



# Semiexclusive $B^0 \rightarrow \tau^+ \tau^-$ Update



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# Analysis Overview



## Event selection:

- A tag  $B$  meson decaying in a hadronic mode is fully reconstructed using the semiexclusive reconstruction:  $B^0 \rightarrow D^{(*)-} n \pi m K r K_S q \pi^0$  (where  $n + m + r + q < 6$ ). We use `RecoilAnalysis/baseClass.cc` for the interface to the semiexclusive ntuples.
- Events with two remaining tracks identify the decays to single track tau modes:  $\tau \rightarrow \pi\nu, \rho\nu,$  or  $l\nu\bar{\nu}$ . This accounts for 51% of all tau pair modes.
- Event remainder kaon, electron, muon and neutral pion multiplicity consistent with a tau pair decay are required. Kinematic correlations in momenta and remaining unassigned neutral energy are exploited by a neural network analysis.

## Changes since the last presentation (February Collaboration Meeting):

- We now use maximum likelihood rather than least chi-squared fits for background subtraction.
- A new preselection on signal side tracks and neutral pions has been implemented.
- The signal selection has been optimized for best upper limit.
- Fit, tracking, PID and neutrals systematics have been evaluated.
- BAD #542 version 3 was released.

# Monte Carlo and Data Samples



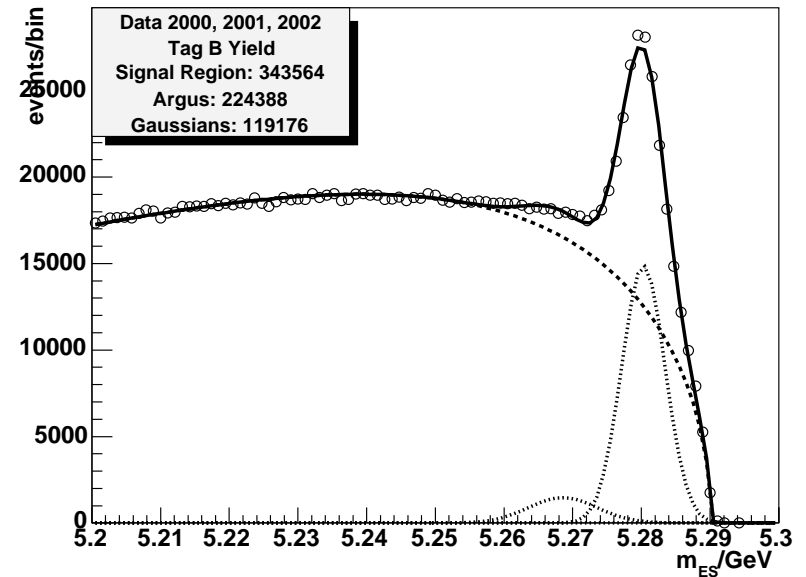
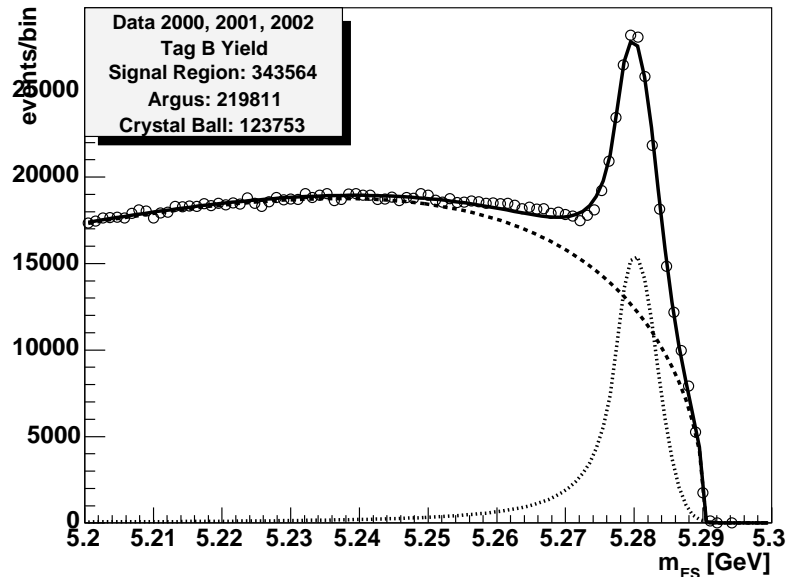
SP4 signal (cocktail and generic) and generic background  $B_0 B_0$  Monte Carlo simulation (cocktail and generic) samples used in this analysis:

Sample	$\sigma/nb$	$\mathcal{L}/fb^{-1}$	Events
$B_0 \rightarrow \tau^+ \tau^- + CC$ (FSR)	$1.63 \times 10^{-8}$	$1.21 \times 10^7$	$1.98 \times 10^5$
... $\tau^+ \tau^-$ vs $D^*(\text{star})X$ cocktail	$1.7 \times 10^{-10}$	$1.88 \times 10^9$	$3.15 \times 10^5$
$B_0 B_0$ generic	0.525	????	????
Weighted $B_0 \rightarrow DX$ and $D^*(\text{star})X$ cocktail	$5.4 \times 10^{-3}$	401	$2.166 \times 10^5$

★ This table in BAD #542 version 3 is badly incorrect.

- It is unknown how many  $B_0 B_0$  events generated the semiexclusive ntuples, stored in `VubAnalysis/chains/generic`.
- SP5 signal samples are not yet included in the analysis. 70K of the generic and 69K of the cocktail have been generated so far.
- Data samples are Runs 1 and 2, stored in `VubAnalysis/chains/data`. Runs 3 and 4 will be included in the final version of the analysis.

# Tag $B$ Yield $N_{B^0\bar{B}^0}$



- At left, a Crystal Ball fit to  $m_{ES}$  in the tag  $B$  sample after requiring  $m_{ES} \in [5.2, 5.3]$  GeV and the reconstruction mode purity greater than 10%. The yield is 123753 in the peak.
- At right, a fit to the data tag yield using two Gaussians rather than a Crystal Ball. The yield is 119176, giving a relative systematic error of 3.7% on the data tag yield  $N_{B^0\bar{B}^0}$ .

# Preselection



Four requirements are imposed on the samples before beginning this analysis:

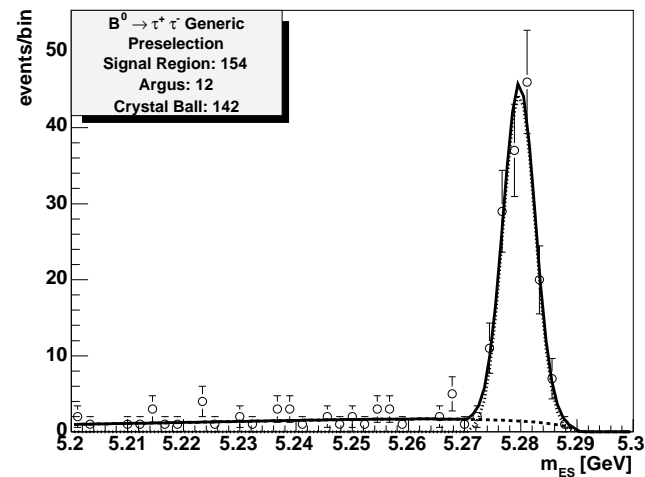
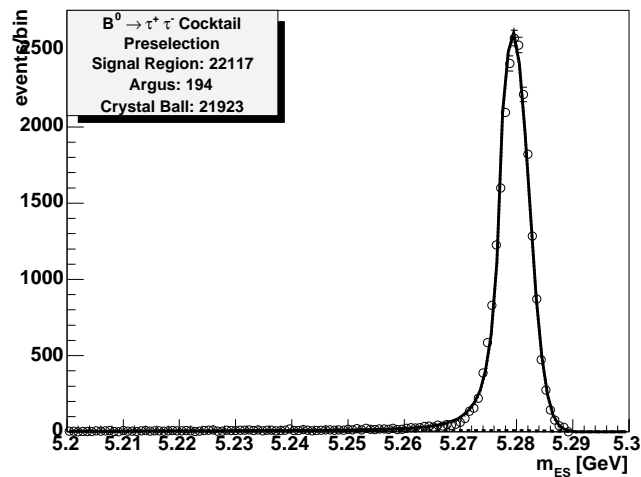
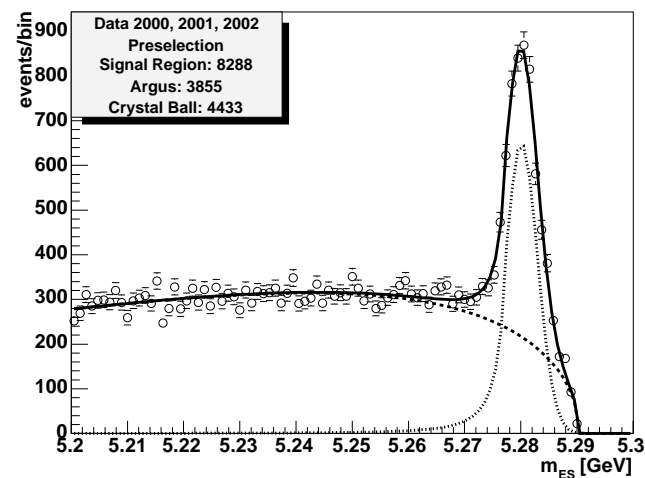
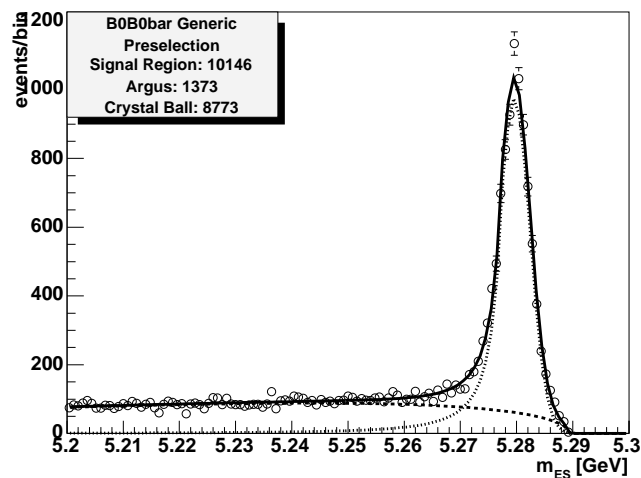
- tag  $B$  energy-substituted mass  $m_{ES} \in [5.2, 5.3]$  GeV
- tag  $B$  reconstruction mode purity greater than 10%
- two very loose track candidates reconstructed opposite the tag  $B$
- two or fewer neutral pions reconstructed opposite the tag  $B$

The yields are

- B0B0bar: 8773 events
- Data Runs 1,2: 4433 events
- Signal Generic: 142 events
- Signal Cocktail: 21923 events

Plots of  $m_{ES}$  are on the following slide: clockwise from top left are the B0B0bar, data, signal generic, and signal cocktail samples.

# Preselection $m_{ES}$ Plots



# Analysis Chain Overview



- Preselection (two signal side GoodTracksVeryLoose, two or fewer pi0DefaultMass). Total charge in GoodTracksLoose is zero. GoodTracksLoose multiplicity is two. Kaon veto: zero candidates in KMicroLoose, KsDefault, KlongEmcTight. Unassigned neutral energy (GoodPhotonsLoose less pi0DefaultMass) less than 0.5 GeV.
- Signal eMicroTight, muMicroLoose, pi0DefaultMass multiplicities and  $\rho$  selection:

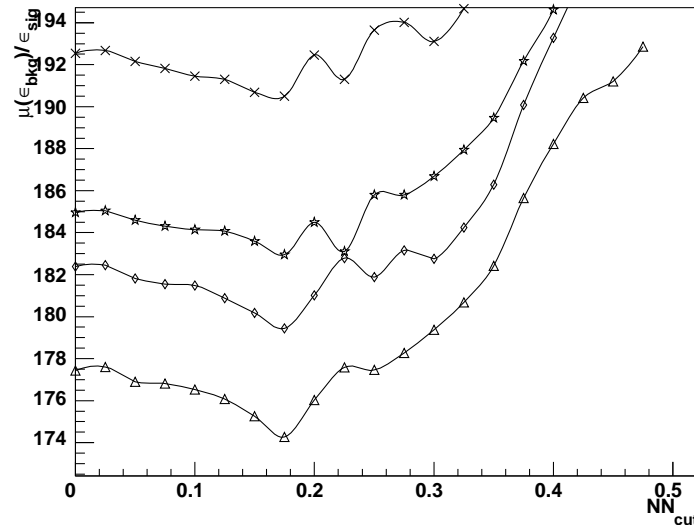
Selection Mode	BR	$N_e + N_\mu$	$N_{\pi^0}$	$m_{(\pi\pi^0)}$	Efficiency
0: $l'l'4\nu$	0.124	2	0	na	0.47
1: $l\pi 3\nu$	0.078	1	0	na	0.64
2: $l\rho 3\nu$	0.177	1	1	[0.6, 1.0] GeV	0.36
3: $2\pi 2\nu$	0.012	0	0	na	0.78
4: $\pi\rho 2\nu$	0.056	0	1	[0.6, 1.0] GeV	0.49
5: $2\rho 2\nu$	0.063	0	2	[0.6, 1.0] GeV	0.29

- Neural network output greater than 0.18. The inputs are: reconstruction mode, cosine of angle between tau daughter candidates in  $B$  frame, tau daughter candidate momenta and unassigned neutral energy (below 0.5 GeV).

# Signal Selection Optimization



We optimize for the lowest upper limit on the branching ratio. The neural network optimization proceeds by applying all requirements in the analysis chain and then varying the neural network output cut value ( $N_{cut}$ ). The maximum signal presence for  $N_{cut}$  is then  $\mu_{sig}^{90}/\epsilon_{sig}$ . We assume  $n_{obs}$  to be the equal to the expected mean background  $\mu_{bkg}$ .



Triangles indicate maximum signal presence  $\mu_{sig}^{90}(\epsilon_{bkg})/\epsilon_{sig}$  versus neural net cut value. Diamonds include the Monte Carlo simulation statistical, fit parameter and fit pdf error; stars include both fit and the neutrals error; crosses include fit, neutrals and  $e, \mu, K$  particle identification error.

# Efficiencies in B0B0bar and Data



Requirement	B0B0bar Monte Carlo		Data 2000,2001,2002	
	Peak Yield	Efficiency	Peak Yield	Efficiency
Tag B Yield	$196068 \pm 480$	$0 \pm 0$	$123753 \pm 839$	$0 \pm 0$
Preselection	$8773 \pm 115$	$100 \pm 0$	$4433 \pm 163$	$100 \pm 0$
$Q_{GTL} = 0$	$6391 \pm 79$	$72.8 \pm 0.835$	$3187 \pm 148$	$71.9 \pm 4.13$
$N_{GTL} = 2$	$6390 \pm 91$	$72.8 \pm 0.977$	$3154 \pm 148$	$71.1 \pm 4.11$
$N_{KML} = 0$	$5240 \pm 77$	$59.7 \pm 0.836$	$2644 \pm 115$	$59.6 \pm 3.28$
$N_{KsD} = 0$	$4456 \pm 74$	$50.8 \pm 0.817$	$2271 \pm 77$	$51.2 \pm 2.46$
$N_{KIET} = 0$	$3029 \pm 59$	$34.5 \pm 0.66$	$1380 \pm 62$	$31.1 \pm 1.76$
$E_{CN} - E_{pDM} < 0.5 \text{ GeV}$	$2287 \pm 47$	$26.1 \pm 0.53$	<i>blind</i>	<i>blind</i>
$mode > -1$	$1186 \pm 35$	$13.5 \pm 0.394$	<i>blind</i>	<i>blind</i>
$N_{out} > 0.18$	$1030 \pm 33$	$11.7 \pm 0.378$	<i>blind</i>	<i>blind</i>

# Efficiencies in Signal

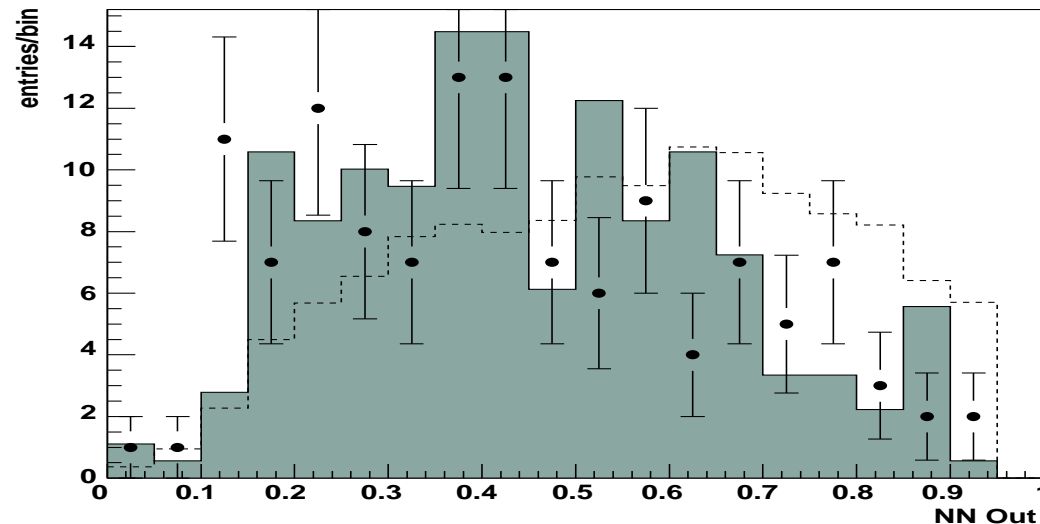


Requirement	Signal Cocktail		Signal Generic	
	Peak Yield	Efficiency	Peak Yield	Efficiency
Tag B Yield	$54993 \pm 240$	$100 \pm 0$	$339 \pm 18$	$100 \pm 0$
Preselection	$21923 \pm 149$	$39.9 \pm 0.219$	$142 \pm 12$	$41.9 \pm 3.03$
$Q_{GTL} = 0$	$19599 \pm 142$	$35.6 \pm 0.215$	$133 \pm 11$	$39.2 \pm 2.95$
$N_{GTL} = 2$	$19529 \pm 142$	$35.5 \pm 0.214$	$133 \pm 11$	$39.2 \pm 2.95$
$N_{KML} = 0$	$17286 \pm 132$	$31.4 \pm 0.203$	$117 \pm 10$	$34.5 \pm 2.82$
$N_{KsD} = 0$	$16508 \pm 129$	$30 \pm 0.201$	$109 \pm 10$	$32.2 \pm 2.76$
$N_{KLET} = 0$	$14051 \pm 120$	$25.6 \pm 0.192$	$95 \pm 9$	$28 \pm 2.55$
$E_{CN} - E_{pDM} < 0.5 \text{ GeV}$	$12414 \pm 111$	$22.6 \pm 0.181$	$77 \pm 8$	$22.7 \pm 2.36$
$mode > -1$	$9642 \pm 98$	$17.5 \pm 0.164$	$55 \pm 7$	$16.2 \pm 2.02$
$N_{out} > 0.18$	$9172 \pm 96$	$16.7 \pm 0.161$	$52 \pm 7$	$15.3 \pm 1.97$

# The Extra $K_S$ Control Sample



The *peaking components* of data (dots),  $B^0 B^0$ bar (solid) and the signal cocktail (dashed) are plotted.

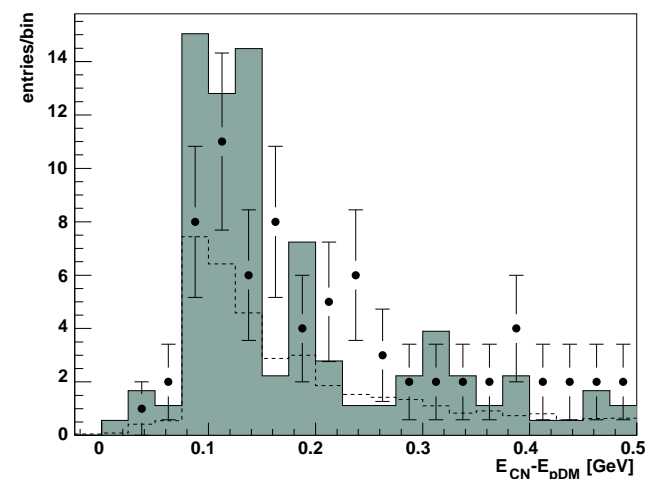
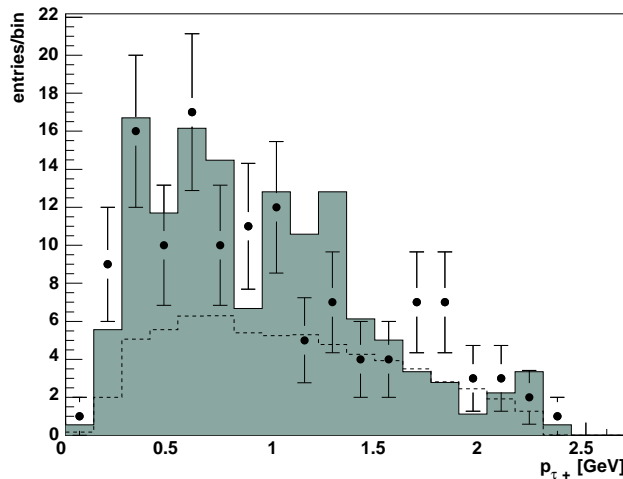
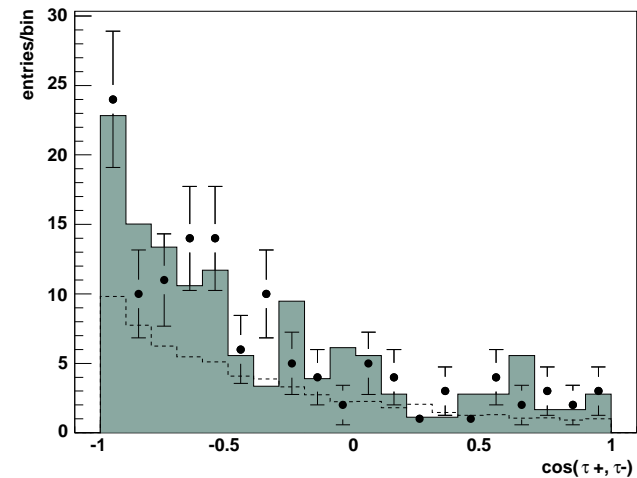
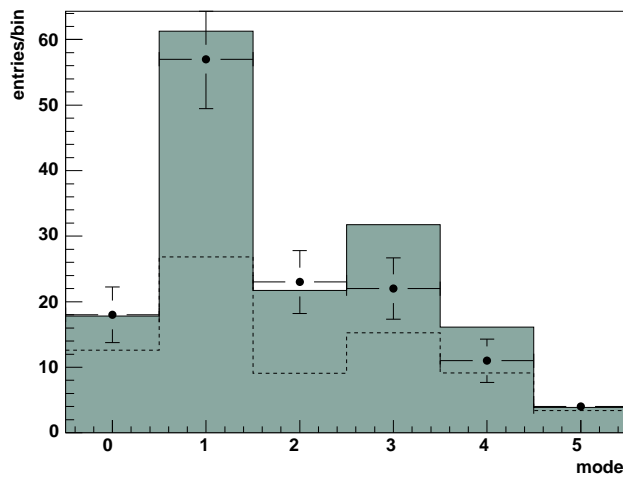


- A typical background event is thus:  $B^0 \rightarrow D^{(*)+}(\rightarrow K_L x_1)x_2$  (where  $K_L$  is undetected). Events like  $B^0 \rightarrow D^{(*)+}(\rightarrow K_S x_1)x_2$  should very closely mimic the background.
- In the *extra  $K_S$*  control sample, the requirement  $N_{K_S D} = 0$  is replaced by the requirement  $N_{K_S D} = 1$ , with the provision that the `KshortDefault` daughter charged pions are invisible to the analysis chain. All other requirements in the signal analysis chain apply.
- From Monte Carlo simulation, the expected number of events is  $128.5 \pm 10.3$ . The observed number of events is  $121 \pm 11$ .

# Control Sample NN Inputs



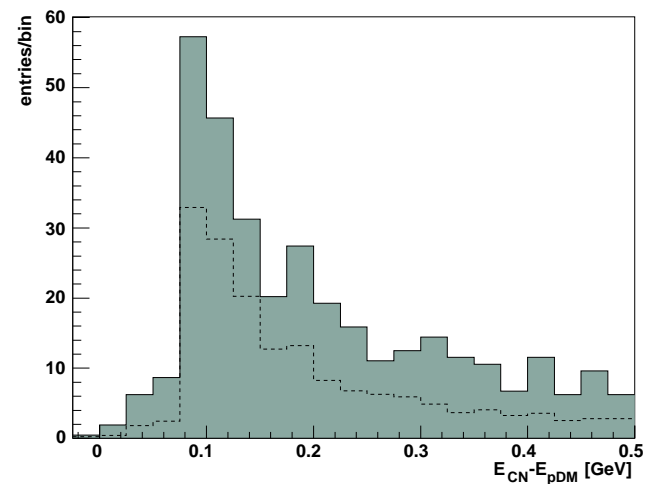
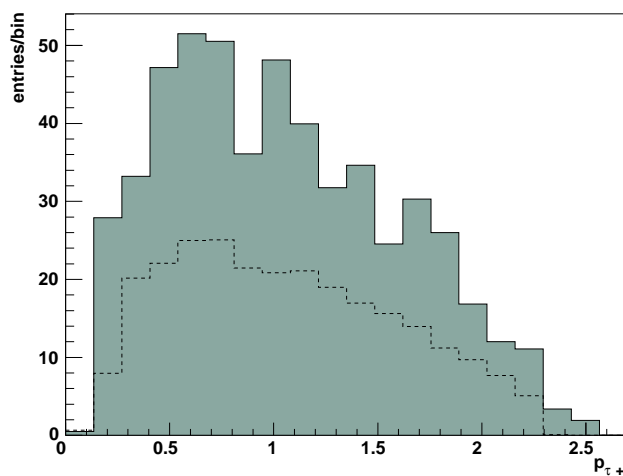
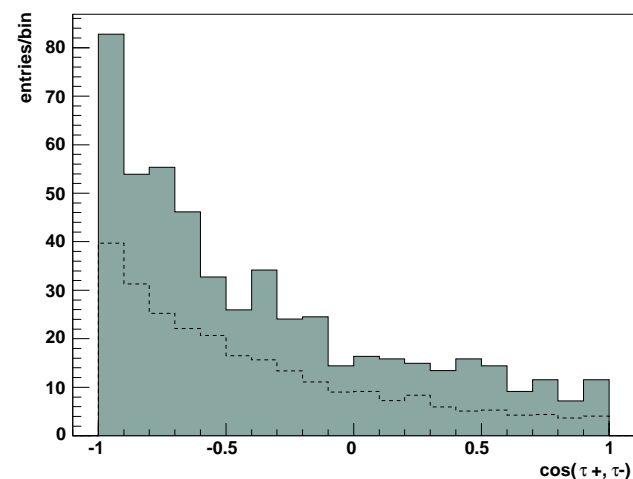
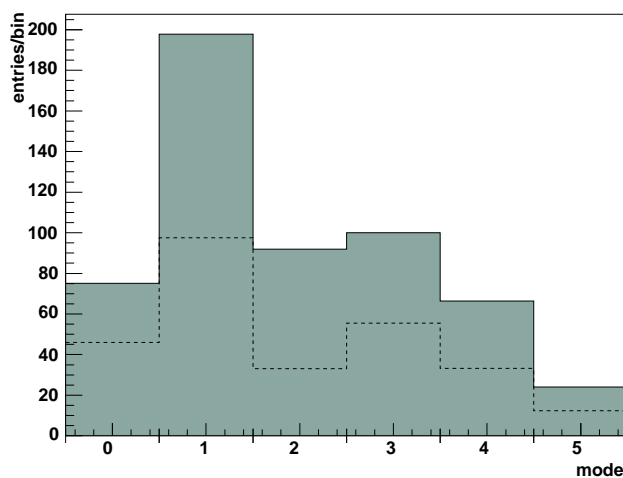
The *peaking components* of data (dots),  $B^0B^0_{\text{bar}}$  (solid) and the signal cocktail (dashed) are plotted.



# Signal Analysis NN Inputs (Blind)



The *peaking components* of data (dots),  $B^0B^0_{\text{bar}}$  (solid) and the signal cocktail (dashed) are plotted.



# Sources of Systematic Error



Several sources of systematic error affect the four quantities ( $\epsilon_{sig}$ ,  $\mu_{bkg}$ ,  $N_{B^0 \bar{B}^0}$  and  $n_{obs}$ ) which will determine the limit on  $\mathcal{B}(B^0 \rightarrow \tau^+ \tau^-)$ .

- For the error due to the choice of probability density function, we refit the  $m_{ES}$  distributions with two Gaussians and an Argus rather than a Crystal Ball and an Argus.
- For two signal side tracks, we take the track reconstruction error to be twice the single track systematic error 0.8% recommended by the tracking group.
- The systematic errors for reconstructing  $e$ ,  $\mu$  and  $K^\pm$  are obtained by comparing the efficiencies before and after the `baseClass` switches `-pe`, `-pm` and `-pk` were employed and calculating the relative difference in efficiency. The PID tables are `RecoilAnalysis/PidTables-200x.txt`.
- The systematic error for neutral energy resolution was obtained by comparing the efficiencies before and after the `baseClass` switch `-SN` was employed.
- The systematic error due to the remaining neutral energy we derive from the extra  $K_S$  control sample: the difference between the Monte Carlo simulation expectation and observation we take to be an upper bound on the error due to the remaining neutral energy systematic.
- An additional track multiplicity error originates in the mismatch between the Monte Carlo simulation of extra junk tracks and the true junk track rate.

# Systematic Errors



Systematic Effect	$\delta\epsilon_{sig(c)}/\epsilon_{sig(c)}(\%)$	$\delta\epsilon_{sig(g)}/\epsilon_{sig(g)}(\%)$	$\delta\epsilon_{bkg}/\epsilon_{bkg}(\%)$
MC Stat and Fit Parameters	0.935	12.5	2.92
Fit PDF Choice	1.18	0.631	0.822
Electron Particle ID	0.477	5.45	0.927
Muon Particle ID	0.545	7.27	3.63
Kaon Particle ID	4.41	9.09	1.52
Neutrals Energy Resolution	0.394	7.27	3.92
Tracking Efficiency	1.6	1.6	1.6
Track Multiplicity	0	0	0
Remaining Neutral Energy	0	0	5.8
Signal Decay Model	0	0	0
Total Error	4.99	19.4	8.78

Relative systematic errors  $\delta\epsilon/\epsilon$  for the signal cocktail efficiency, signal generic efficiency, B0B0bar efficiency. Errors which are set to zero have not yet been evaluated.

# Outlook



Near term plans:

- Finish evaluating systematic errors.
- Finalize limit setting procedure.
- Obtain AWG approval to...
- Meet with our Review Committee.
- Unblind.

Long term plans: Include SP5 signal Monte Carlo, include Runs 3 and 4 and begin work on  $B \rightarrow e\tau, \mu\tau$ :

