

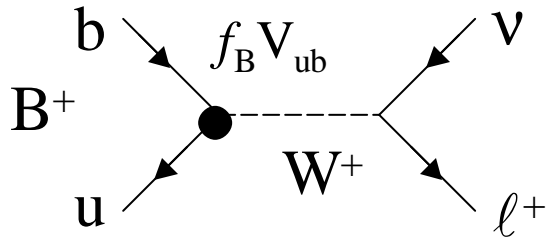
$B^+ \rightarrow \mu^+ \nu$ at SuperBaBar

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Second Workshop on the Discovery Potential
of an
Asymmetric B Factory at 10^{36} Luminosity

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Introduction



$$BR(B^+ \rightarrow \ell^+ n) = \frac{G_F^2 m_B m_\ell^2}{8p} \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 t_B$$

- Purely leptonic B decays are highly suppressed in the SM by factors of $|V_{ub}|^2$ and m_ℓ^2 (helicity suppression) \Rightarrow not yet observed.
- Branching fraction is sensitive to: $f_B |V_{ub}|$.
- Uncertainty on f_B is currently about 15% from lattice QCD \Rightarrow limits precision that $|V_{td}|$ can be determined from B_d mixing measurements.
- If $|V_{ub}|$ is measured in semi-leptonic decays, $B \rightarrow lv$ would provide the first direct measurement of f_B .
- If lattice QCD calculations improve, $B \rightarrow lv$ provides a theoretically clean measurement of $|V_{ub}|$.

SM Predictions

$$BR(B^+ \rightarrow \tau^+ \nu) \approx 9 \times 10^{-5}$$

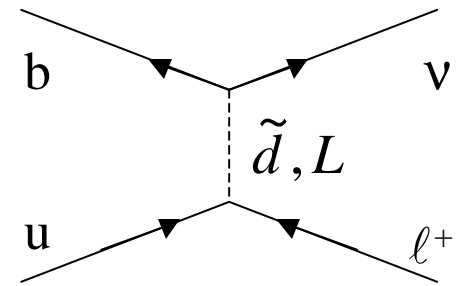
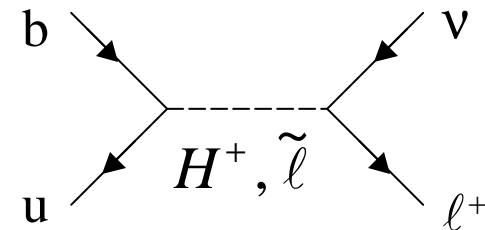
$$BR(B^+ \rightarrow \mu^+ \nu) \approx 4 \times 10^{-7}$$

$$BR(B^+ \rightarrow e^+ \nu) \approx 10^{-12}$$

New Physics Contributions

Possible New Physics contributions include mediation by:

- H^+ in 2-Higgs Doublet Models (MSSM)
 - * could enhance $B^+ \rightarrow \tau^+ \nu$ up to current experimental limits.
 - * $BR(B \rightarrow \mu \nu) / BR(B \rightarrow \tau \nu)$ is unchanged so $B \rightarrow \mu \nu$ is limited to $\sim \text{few} \times 10^{-6}$.
 - * BR upper limits can constrain $\tan\beta / m_{H^+}$.
- Scalar sparticles in R-parity violating extensions of MSSM
 - * BR upper limits constrain R-parity violating couplings.
- Leptoquarks in Pati-Salam model of quark-lepton Unification



Experimental Status

- Purely leptonic B decays have not yet been observed.
- BR upper limits exist from CLEO, Belle, and BaBar:

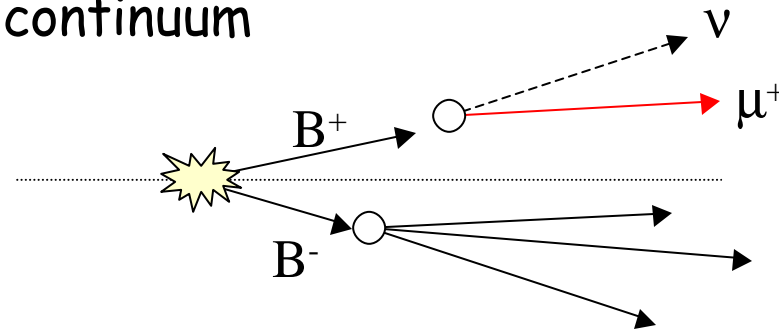
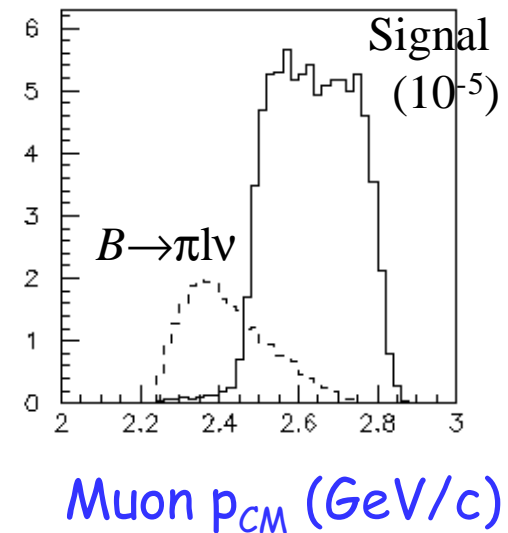
	BaBar(81 fb ⁻¹)	Belle (60 fb ⁻¹)	CLEO (≈2 fb ⁻¹)
BR(B ⁺ → μ ⁺ ν)	< 6.6×10 ⁻⁶	< 6.8×10 ⁻⁶	< 2.1×10 ⁻⁵
BR(B ⁺ → e ⁺ ν)	-	< 5.4×10 ⁻⁶	< 1.5×10 ⁻⁵

CLEO, Belle, and BaBar have all used very similar analysis techniques.

- Future hadronic experiments (LHC-B and B-TeV) will have difficulty with these decays due to missing energy.

Current Analysis Method

- The charged lepton is mono-energetic in the B rest frame ($p^* \approx m_B/2$).
- Select muons in the expected momentum range. The rest of the visible energy should be from the opposite B.
- Reconstruct opposite B from remaining tracks and clusters. Make selection based on m_{ES} and ΔE .
- Use shape variables to suppress continuum background.
- Primary backgrounds:
 - ◆ continuum with mis-id π and significant energy loss
 - ◆ $b \rightarrow ul\nu$

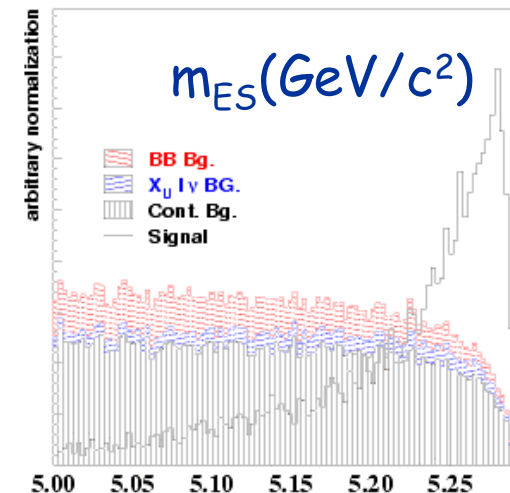
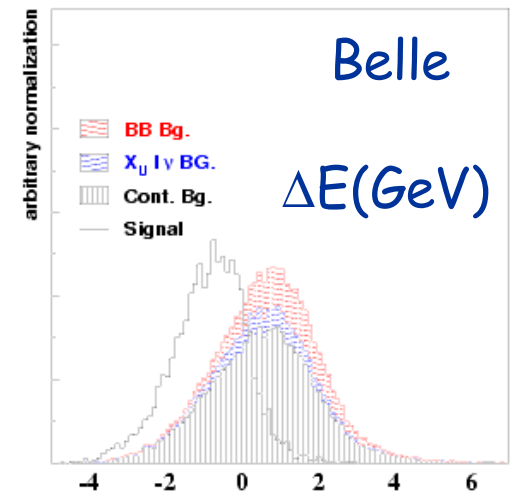


ΔE and m_{ES} (Opposite B)

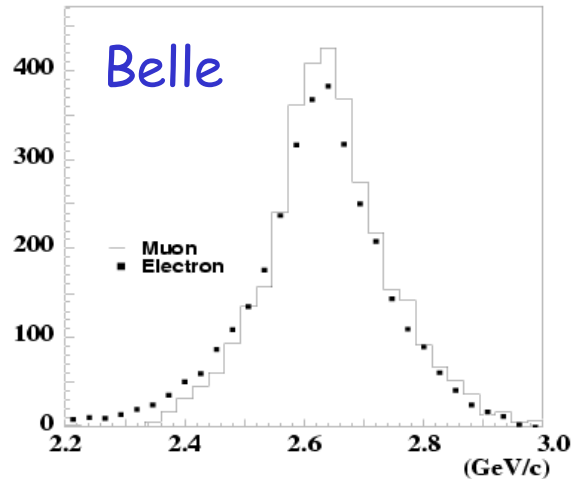
For all events with a well-identified muon with $p_{CM} \sim m_B/2$, we attempt to reconstruct an opposite B.

- muon is removed from event.
- B is formed from the remaining charged tracks and neutral calorimeter clusters.
- Identify muons, electrons, kaons, protons and substitute appropriate mass.
- Events with extra leptons are rejected.
- Calculate ΔE and m_{ES} ,

$$\Delta E = E_B - E_{Beam} \quad m_{ES} = \sqrt{E_{Beam}^2 - \vec{p}_B^2}$$

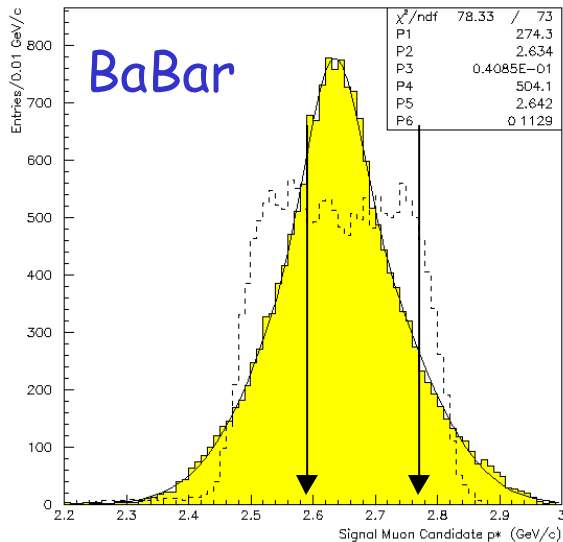


p^* Calculation



Use the opposite B momentum direction to boost the lepton to the reconstructed B rest frame assuming B momentum is 320 MeV/c.

Belle performs likelihood fit to this distribution.



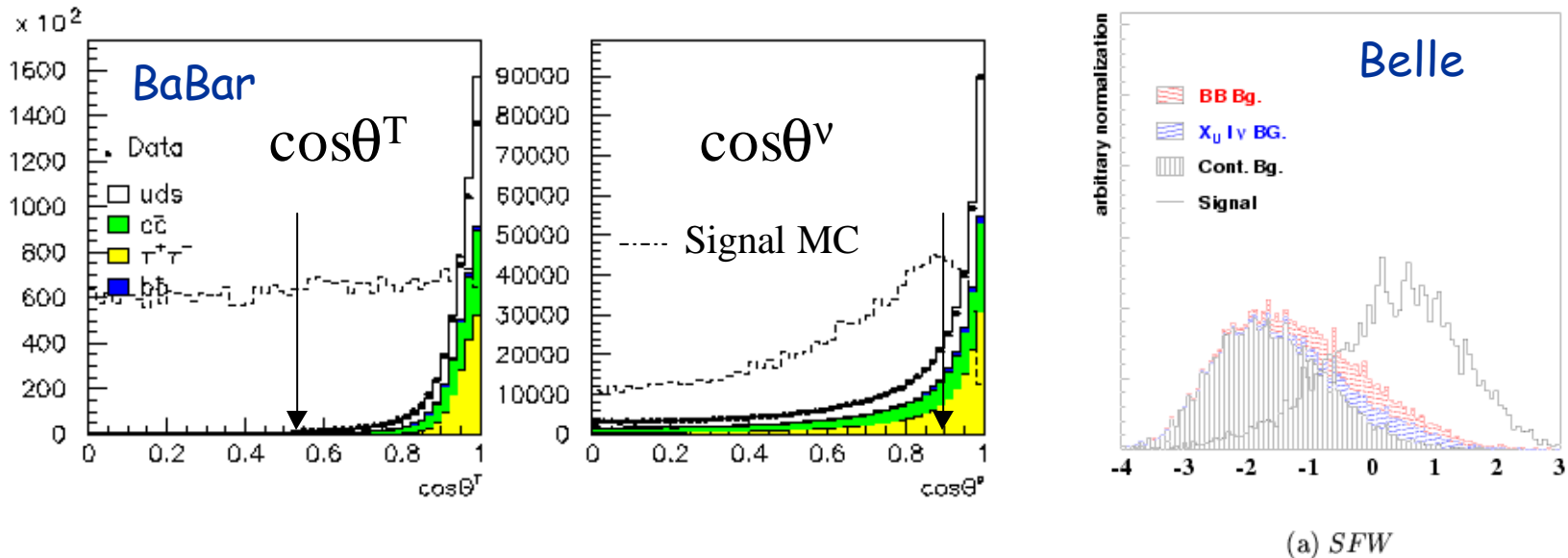
BaBar Requires:

$$2.58 > p^* > 2.78 \text{ GeV/c}$$

The cut is asymmetric since backgrounds decreases vs p^* .

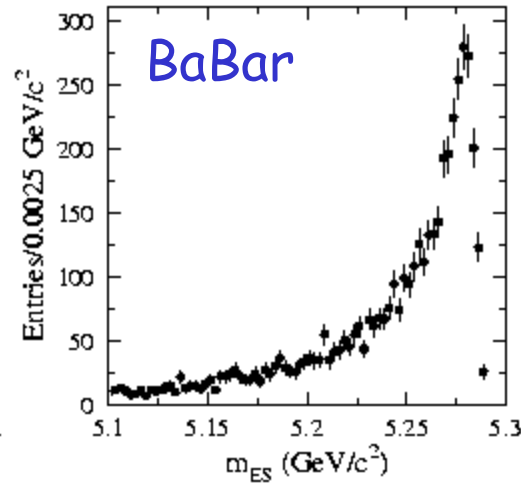
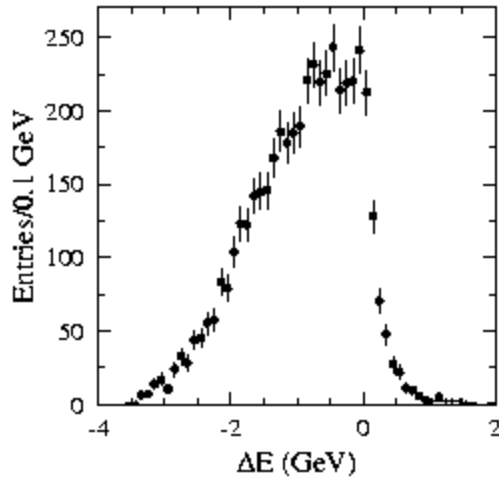
Continuum Suppression

Suppress continuum using event shape variables,



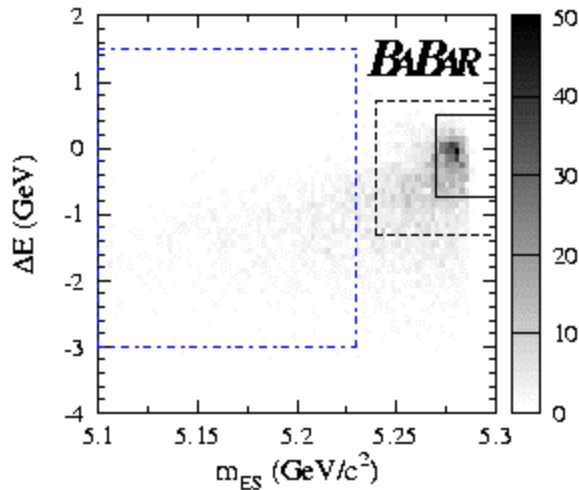
- $\cos\theta^T$: angle of muon w/r thrust axis of the rest of the event.
- $\cos\theta^\nu$: direction of the missing momentum in lab frame.
- Belle also includes a "super" Fox-Wolfram variable.

Signal ΔE vs m_{ES}



52,000 $B^+ \rightarrow \mu^+ \nu$ MC
 $\epsilon = 2.236 \pm 0.065 \%$

Year	efficiency(%)
2000	2.63 ± 0.13
2001	2.24 ± 0.10
2002	1.92 ± 0.10



Signal box:

$$m_{ES} > 5.27 \text{ GeV}$$

$$-0.75 < \Delta E < 0.5 \text{ GeV}$$

Blinding box:

$$m_{ES} > 5.24 \text{ GeV}$$

$$-1.3 < \Delta E < 0.7 \text{ GeV}$$

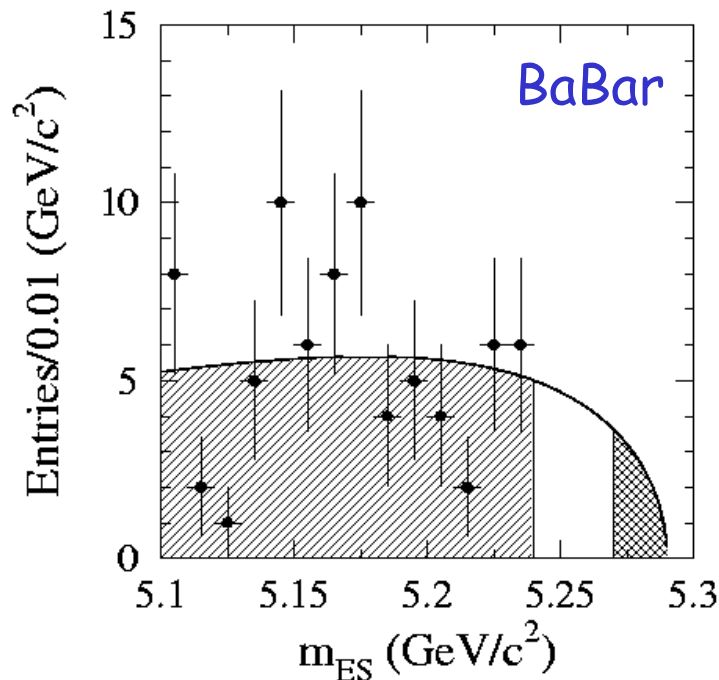
GSB:

$$5.10 > m_{ES} > 5.23 \text{ GeV}$$

$$-3.0 < \Delta E < 1.5 \text{ GeV}$$

Background Estimate

The background is estimated by extrapolating from the data sidebands. We assume that the background m_{ES} distribution has an Argus shape:



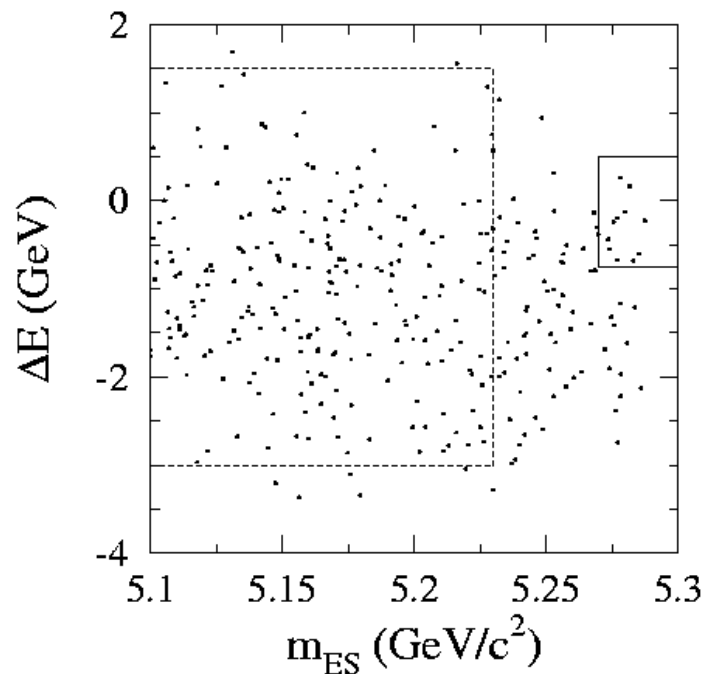
- Fit Argus to data in the region,
 $5.1 < m_{ES} < 5.24 \text{ GeV}/c^2$
 $-0.75 < \Delta E < 0.5 \text{ GeV}$
- Fix endpoint at 5.29 (E_{beam})

$$N_{Bkg} = N_{fit} \times \frac{\int_{5.27}^{5.29} A(m_{ES}) dm_{ES}}{\int_{5.10}^{5.24} A(m_{ES}) dm_{ES}}$$

$$N_{Bkg} = 5.0^{+1.8}_{-1.4} \text{ events}$$

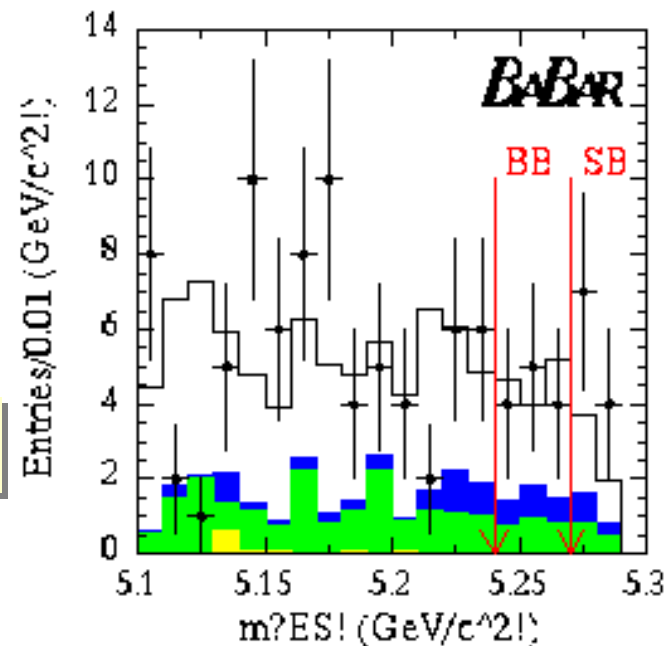
MC indicates that the remaining background is 57% uds, 23% cc, 20% BB.

BaBar Results



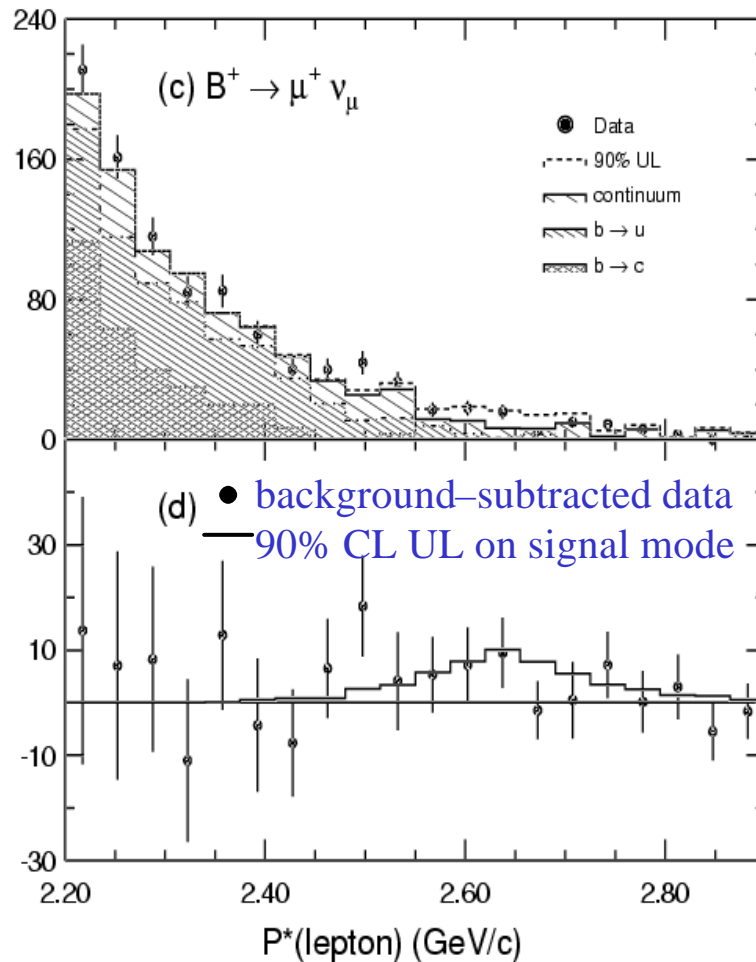
- We see **11** events in the signal box.
- The probability of observing 11 or more events when 5.0 ± 1.6 were expected is about 4%.

$BR(B^+ \rightarrow \mu^+ \nu) < 6.6 \times 10^{-6}$ (90% CL)



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hep-ex/0307047

Belle Likelihood Fit



Belle performs a likelihood fit to the p^* distribution of signal muon candidates.

$$N(\text{signal}) = 18 \pm 21 \pm 6$$

$$BR(B^+ \rightarrow \mu^+ \nu) < 6.8 \times 10^{-6} \text{ (90\% CL)}$$

Analysis Comparison

	BaBar(81 fb ⁻¹)	Belle(60 fb ⁻¹)	CLEO(2 fb ⁻¹)
p*(GeV/c)	[2.58, 2.78]	-	[2.545, 2.745]
cosθ ^T	< 0.55	< 0.65	< 0.7
m _{ES} (GeV/c ²)	> 5.27	> 5.23	> 5.23
ΔE(GeV)	[-0.75, 0.5]	[-1.5, 0.0]	[-2.0, 0.5]
μ ID ε	≈ 61%	≈ 90%	
signal ε(%)	2.09 ± 0.14	13.6±1.2	13±1
observed events	11	18±21±6 (signal)	2
BR(B ⁺ → μ ⁺ ν)	< 6.6×10 ⁻⁶	< 6.8×10 ⁻⁶	< 2.1×10 ⁻⁵

10^{36} Luminosity - Pravda MC

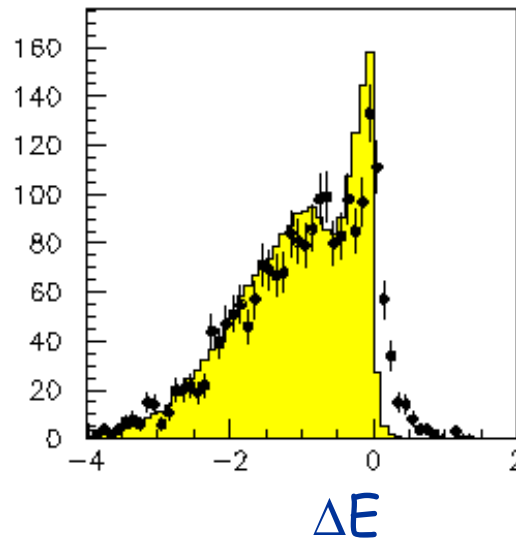
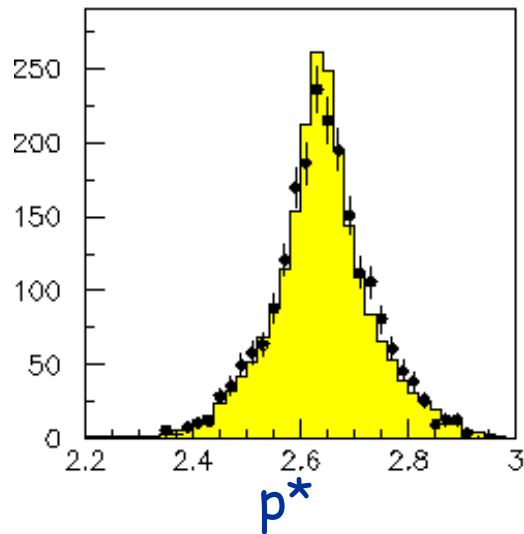
Use Pravda fast MC to simulate $\sim 5 \text{ ab}^{-1}$ of:

- $B \rightarrow \mu\nu$
- $B \rightarrow X_{\mu}\mu\nu$
- $e+e^- \rightarrow uds$
- $e+e^- \rightarrow cc$

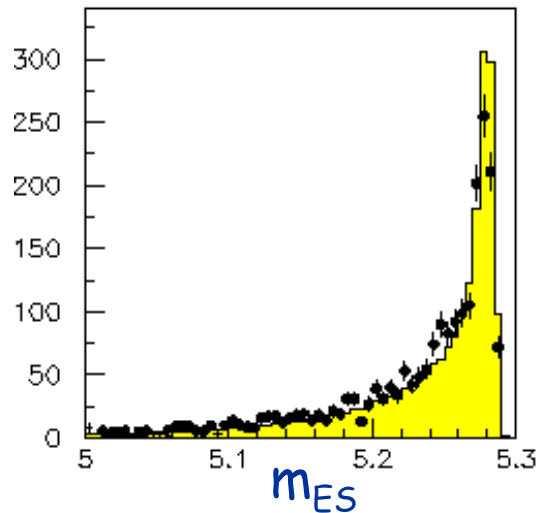
Assumptions we make:

- $b \rightarrow c\mu\nu$ background is negligible.
- $e+e^- \rightarrow t+t^-$ background is negligible.
- Muon ID for current BaBar comes from PID tables ($\sim 61\%$).
Muon ID at SuperBaBar is 90%.
- Hadron (π/K) mis-ID is 2% at current BaBar
1% at SuperBaBar
- For continuum backgrounds, we do not apply muon ID.
We scale the luminosity by the assumed hadron mis-ID.

Pravda/SP4 Comparison



■ Pravda
● SP4
 $B \rightarrow \mu\nu$ signal MC



Limitations of Pravda:

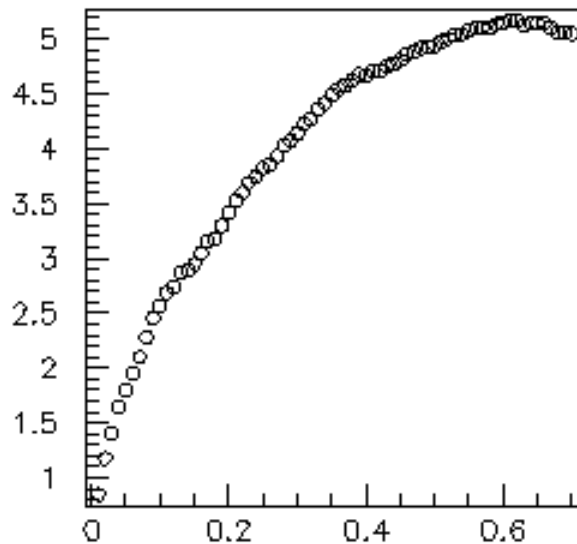
- No simulation of fake tracks and clusters.
- Detector interaction of K_L appears to be missing (enhanced $B^+ \rightarrow K_L \pi^+$ etc).
- No Beam Backgrounds.

Event Yields (81 fb^{-1})

Source	<u>Signal Box</u>		<u>GSB</u>	
	SP4	Pravda	SP4	Pravda
$B^+ \rightarrow \mu^+ \nu$	0.73 ± 0.01	1.4	0.76 ± 0.01	1.06
$B^+ \rightarrow \pi^0 \mu \nu$	0.30 ± 0.12	0.24	1.26 ± 0.23	1.65
$B^+ \rightarrow \rho^0 \mu \nu$	0.00 ± 0.00	0.11	0.79 ± 0.21	1.03
$B^+ \rightarrow \omega \mu \nu$	0.07 ± 0.05	0.09	0.50 ± 0.18	0.49
$B^0 \rightarrow \pi^+ \mu^- \nu$	0.16 ± 0.09	0.65	1.68 ± 0.31	3.97
$B^0 \rightarrow \rho^+ \mu^- \nu$	0.03 ± 0.03	0.14	2.03 ± 0.23	1.80
$b \rightarrow \text{fake } \mu$	0.16 ± 0.07	0.98	2.62 ± 0.24	1.96
cc	1.29 ± 0.23	1.7	53.69 ± 5.31	51.9
uds	3.26 ± 0.35	3.7	137.8 ± 3.6	194.2
Total Bkg	5.3 ± 0.5	7.6	200.4 ± 6.7	257.0

Cut Re-Optimization

With higher luminosity the optimum values of analysis cuts may change. Try Re-optimizing $|\cos\theta_T|$ cut with signal boxes of various sizes (ΔE window from 300 MeV to 1.25 GeV) and $2.55 < p^* < 2.75 \text{ GeV}/c$.



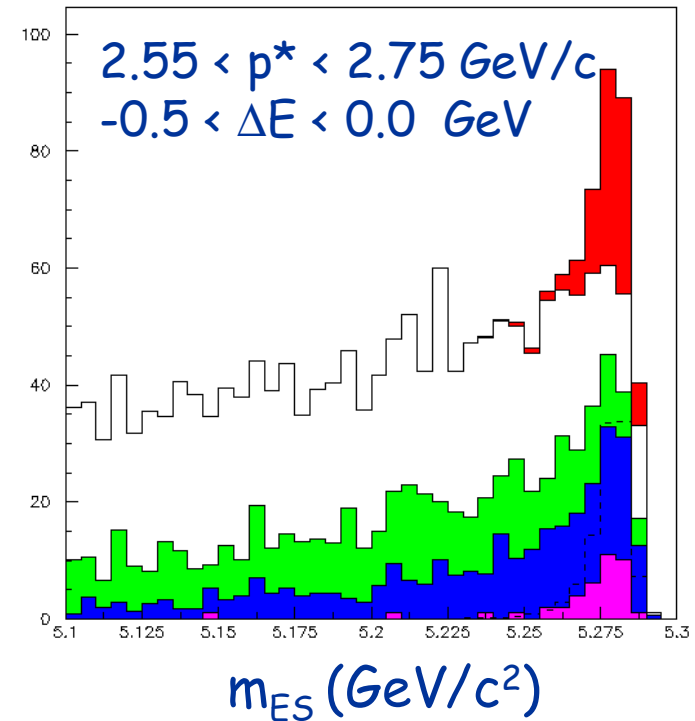
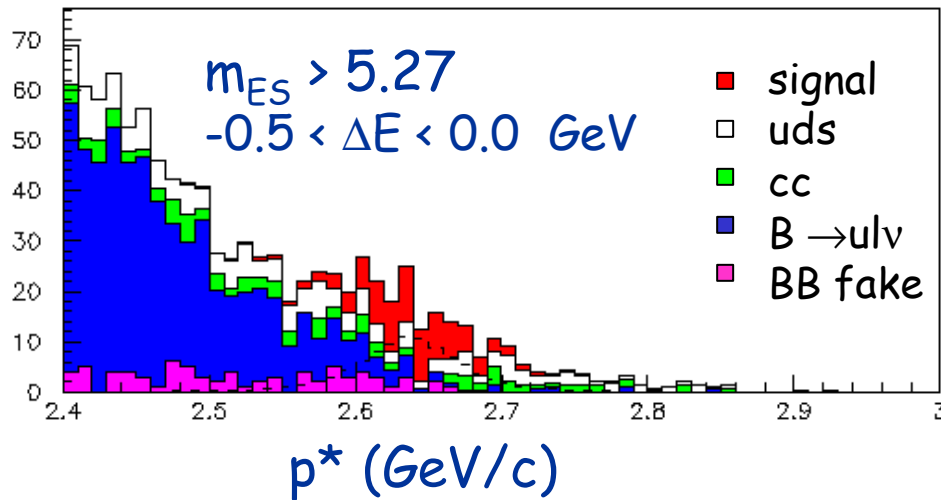
$$S/(S+B)^{1/2}$$

Resulting Cuts:

- $-0.82 < \cos\theta_\mu < 0.92$
- $2.55 < p^* < 2.75 \text{ GeV}/c$
- $-0.76 < |\cos\theta_\nu| < 0.95$ (EMC)
- No additional leptons
- Event Charge = 0 *New*
- $|\cos\theta_T| < 0.6$
- $-0.5 < \Delta E < 0.0 \text{ GeV}$
- $mES > 5.27 \text{ GeV}/c^2$

$$\text{Signal } \varepsilon \sim 4\% \quad S/(S+B)^{1/2} \sim 5.1 \\ (1.7\% \text{ SP4})$$

Pravda Results

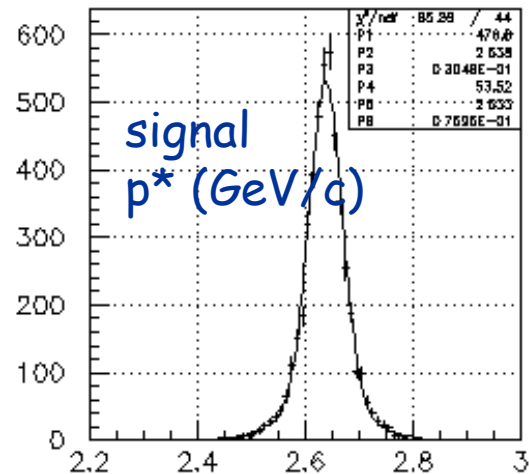
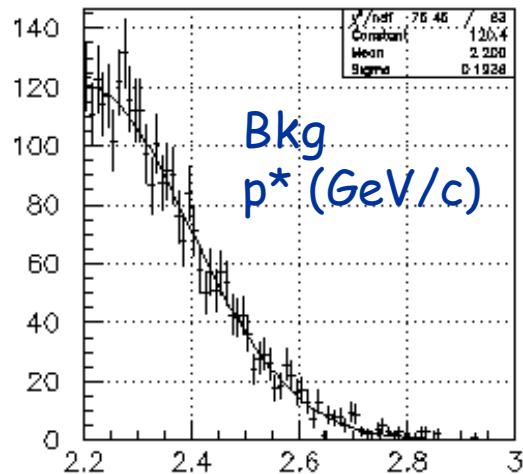


For m_{ES} , ΔE , p^* cuts above:

Signal	89 events
Bkg	209
uds	71
cc	38
B → ulv	72
BB fake	28

85% of the continuum background involves a neutral hadron!

p* Fit

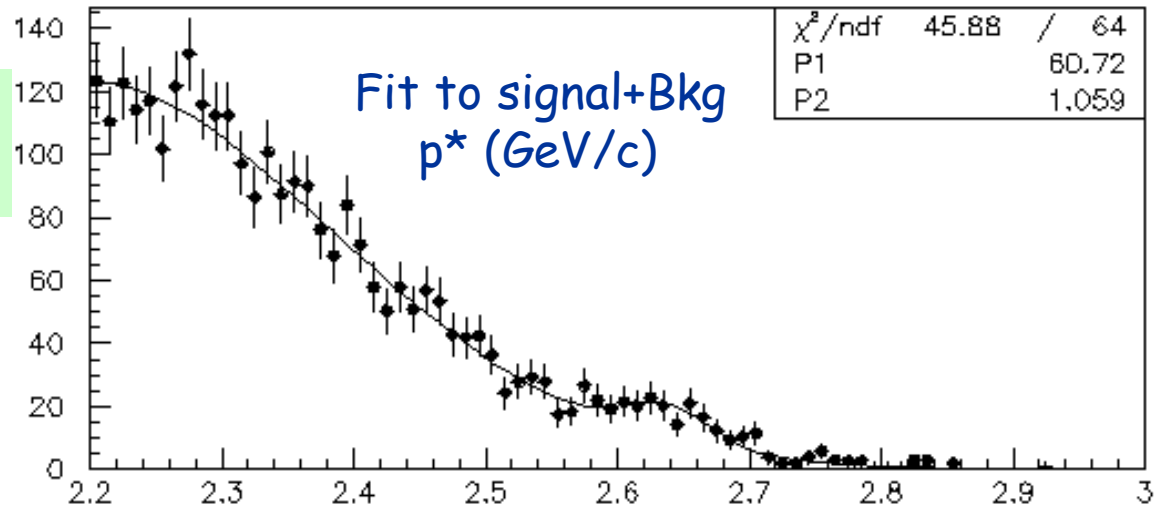


Background PDF:
Gaussian
Signal PDF:
2 Gaussian

In future, we could fit ΔE , m_{ES} , p^* simultaneously

$N(\text{signal}) = 106 \pm 16$
 $\sigma \approx 15\%$

For $2 \times \text{BF}(e)$
 $s \rightarrow 9\%$
For $\frac{1}{2} \text{BF}(e)$
 $s \rightarrow 27\%$



Systematic Uncertainty

Calculate upper limit using: $BR(B^+ \rightarrow m^+n) < \frac{UL(n-b)}{\#B^\pm \cdot e}$

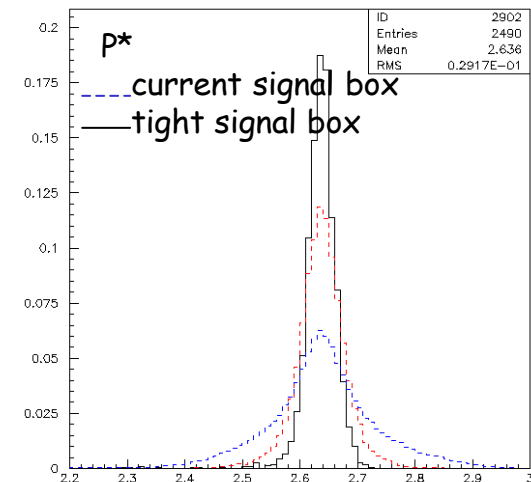
Source	Correction	Uncertainty
Background subtraction	-	1.6 events
B Counting	-	1.1%
Signal Efficiency	0.932	6.3%
Tracking Efficiency(muon)	0.992	2.0%
Muon ID	-	4.2%
Opposite B Reconstruction	0.94	4.3%

Systematic uncertainty is dominated by muon ID and opposite B reconstruction efficiency. These are determined by control samples \Rightarrow decrease as $L^{1/2}$.

$B^+ \rightarrow \mu^+ \nu$ in the Recoil?

- We could reduce the background significantly if we require a fully reconstructed B tag (at the expense of efficiency).
- The simplicity of the signal side (1 track) improves the B tagging efficiency and combinatorial background.
- $B^+ \rightarrow \tau^+ \nu$ analyses have demonstrated B tagging efficiencies of:
 - ~ 0.2% semi-exclusive hadronic modes $B^+ \rightarrow D^{(*)0} X^+$
 - ~ 0.45% semi-leptonic modes $B \rightarrow D \ell^- \bar{\nu}_\ell$
- The muon p^* distribution improves given better knowledge of the opposite B direction.
- Possible signal-side selection:
 - * 1 remaining track (91% acceptance)
 - * passes muon ID (90%)
 - * $2.6 < p^* < 2.7 \text{ GeV}$ (95%)

$\epsilon \approx 78\%$



Expected Yields

- Assume:
 $\text{signal } \varepsilon = 0.6\%(\text{BRECO tag}) \times 78\%(\text{signal-side}) \approx 0.5\%$
- In 5 ab^{-1} we expect:
 $N(\text{signal}) \approx 5.25 \times 10^9 \text{ B}^\pm \times 4 \times 10^{-7}(\text{BR}) \times 0.5\% \approx 10.5 \text{ events}$
- Backgrounds have been estimated in current $\text{B} \rightarrow \tau \nu$ analysis:

$198.4 \text{ fb}^{-1} \text{ B}^+\text{B}^- \text{ Generic:}$	0 events	} SP4
$190.5 \text{ fb}^{-1} \text{ B}^0\text{B}^0 \text{ Generic:}$	0 events	
$50.9 \text{ fb}^{-1} \text{ cc Generic:}$	0 events	
$50.4 \text{ fb}^{-1} \text{ uds Generic:}$	0 events	
$44 \text{ fb}^{-1} \tau^+\tau^- \text{ Generic:}$	0 events	
$985.2 \text{ fb}^{-1} \text{ B}^+ \rightarrow \text{D}^{(*)0} \nu, \text{ B}^- \rightarrow \text{X:}$	4 events (Pravda)	
	$3 \text{ B}^+ \rightarrow \pi^0 \mu^+ \nu, 1 \text{ B}^+ \rightarrow \text{K}_L \pi^+$	

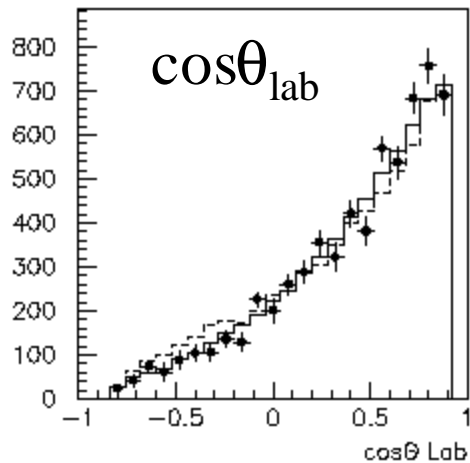
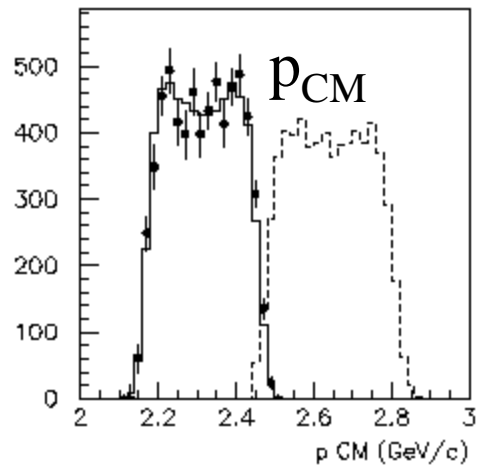
Assuming backgrounds are negligible, $\sigma(\text{BF}(\text{B} \rightarrow \mu \nu)) \approx 30\%$

Conclusions

- $B^+ \rightarrow \mu^+ \nu$ is sensitive to poorly constrained SM parameters (f_B and $|V_{ub}|$) as well as new physics.
- With 5 ab^{-1} , we estimate that the (SM) $\text{BR}(B^+ \rightarrow \mu^+ \nu)$ could be measured with a precision of 10-30% using inclusive and "tag B " techniques.
- Assuming an improved theoretical uncertainty in f_B ($\sim 2\%$), $|V_{ub}|$ could be determined to 5-15%.
- The critical detector considerations are acceptance and neutral hadron ID (and muon ID, of course). The effect of beam backgrounds is unknown.
- We do not expect these measurements to be possible at hadronic machines. Hadronic machines may, however, provide complimentary information on leptonic decays involving B_s and B_c .

BackUps

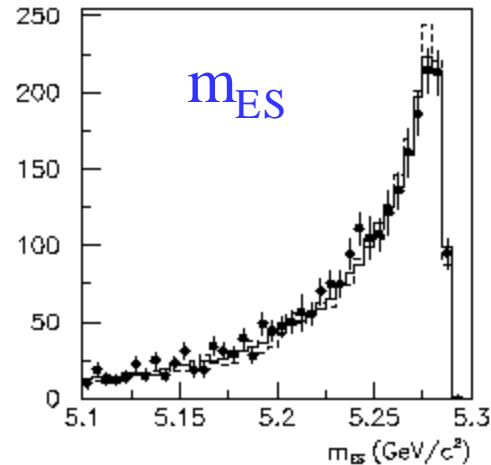
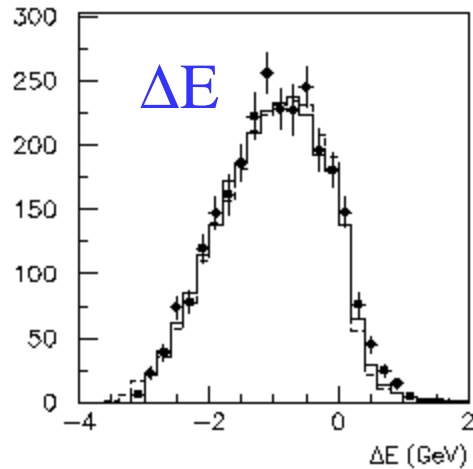
$B^+ \rightarrow D^{(*)0} \pi^+$ Control Sample



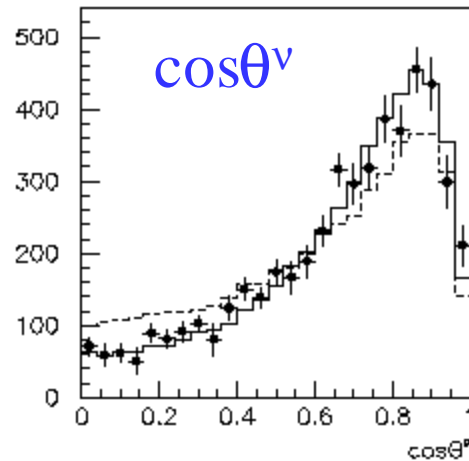
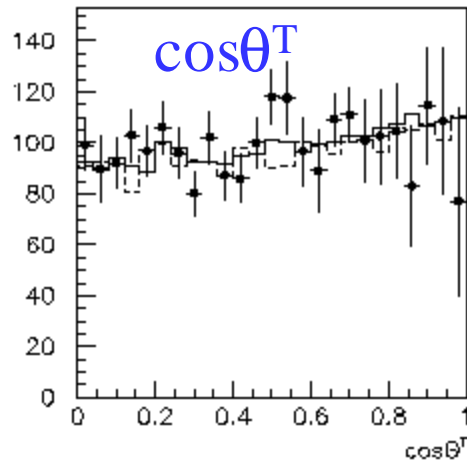
B reconstruction systematics are evaluated with fully reconstructed $B^+ \rightarrow D^{(*)0} \pi^+$ events in data.

- pion is mono-energetic like signal muon
- once D is located it can be ignored to simulate neutrino. We reconstruct $D^* \rightarrow D^0 \gamma$ and $D^0 \pi^0$ with $D^0 \rightarrow k^+ \pi^-$ only.
- opposite B reconstruction is then performed as if signal.
- we require $|\Delta E| < 50$ MeV and $m_{ES} > 5.275$ for the fully-reconstructed B
- luminosity-scaled off-peak data is subtracted
- we have 11,922.2 events in 2000-2002 data.

$B^+ \rightarrow \mu^+ \nu$ vs $B^+ \rightarrow D^0 \pi^+$



- $B^+ \rightarrow D^0 \pi^+$ data
- $B^+ \rightarrow D^0 \pi^+$ MC
- $B^+ \rightarrow \mu^+ \nu$ MC



After all cuts, the data/MC efficiency ratio is

$$R = 0.94 \pm 0.04$$

which is applied as a correction to the MC signal efficiency.

