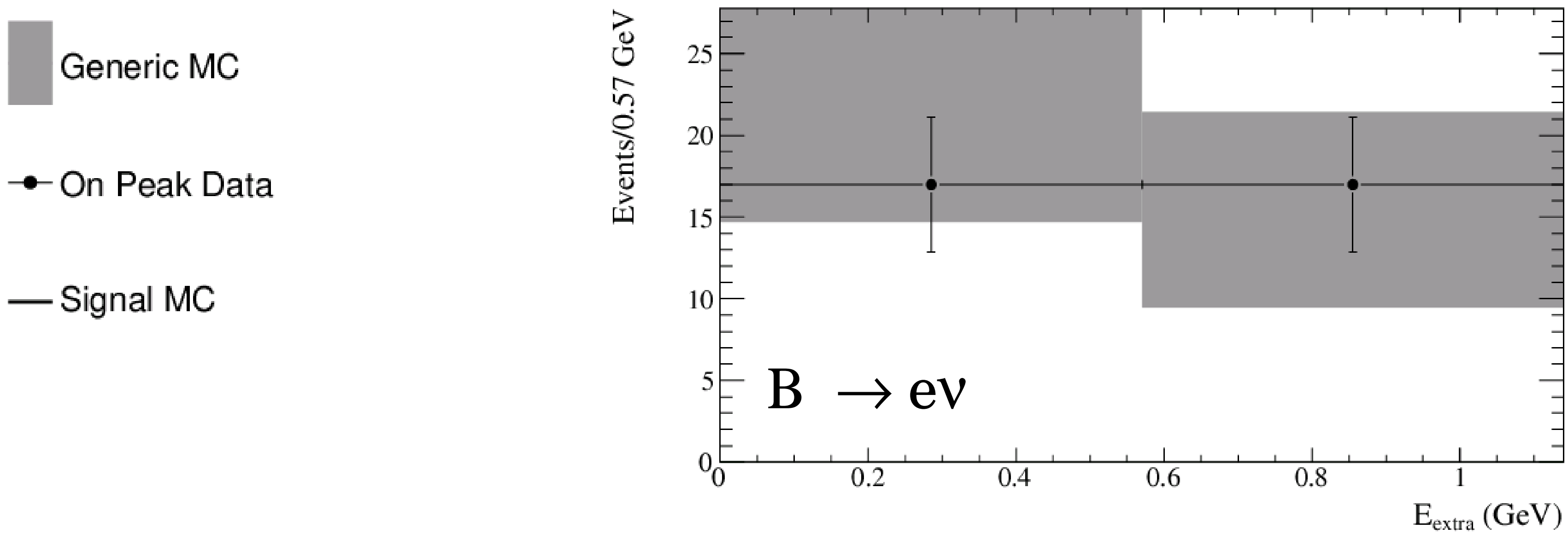
Tag Efficiency

- For single tags, use one D^0 decay mode, subtract D^0 mass sidebands
- For double tags, use one tag D^0 mode, all signal D^0 modes, and no SB subtraction

Tag $D^0 \to K^- \pi^+$			
	Single Tags	Double Tags	N_2/N_1
Data	812182.0 ± 1132.4	2278.0 ± 47.7	$(0.280 \pm 0.006) \times 10^{-2}$
MC	2611475.0 ± 1945.4	8225.0 ± 90.7	$(0.315 \pm 0.003) \times 10^{-2}$
Data/MC	-	-	0.891 ± 0.021

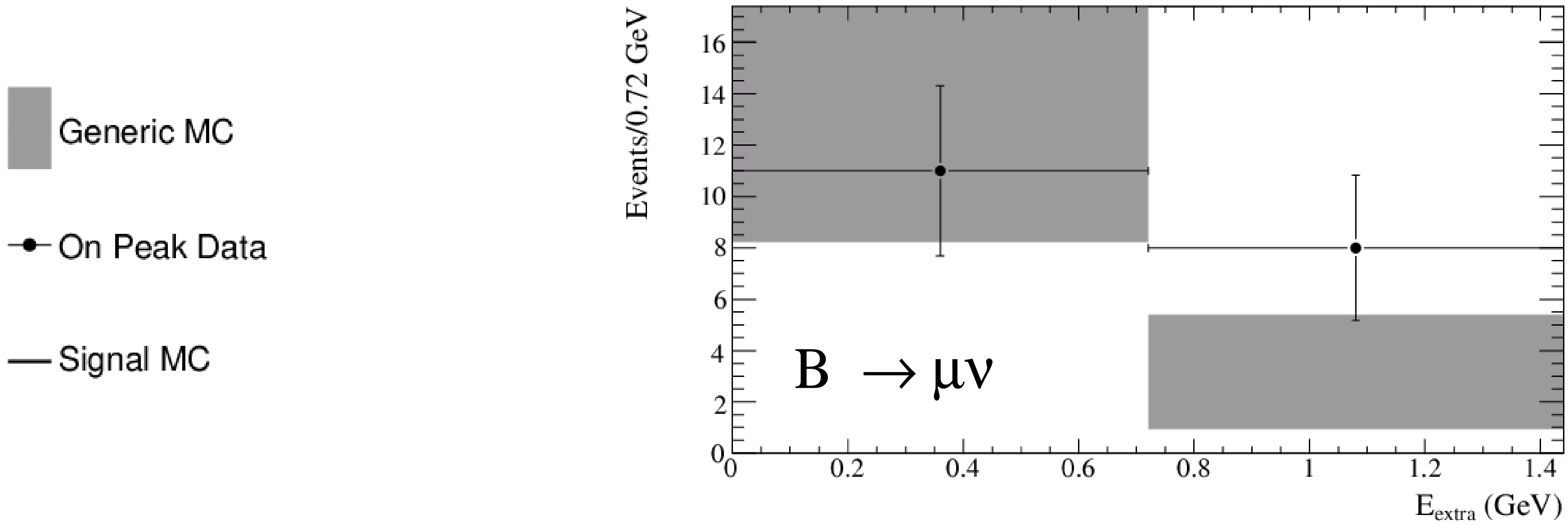
Tag $D^0 \to K^- \pi^+ \pi^- \pi^+$			
	Single Tags	Double Tags	N_2/N_1
Data	602762.0 ± 2034.0	2138.0 ± 46.2	$(0.355 \pm 0.008) \times 10^{-2}$
MC	2051028.0 ± 3468.0	8549.0 ± 92.5	$(0.417 \pm 0.005) \times 10^{-2}$
Data/MC	-	-	0.851 ± 0.021

Results B → eν



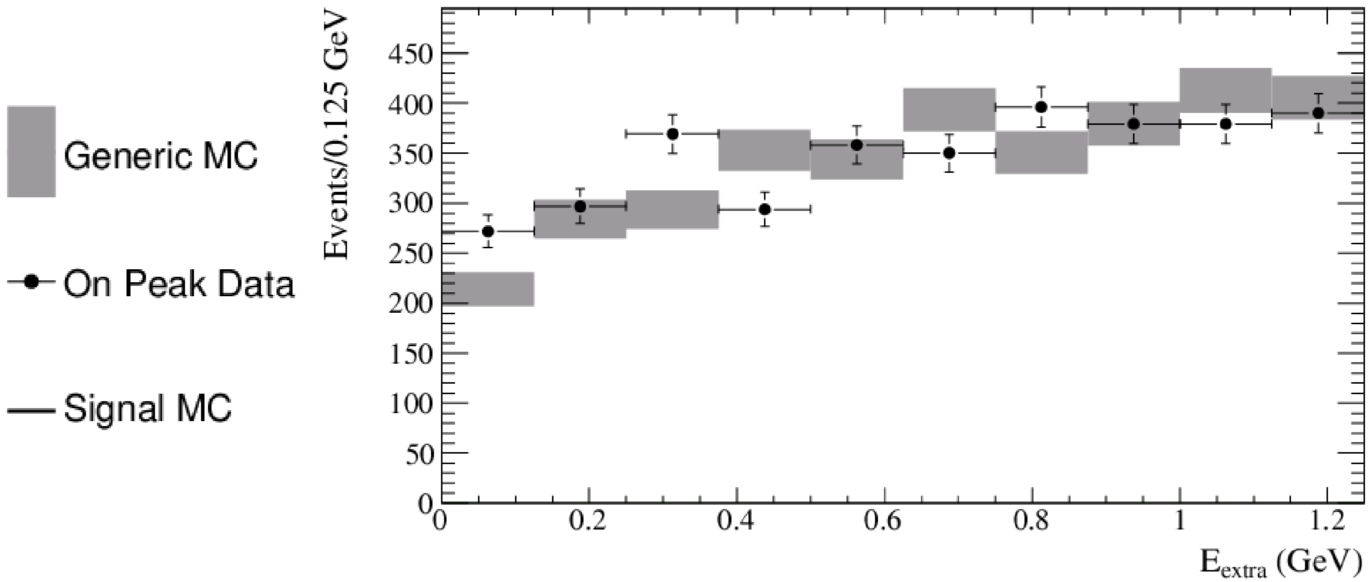
- Expected BG = 24 ± 11, Observed 17
- Set upper limit.

Results B → μν



- Expected BG = 15 ± 10, Observed 11
- Set upper limit.

Results B $\to \tau\nu$



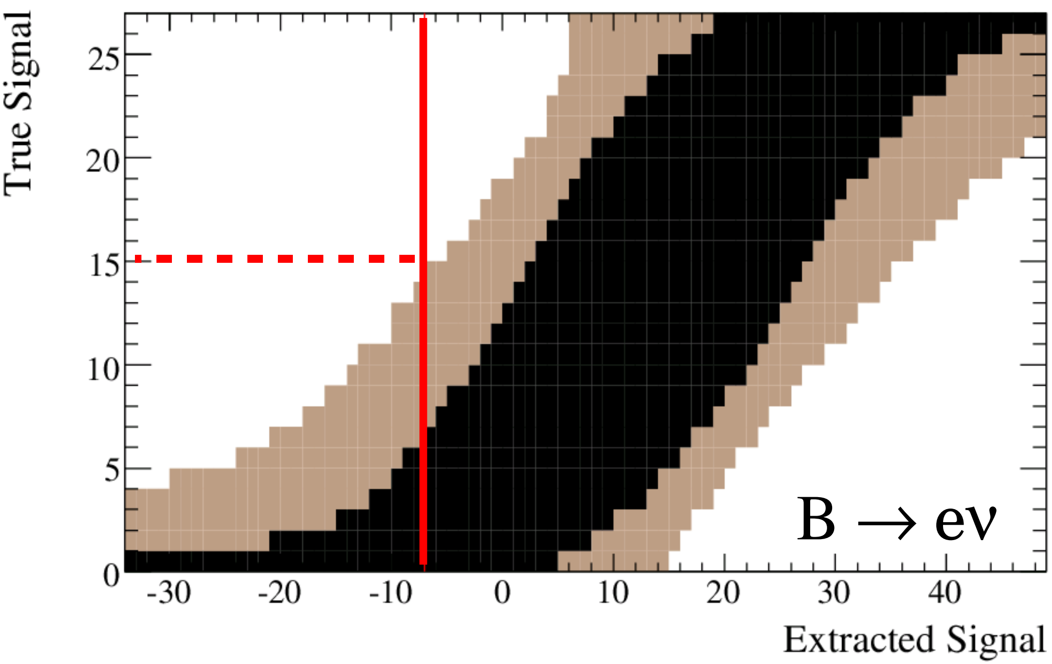
Mode	Expected Background (N_{BG})	Observed Events (N_{obs})
$\tau^+ \to e^+ \nu_e \overline{\nu}_\tau$	91 ± 13	148
$\tau^+ \to \mu^+ \nu_\mu \overline{\nu}_\tau$	137 ± 13	148
$\tau^+ \to \pi^+ \overline{\nu}_\tau$	233 ± 19	243
$\tau^+ \to \pi^+ \pi^0 \overline{\nu}_\tau$	59 ± 9	71

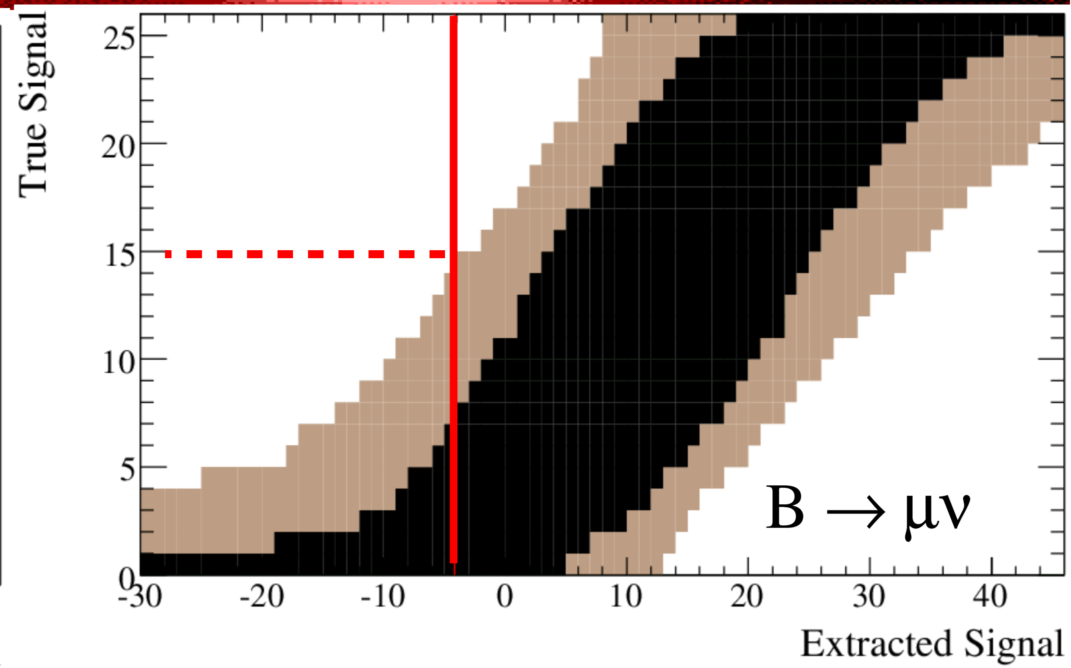
- Total Expected BG 521 ± 31
- Observed 610
- Measure branching fraction.

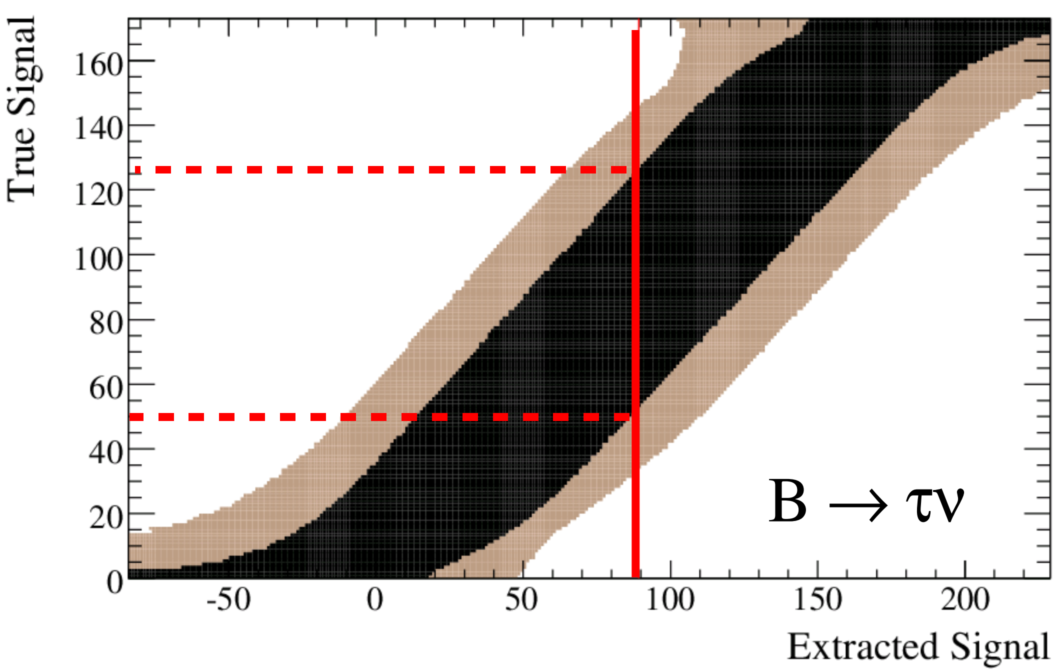
Feldman-Cousins

- How do we convert raw numbers in branching fractions and upper limits?
- We choose Feldman-Cousins method
  - *Phys. Rev.* **D57**:3873-3889
- Uses MC to set branching fraction or upper limit
- Works in high and low background environments

CL Histograms



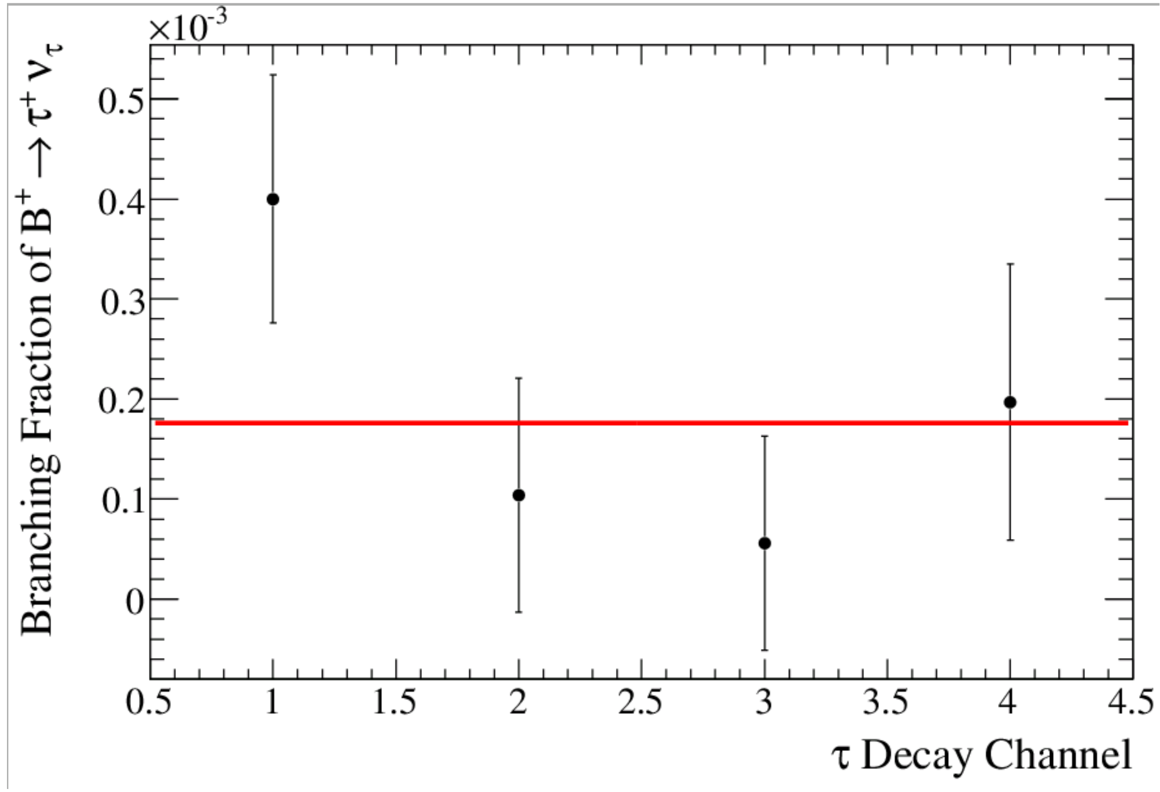




- Red line is unblinded value
  - Central Band = 1 σ
  - Outer Band is 90% CL

Agreement of Branching Fractions

- Fit histogram of separate BFs
- Fit to constant -> probability of 18%



	Mode	Expected Background (N_{BG})	Observed Events (N_{obs})	Overall Efficiency (ε)	Branching Fraction
1	$\tau^+ \to e^+\nu_e\overline{\nu}_\tau$	91 ± 13	148	$(3.08 \pm 0.14) \times 10^{-4}$	$(4.0 \pm 1.2) \times 10^{-4}$
2	$\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$	137 ± 13	148	$(2.28 \pm 0.11) \times 10^{-4}$	$\left(1.0^{+1.2}_{-0.9}\right) \times 10^{-4}$
3	$\tau^+ \to \pi^+\overline{\nu}_\tau$	233 ± 19	243	$(3.89 \pm 0.15) \times 10^{-4}$	$\left(0.6^{+1.1}_{-0.5}\right) \times 10^{-4}$
4	$\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$	59 ± 9	71	$(1.30 \pm 0.07) \times 10^{-4}$	$\left(2.0^{+1.4}_{-1.3}\right) \times 10^{-4}$

Results

$$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.8 \pm 0.8 \pm 0.1) \times 10^{-4} (2.4\sigma)$$

$$f_B = 230 \pm 57 \text{ MeV}$$

$$\mathcal{B}(B^+ \to \mu^+ \nu) < 11 \times 10^{-6} \text{ @ 90\% CL}$$

$$\mathcal{B}(B^+ \to e^+ \nu) < 7.7 \times 10^{-6} \text{ @ 90\% CL}$$

- Combined with hadronic tag (*Phys. Rev.* **D77**:011107)

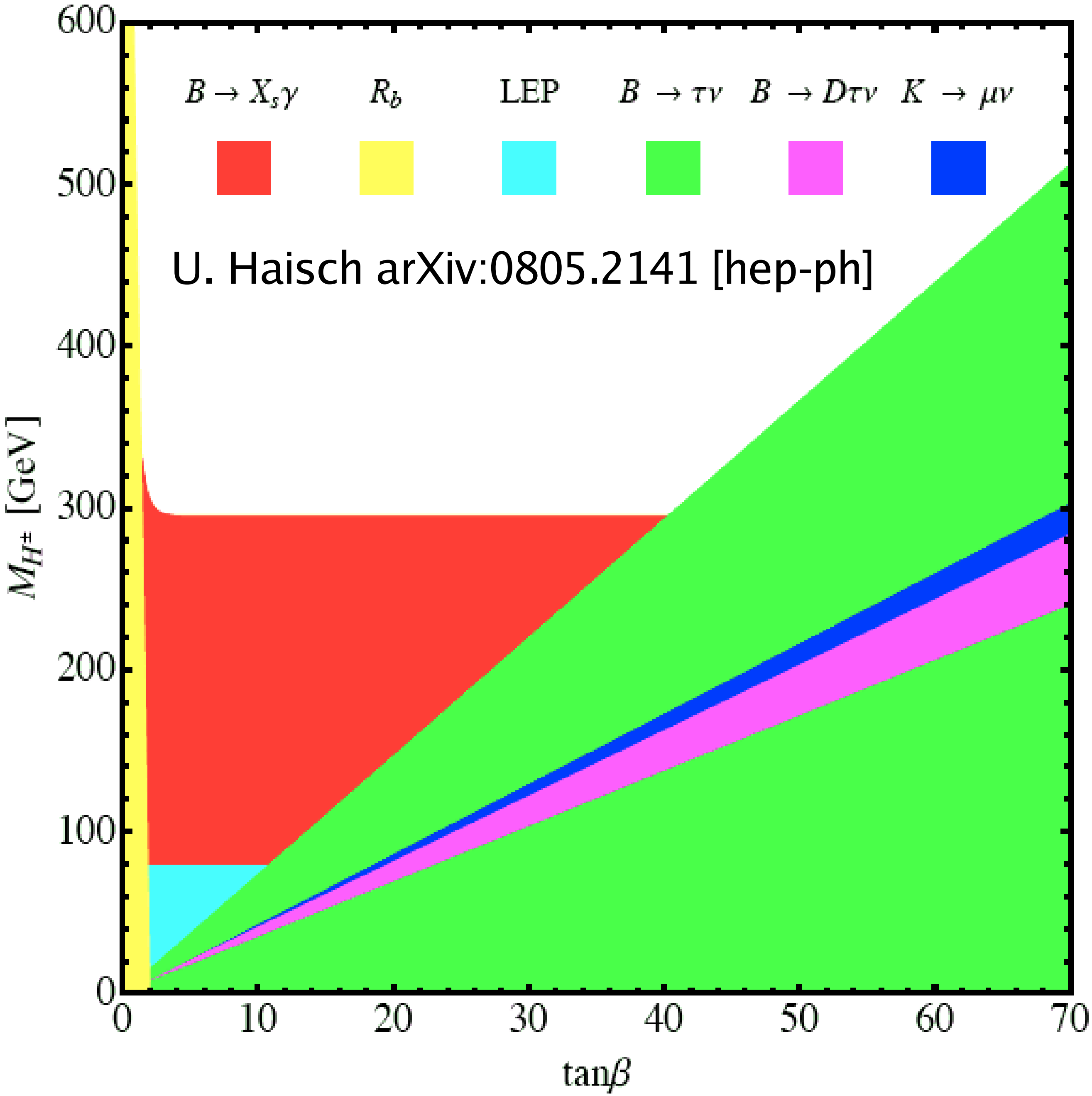
$$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.8 \pm 0.6) \times 10^{-4} (3.2\sigma)$$

Context

		$B^+ \to e^+\nu_e$	$B^+ \to \mu^+\nu_\mu$	$B^+ \to \tau^+\nu_\tau$
PDG Values [1]		$< 9.8 \times 10^{-7}$	$< 1.7 \times 10^{-6}$	$(1.4 \pm 0.4) \times 10^{-4}$
Inclusive Meas.	BABAR [9]	-	$< 1.3 \times 10^{-6}$	N/A
	Belle [10]	$< 9.8 \times 10^{-7}$	$< 1.7 \times 10^{-6}$	N/A
Hadronic	BABAR	$< 5.2 \times 10^{-6}$ [11]	$< 5.6 \times 10^{-6}$ [11]	$(1.8^{+1.0}_{-0.9}) \times 10^{-4}$[12]
Tag Meas.	Belle	-	-	$(1.8 \pm 0.7) \times 10^{-4}$ [13]
Semilep.	BABAR	$< 7.7 \times 10^{-6}$	$< 11 \times 10^{-6}$	$(1.8 \pm 0.8 \pm 0.1) \times 10^{-4}$
Tag Meas.	Belle [14]	-	-	$(1.65^{+0.38+0.35}_{-0.37-0.37}) \times 10^{-4}$

- B → τν: consistent with all recent measurements
- B → μν: 11 events in sig. region (Inclusive: 600)
  - Smaller backgrounds are more conducive to discovery
  - Precision measurement at Super B factory

New Physics from B → τν ?



- Shaded regions are excluded at 95% CL

Future Outlook

- Publish this work
- Combined tags and Belle + Babar
  - $B \to \tau\nu$ @ 5σ
  - $B \to u\nu$ first evidence
- Super B precision measurements.

Backup Slides

Predictions before mll cut

Signal Predictions

Mode	Prediction
$\tau^+ \to e^+\nu_e\overline{\nu}_\tau$	15.42 ± 0.33
$\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$	12.09 ± 0.29
$\tau^+ \to \pi^+\overline{\nu}_\tau$	18.96 ± 0.37
$\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$	6.56 ± 0.22
$B^+ \to \tau^+\nu_\tau$	53.03 ± 0.63
$B^+ \to \mu^+\nu_\mu$	0.74 ± 0.01
$B^+ \to e^+\nu_e$	$(1.84 \pm 0.02) \times 10^{-5}$

<u>Signal Predictions Assuming</u>

$$\mathcal{B}(B^+ \to \tau^+ \nu) = 1.0 \times 10^{-4}$$

$$\mathcal{B}(B^+ \to \mu^+ \nu) = 5.0 \times 10^{-7}$$

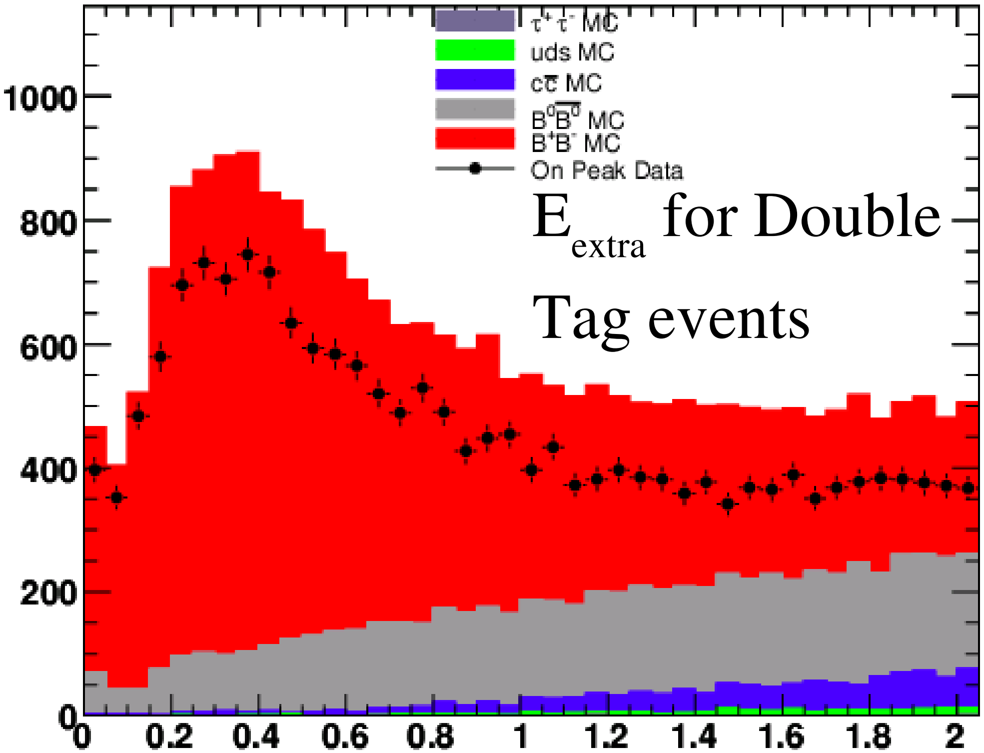
$$\mathcal{B}(B^+ \to e^+ \nu) = 1.0 \times 10^{-11}$$

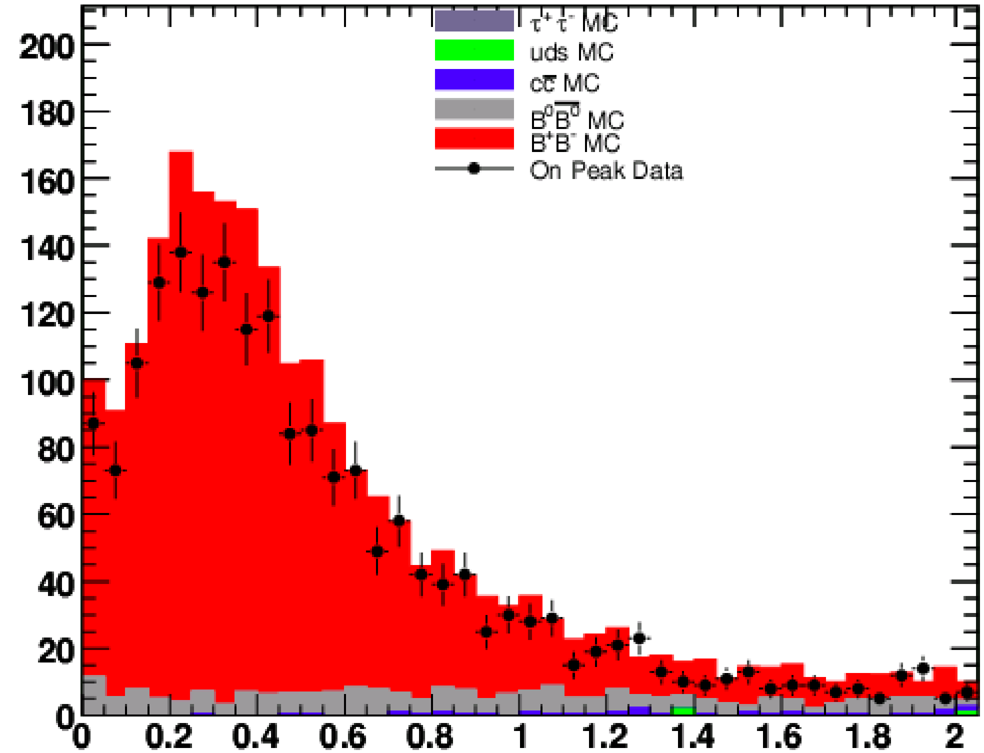
We do not use $\tau \to \pi\pi\pi$ mode because it lowers significance

Table 83: Comparison of BG predictions from various sidebands.

Mode	MC Counting	D^0 Mass	E_{extra}	$LHR_{\text{cont.}}$	$LHR_{B\overline{B}}$	$p^{*}_{\text{sig}\ \ell}$
$\tau^+ \to e^+\nu_e\overline{\nu}_\tau$	109.8 ± 12.0	123.8 ± 17.7	104.5 ± 14.3	198.9 ± 112.4	110.3 ± 18.9	-
$\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$	136.1 ± 11.8	146.1 ± 16.0	137.2 ± 13.3	192.4 ± 48.8	79.3 ± 50.2	-
$\tau^+ \to \pi^+\overline{\nu}_\tau$	212.1 ± 16.8	239.2 ± 20.0	233.0 ± 18.9	228.6 ± 24.8	279.8 ± 80.1	-
$\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$	62.4 ± 9.0	57.7 ± 11.4	59.2 ± 8.8	52.8 ± 11.7	64.7 ± 14.0	-
$\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$	122.9 ± 12.2	119.8 ± 17.3	121.7 ± 12.6	116.6 ± 16.2	127.0 ± 14.0	-
$B^+ \to \mu^+\nu_\mu$	11.5 ± 5.0	13.9 ± 5.8	15.1 ± 9.9	11.5 ± 7.3	14.8 ± 19.1	12.7 ± 7.6
$B^+ \to e^+\nu_e$	14.6 ± 5.3	13.6 ± 8.5	24.0 ± 11.2	-	-	35.0 ± 17.8

E_{extra} in Double Tags



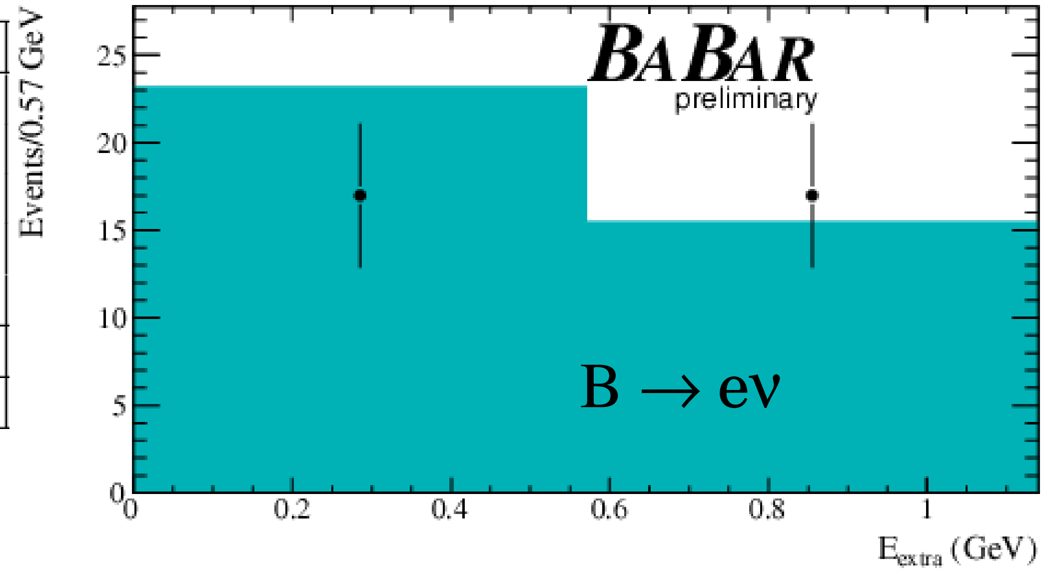


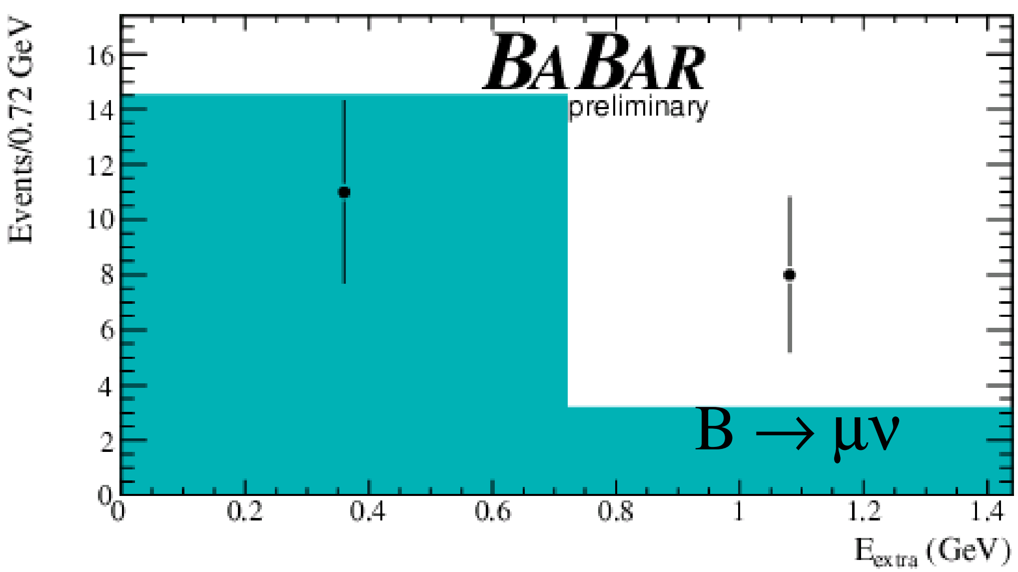
Left: same cuts on second tag as on first

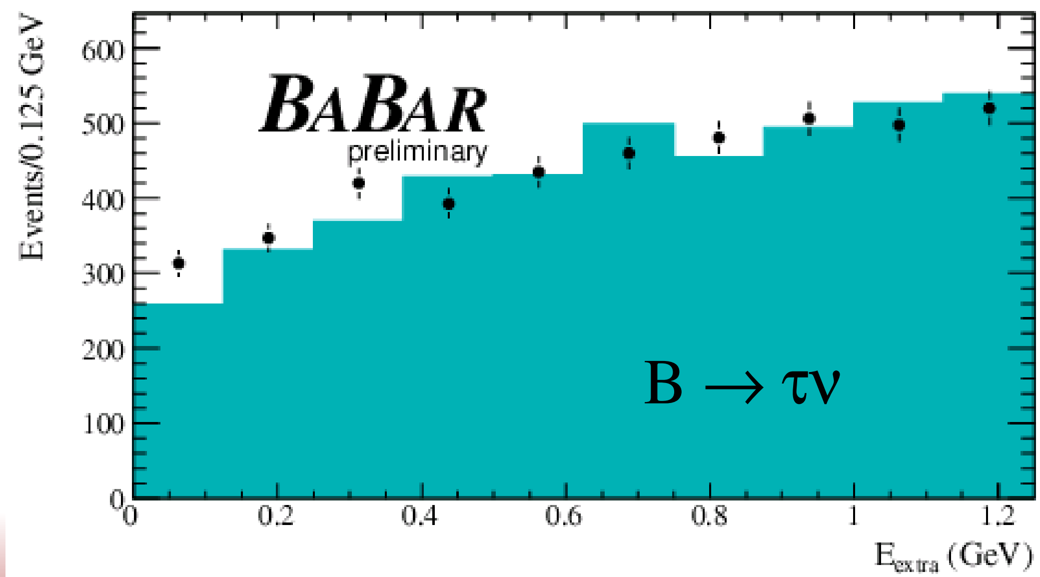
Right: Add cut -2.0<CosBY<1.1 Net Charge = 0

Unblinded Results before

Mode	Expected Background	Observed Events
$\tau^+ \to e^+\nu_e\overline{\nu}_\tau$	104.5 ± 14.3	170
$\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$	137.2 ± 13.3	148
$\tau^+ \to \pi^+\overline{\nu}_\tau$	233.0 ± 18.9	243
$\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$	59.2 ± 8.8	71
$B^+ \to \tau^+\nu_\tau$	533.9 ± 31.3	632
$B^+ \to \mu^+\nu_\mu$	15.2 ± 9.9	11
$B^+ \to e^+\nu_e$	24.0 ± 11.2	17







Only applies for

Assume that most of our π^0 candidates are not merged

According to Wolfgang Gradl, we should usethe same correction and error as in R18

0.984 ± 0.030

Tracking Eff.

- No correction, Overall uncertainty of 0.27%
- Additional uncertainty of 0.23% per track
- Total 0.69% for $\tau \to \pi\pi\pi$, 0.36% for all others

Particle ID

- Time constraints prevented full study before ICHEP deadlines
- Use systematics from previous analysis (BAD 1456)

Solution 2

- Frank Porter pointed out that I was underestimating error in Feldman Cousins
- Two sources of error
  - Error in the background prediction
  - Stat. error in the number of observed events (N_{obs})
- In FC method, toy MC (random numbers) are used to estimate the probability the probability of various measurements.

Conclusions I

Use Feldman-Cousins Method

$$\mathcal{B}(B^+ \to \tau^+ \nu) = (2.0 \pm 0.6 \pm 0.1) \times 10^{-4}$$

Belle (Hadronic Tag): $(1.8 \pm 0.7) \times 10^{-4}$ (PDG)

Babar Hadronic $(1.8^{+1.0}_{-0.9}) \times 10^{-4}$

PRD 77:011107, 2008

$$f_B = 240 \pm 48 \pm 4\,\text{MeV}$$

Using $|V_{ub}| = (4.39 \pm 0.54) \times 10^{-3}$

Compare Belle $f_B = 229^{+36+34}_{-31-37}\,\text{MeV}$ (PRL 97:251802, 2006)

Conclusions II

$$\mathcal{B}(B^+ \to \mu^+ \nu) < 10 \times 10^{-6} \text{ @ 90\% CL}$$

Babar Inclusive: $< 1.3 \times 10^{-6}$

Elisabetta Baracchini (BAD 1956)

This work: 11 events in sig. region (Inclusive: 600)

$$\mathcal{B}(B^+ \to e^+ \nu) < 6.9 \times 10^{-6} \text{ @ 90\% CL}$$

Belle Inclusive: $< 9.8 \times 10^{-7}$ (PDG)

Smaller backgrounds are more conducive to discovery

Problem Found

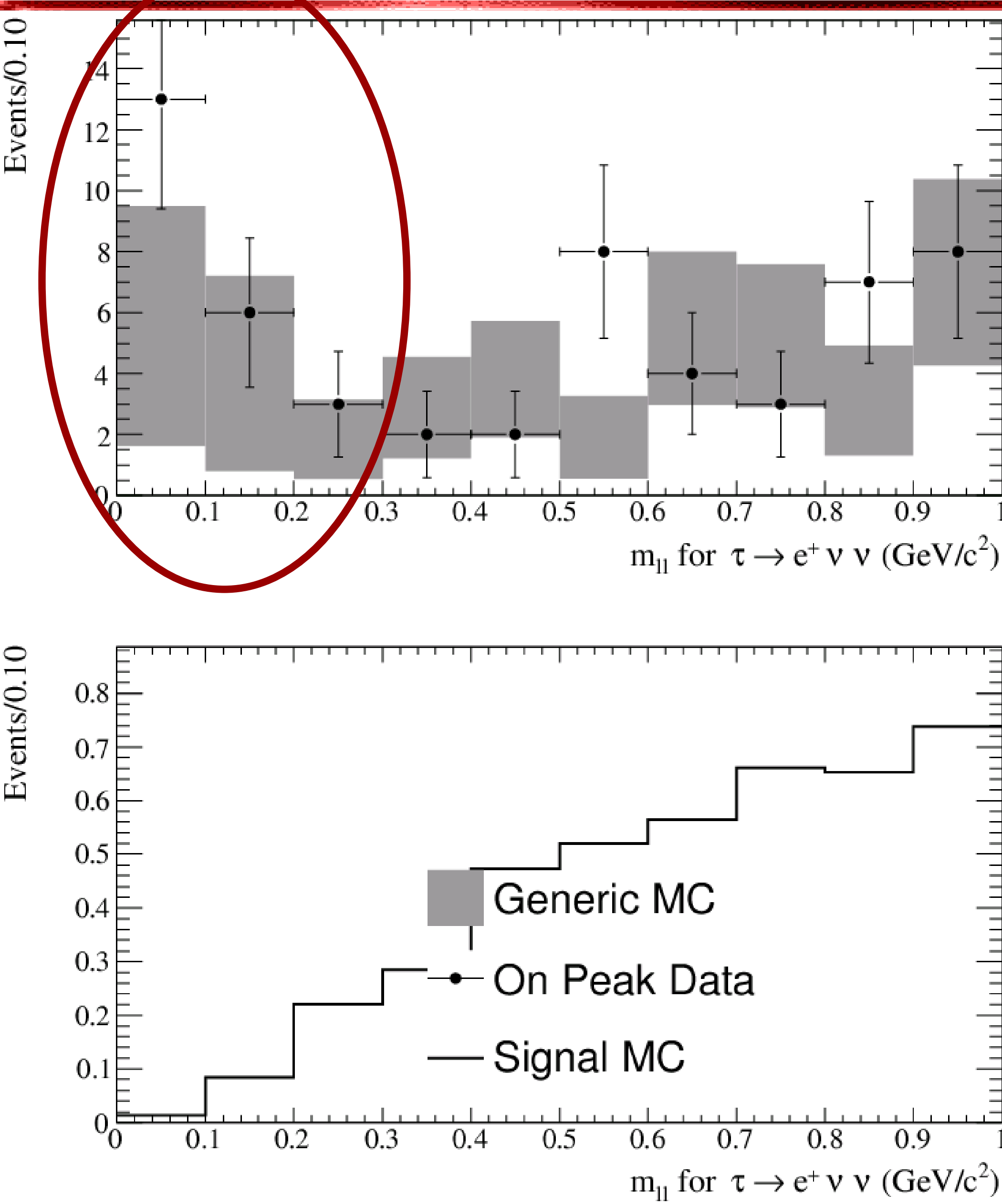
Mode	Expected Background	Observed Events	FOM
$\tau^+ \to e^+ \nu_e \overline{\nu}_\tau$	104.5 ± 14.3	170	5.03
$\tau^+ \to \mu^+ \nu_\mu \overline{\nu}_\tau$	137.2 ± 13.3	148	0.89
$\tau^+ \to \pi^+ \overline{\nu}_\tau$	233.0 ± 18.9	243	0.64
$\tau^+ \to \pi^+ \pi^0 \overline{\nu}_\tau$	59.2 ± 8.8	71	1.4
$B^+ \to \tau^+ \nu_\tau$	533.9 ± 31.3	632	3.9
$B^+ \to \mu^+ \nu_\mu$	15.2 ± 9.9	11	-2.77
$B^+ \to e^+ \nu_e$	24.0 ± 11.2	17	-4.67

- Problem: Large excess found only in $\tau \to e\nu\nu$
- Re-examine potential background sources.

Potential Background Sources

- Two photon fusion QED events
- "Events" with two overlapping e^+e^- collisions
- Overzealous Bremsstrahlung recovery
- Photon pair production
  - e^+, e^- reconstructed as the tag and signal lepton
  - One lepton is lost, and the other reconstructed as the signal electron.

One source found



- Photon pair production: e^+, e^- reconstructed as the tag and signal lepton
  - Found in invariant mass of two leptons m_{ll}
- Other sources shown to not contribute

Solution

- m_{ll} included in a PDF, but this was not sufficiently effective
- After all cuts have been made, optimize m_{ll} cut separately
- No data used in optimization, only generic and signal MC.
- Optimizer returns $m_{ll} > 0.29$ GeV

Feldman-Cousins

- For each value N_{true}, order values of N_{sig} by $R = P(N_{sig} | N_{true})/P(N_{sig} | N_{best})$
  - N_{best} is the value of N_{true} that maximizes the probability of observing N_{sig} (usually N_{true})
- Sum probabilities until one reaches desired confidence level.
- For unblinded data $N_{sig} = N_{obs} - N_{BG}$

Summary of Systematics

Source	Applicable Mode(s)	Correction	Fractional Uncertainty (%)
B Counting	All	1.0	1.1
Tag efficiency	All	0.891 ± 0.021	2.4
E_{extra}	All	1.015 ± 0.021	2.1
π^0 Reconstruction	$\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$	0.984 ± 0.030	3.0
Tracking Efficiency	$\tau^+ \to e^+\nu_e\overline{\nu}_\tau$	1.0	0.36
	$\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$	1.0	0.36
	$\tau^+ \to \pi^+\overline{\nu}_\tau$	1.0	0.36
	$\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$	1.0	0.36
	$\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$	1.0	0.74
	$B^+ \to \mu^+\nu_\mu$	1.0	0.36
	$B^+ \to e^+\nu_e$	1.0	0.36
Particle Identification	$\tau^+ \to e^+\nu_e\overline{\nu}_\tau$	1.01	2.5
	$\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$	0.92	3.1
	$\tau^+ \to \pi^+\overline{\nu}_\tau$	1.02	0.8
	$\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$	1.00	1.5
	$\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$	1.06	2.4
	$B^+ \to \mu^+\nu_\mu$	0.92	3.1
	$B^+ \to e^+\nu_e$	1.01	2.5

Signal Reconstruction

- After tag is reconstructed, search remainder of event.
- Events are assigned to different signal categories in a heierachy based on mass, PID and other requirements

Decay Mode	Branching Ratio
$\tau^+ \to e^+ \nu_e \overline{\nu}_\tau$	$(17.84 \pm 0.05)\%$
$\tau^+ \to \mu^+ \nu_\mu \overline{\nu}_\tau$	$(17.36 \pm 0.05)\%$
$\tau^+ \to \pi^+ \overline{\nu}_\tau$	$(10.90 \pm 0.07)\%$
$\tau^+ \to \pi^+ \pi^0 \overline{\nu}_\tau$	$(25.50 \pm 0.10)\%$
$\tau^+ \to \pi^+ \pi^- \pi^+ \overline{\nu}_\tau$	$(9.33 \pm 0.08)\%$

Predictions

Signal Predictions

Mode	Signal Prediction
$\tau^+ \rightarrow e^+\nu_e\overline{\nu}_\tau$	15.14 ± 0.33
$\tau^+ \rightarrow \mu^+\nu_\mu\overline{\nu}_\tau$	12.09 ± 0.29
$\tau^+ \rightarrow \pi^+\overline{\nu}_\tau$	18.96 ± 0.37
$\tau^+ \rightarrow \pi^+\pi^0\overline{\nu}_\tau$	6.56 ± 0.22
$B^+ \rightarrow \tau^+\nu_\tau$	53.03 ± 0.63
$B^+ \rightarrow \mu^+\nu_\mu$	0.74 ± 0.01
$B^+ \rightarrow e^+\nu_e$	$(1.84 \pm 0.02) \times 10^{-5}$

Signal Predictions Assuming

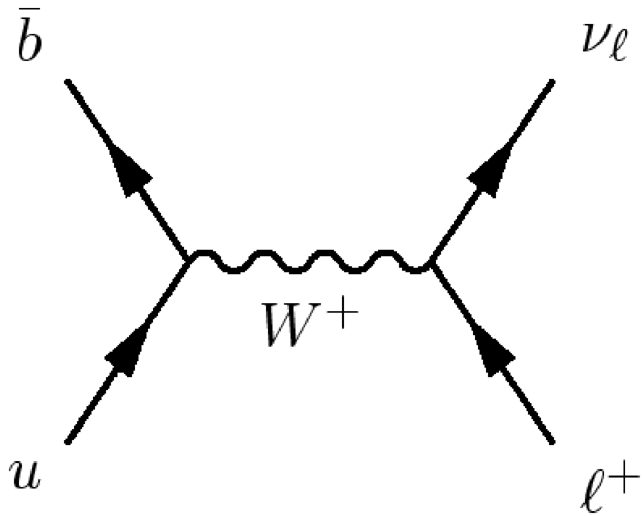
$$\mathcal{B}(B^+ \rightarrow \tau^+\nu) = 1.0\times 10^{-4}$$

$$\mathcal{B}(B^+ \rightarrow \mu^+\nu) = 5.0\times 10^{-7}$$

$$\mathcal{B}(B^+ \rightarrow e^+\nu) = 1.0\times 10^{-11}$$

Mode	MC Counting	D^0 Mass	E_{extra}	$LHR_{\text{cont.}}$	$LHR_{B\overline{B}}$	$p'_{\text{sig }\ell}$
$\tau^+ \rightarrow e^+\nu_e\overline{\nu}_\tau$	98.4 ± 10.8	102.6 ± 15.3	91.4 ± 12.8	127.4 ± 118.8	99.7 ± 17.1	-
$\tau^+ \rightarrow \mu^+\nu_\mu\overline{\nu}_\tau$	136.1 ± 11.8	146.1 ± 16.0	137.2 ± 13.3	192.4 ± 48.8	79.3 ± 50.2	-
$\tau^+ \rightarrow \pi^+\overline{\nu}_\tau$	212.1 ± 16.8	239.2 ± 20.0	233.0 ± 18.9	228.6 ± 24.8	279.8 ± 80.1	-
$\tau^+ \rightarrow \pi^+\pi^0\overline{\nu}_\tau$	62.4 ± 9.0	57.7 ± 11.4	59.2 ± 8.8	52.8 ± 11.7	64.7 ± 14.0	-
$\tau^+ \rightarrow \pi^+\pi^-\pi^+\overline{\nu}_\tau$	122.9 ± 12.2	119.8 ± 17.3	121.7 ± 12.6	116.6 ± 16.2	127.0 ± 14.0	-
$B^+ \rightarrow \mu^+\nu_\mu$	11.5 ± 5.0	13.9 ± 5.8	15.1 ± 9.9	11.5 ± 7.3	14.8 ± 19.1	12.7 ± 7.6
$B^+ \rightarrow e^+\nu_e$	14.6 ± 5.3	13.6 ± 8.5	24.0 ± 11.2	-	-	35.0 ± 17.8

Standard Model Predictions



$$\mathcal{B}(B^+ \to \ell^+ \nu_\ell) = \frac{G_F^2 m_B}{8\pi} m_\ell^2 \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

Calculate f_B^2 from branching fraction

- Helicity suppresses the BFs of the light leptons
- SM Prediction
  - $|V_{ub}| = (4.39 \pm 0.54) \times 10^{-3}$ [3], $f_B = 0.189 \pm 0.027$ GeV [8]

		$B^+ \to e^+\nu_e$	$B^+ \to \mu^+\nu_\mu$	$B^+ \to \tau^+\nu_\tau$
Prediction	Naive SM	$(1.3 \pm 0.4) \times 10^{-11}$	$(5.6 \pm 1.7) \times 10^{-7}$	$(1.2 \pm 0.4) \times 10^{-4}$
	CKM Fitter [8]	$0.89^{+0.12}_{-0.09} \times 10^{-11}$	$(3.8^{+0.5}_{-0.4}) \times 10^{-7}$	$(0.93^{+0.12}_{-0.09}) \times 10^{-4}$
	UT Fitter [7]	-	-	$(0.86 \pm 0.16) \times 10^{-4}$
PDG Values [1]		$< 9.8 \times 10^{-7}$	$< 1.7 \times 10^{-6}$	$(1.4 \pm 0.4) \times 10^{-4}$

[3] B. Aubert, *et al*. PRL, 96:221801 (2006) [8] http://ckmfitter.in2p3.fr [1] PDG 2008
[7] http://utfit.roma1.infn.it/btaunu/ckm-btaunu.html

Signal Eff. systematics

- Optimized cuts on all variables except E_{extra}
- Take (# events in signal region/# of total events) for Data and MC.
- Ratio of Data/MC gives the systematic correction and error on modeling of E_{extra}
- Result 1.015 ± 0.021

π^0 Selection, Tracking Eff., PID

- For $\tau^+ \to \rho^+\nu$ ($\rho^+ \to \pi^+\pi^0$) error: 0.984 ± 0.030
- Tracking Eff.
  - No correction, Overall uncertainty of 0.27%
  - Additional uncertainty of 0.23% per track
- Particle ID
  - Few differences with previous analysis
    - *Phys. Rev.* **D76**:052002
  - Use same systematics in this one

Feldman-Cousins

- Create 2D histogram of N_{true} (generated) signal vs. extracted signal
  - 100,000 experiments per true value
  - Extracted signal = total entries – BG prediction
  - Smooth statistical variations by fitting each horizontal strip to sum of two Gaussians

First Histogram B -> μν