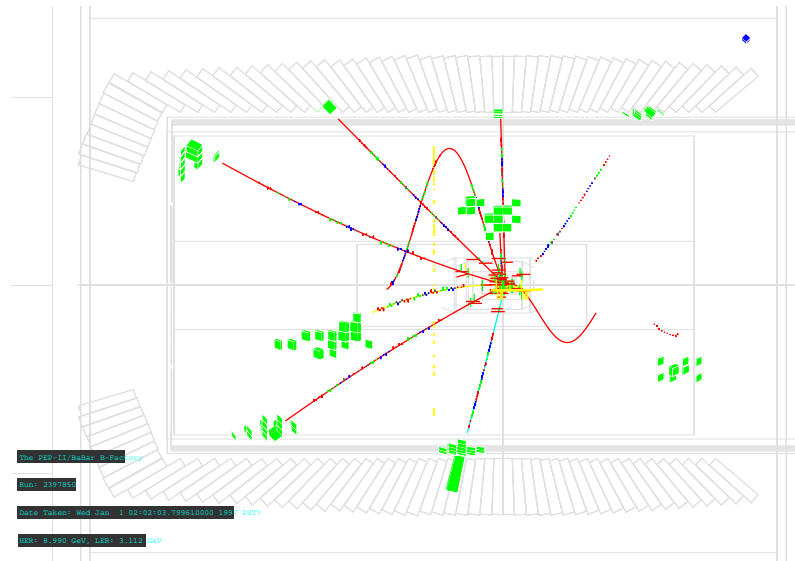




$B^0 \rightarrow \tau^+ \tau^-$ With Hadronic Tags



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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 (October AWG Meeting):

- Incorporated 1M SP5 and SP6 signal generic Monte Carlo events.
- Included a new parameter (the cosine of the angle between the tag B and the rest of the event) which dramatically reduces the background.
- Evaluated our systematic errors, in particular for the signal decay model.
- Established the limit setting procedure and optimized the cut selection for best upper limit.
- Released BAD 542 version 4. Please provide feedback!

Data and Simulation Samples



Data Sample	$\sigma_{B^0 \bar{B}^0} / nb$	\mathcal{L} / fb^{-1}	$B^0 \bar{B}^0$ Events
Run 1	0.5443	19.459	1.0591×10^7
Run 2	0.5512	60.267	3.3221×10^7
Run 3	0.5485	31.067	1.7039×10^7
Run 4	0.5519	99.763	5.5055×10^7
Runs 1-4	0.5505	210.55	1.15906×10^8

We analyzed Runs 1 through 4 data (startup to 2004 summer shutdown) in the BSEmiExcl skim, which yielded 210.55 fb^{-1} of integrated luminosity. The simulation corrections recommended by the tracking, PID and neutrals groups.

- We employ the PID killing tables obtained from Release-14 control samples, provided by the particle identification working group in `$BFROOT/physicstools/pid/tables`.
- We smear the photon energy E resolution obtained in the EMC by resampling the energy from a Gaussian with mean E and width Ec_{sm} , and then scale the resampled energy up by the factor $1 + c_{sc}$ using factors prescribed by the neutral working group.
- The tracking efficiency task force recommends an averaged flat 0.8% efficiency reduction for reconstruction of loose tracks, which corresponds to 1.3% tracking efficiency systematic error per GoodTracksLoose.

Simulation Sample



Simulation Sample	SP Cycle	σ/nb	\mathcal{L}/fb^{-1}	Events
B0->tau+tau- +CC (FSR) (Run1)	SP5	1.63×10^{-8}	7.91×10^6	1.29×10^5
B0->tau+tau- +CC (FSR) (Run2)	SP5	1.63×10^{-8}	1.85×10^7	3.01×10^5
B0->tau+tau- +CC (FSR) (Run3)	SP5	1.63×10^{-8}	9.14×10^6	1.49×10^5
B0->tau+tau- +CC (FSR) (Run4)	SP6	1.63×10^{-8}	3.50×10^7	5.70×10^5
B0B0bar generic	SP5	0.525	396.0	2.079×10^8
BpBm generic	SP5	0.525	396.2	2.080×10^8
ccbar generic	SP5	1.30	110.8	1.441×10^8
uds generic	SP5	2.09	117.4	2.453×10^8
B0B0bar generic	SP6	0.525	300.2	1.576×10^8
BpBm generic	SP6	0.525	266.9	1.401×10^8
ccbar generic	SP6	1.30	8.692	1.130×10^7
uds generic	SP6	2.09	11.48	2.400×10^7
Signal Cocktail	SP4	1.70×10^{-10}	1.88×10^9	3.15×10^5
Background Cocktail	SP4	5.40×10^{-3}	401	2.17×10^6

Tag B Reconstruction



Particle	SemiExclUser Reconstructed Decay
B^0	$D^{(*)} X$
D^{*-}	$D^0 \pi^-$
D^-	$K_S \pi^-, K^+ \pi^- \pi^-, K_S \pi^- \pi^0, K^+ \pi^- \pi^- \pi^0, K_S 3\pi, K^+ K^- \pi^-$
D^0	$K^- \pi^+, K^- \pi^+ \pi^0, K^- \pi^+ \pi^- \pi^+, K_S \pi^- \pi^+$
X	$\pi, K, \pi\pi^0, K\pi^0, \pi K_S, K K_S, \pi 2\pi^0, K 2\pi^0, 3\pi, K 2\pi, 2K\pi, 3\pi\pi^0, K 2\pi\pi^0$ $2K\pi\pi^0, \pi\pi^0 K_S, K\pi^0 K_S, K 2\pi^0 K_S, 2K_S X, 3\pi 2\pi^0, K 2\pi 2\pi^0, 2K\pi 2\pi^0$ $5\pi, K 4\pi, 2K 3\pi, 5\pi\pi^0, K 4\pi\pi^0, 2K 3\pi\pi^0, 3\pi K_S, K 2\pi K_S, 3\pi K_S \pi^0$

- The reconstruction technique employs the SemiExclApp package. It proceeds by reconstructing a seed $D^{(*)}$ and then adds additional pions and kaons until the system is in a $m_{ES}, \Delta E$ signal region.
- From among the many reconstructed candidates in a single event, the B^0 candidate whose mode is reconstructed with the highest integrated purity is selected as the tag B . If the candidate is a charged B the event is rejected. We reject modes with purity less than 10%.
- The semiexclusive n-tuples and the purities have been generated by the package IslBrecoilUserApp (which employs SemiExclApp) in the IslBrecoilUser package by others in analysis-21. [Collaboration Meeting, 7 December 2004](#) – p.5/25

Fitting Procedure



- The combinatorial and continuum background are subtracted by fitting the m_{ES} distribution. Peaking events lying in the signal region defined by $m_{ES} \in [5.27, 5.29]$ GeV are considered tag B signal.
- The m_{ES} fits are maximum likelihood fits performed with the ROOT v3.10/01 interface to the MINUIT v94.1 package.
- Two probability density functions are used in constructing the overall fitting function, a single Argus function and a Crystal Ball function:

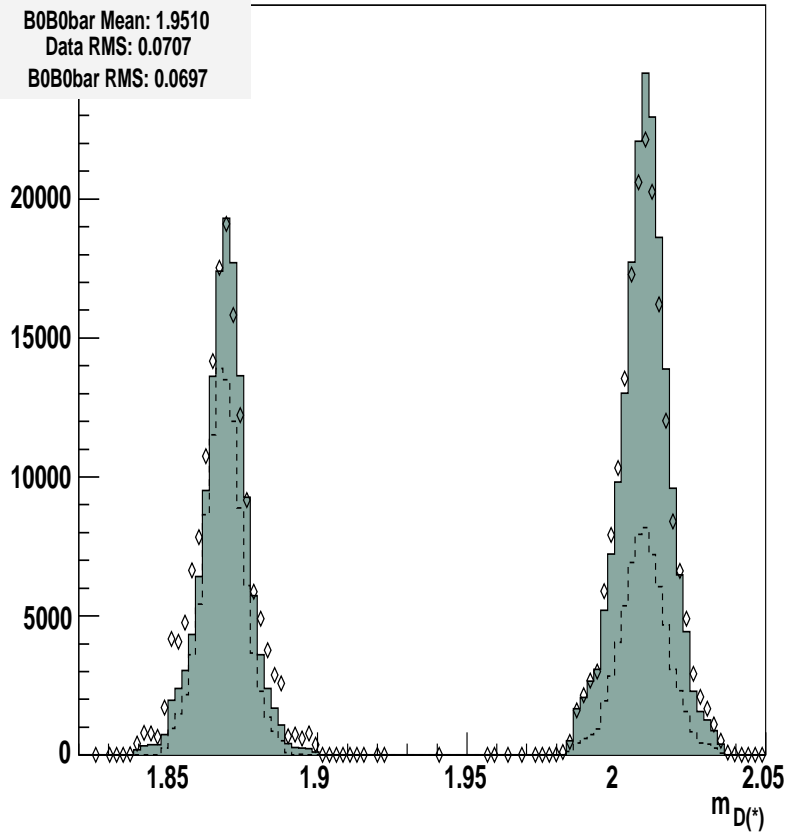
$$A(m; a, m_c) = m \sqrt{1 - (m/m_c)^2} \exp \left[a \left(1 - (m/m_c)^2 \right) \right]$$
$$X(m; \sigma, m_0, \alpha, n) = \begin{cases} (1 + \alpha(m - m_0)/\sigma - \alpha^2)^{-n} \exp \left[-\frac{1}{2} \alpha^2 \right] & (m - m_0)/\sigma < \alpha \\ \exp \left[-(m - m_0)^2 / 2\sigma^2 \right] & (m - m_0)/\sigma \geq \alpha \end{cases}$$

- The Argus function $A(m; a, m_c)$ models the continuum and combinatorial background. In all cases the Argus cutoff m_c is fixed at half the nominal center-of-momentum beam energy ($m_c = 5.29$ GeV). The Crystal Ball function $X(m; \sigma, m_0, \alpha, n)$ models the signal peak with a Gaussian above a cutoff defined by α and a tail with a power n for modelling radiative losses from neutral pion decays.

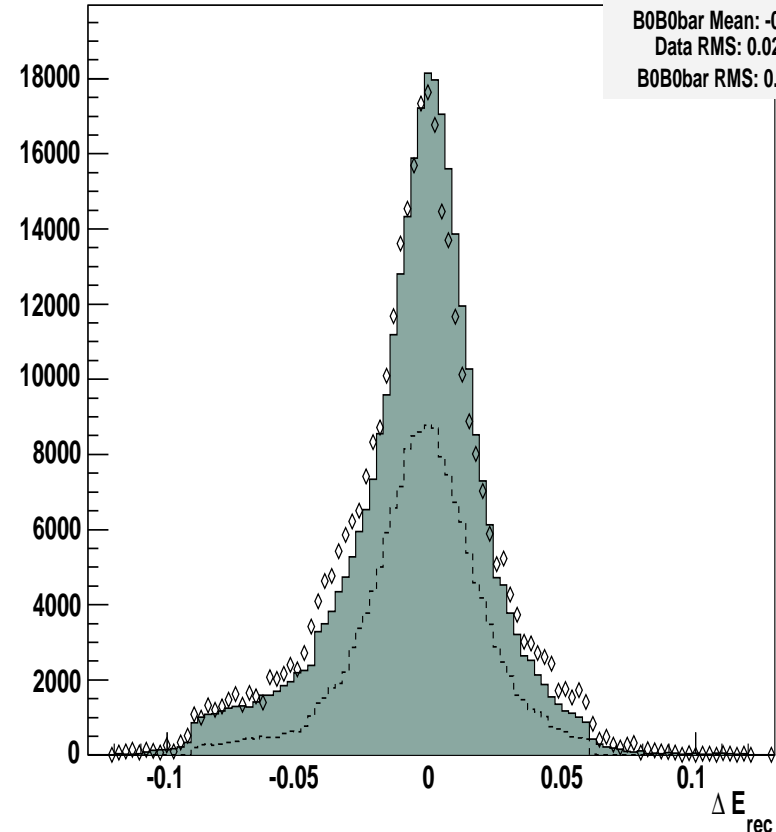
The $D^{(*)}$ Mass and Tag B ΔE



Data Runs 1-4 & SP5/6 MC
Before Preselection
Data Mean: 1.9452
B0B0bar Mean: 1.9510
Data RMS: 0.0707
B0B0bar RMS: 0.0697

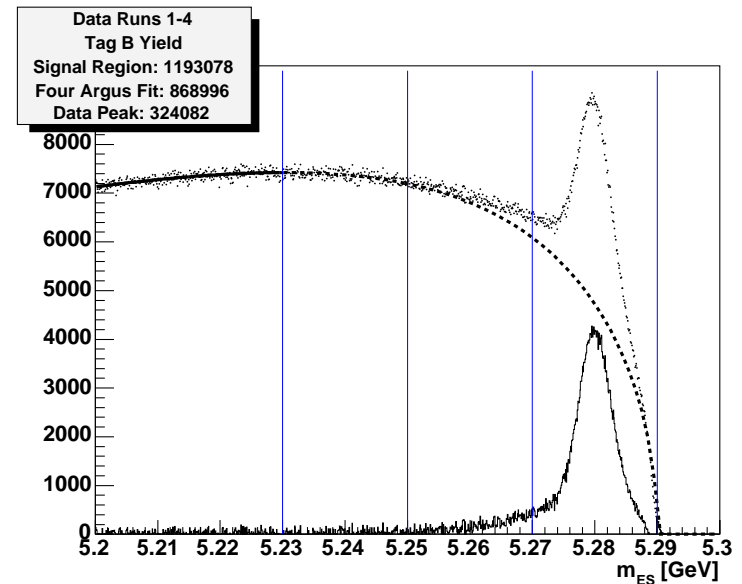
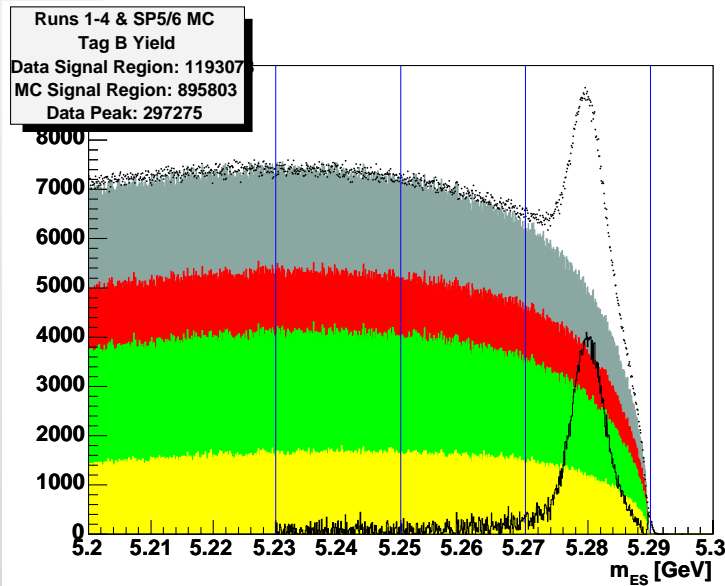


Data Runs 1-4 & SP5/6 MC
Before Preselection
Data Mean: -0.0064
B0B0bar Mean: -0.0057
Data RMS: 0.0298
B0B0bar RMS: 0.0276



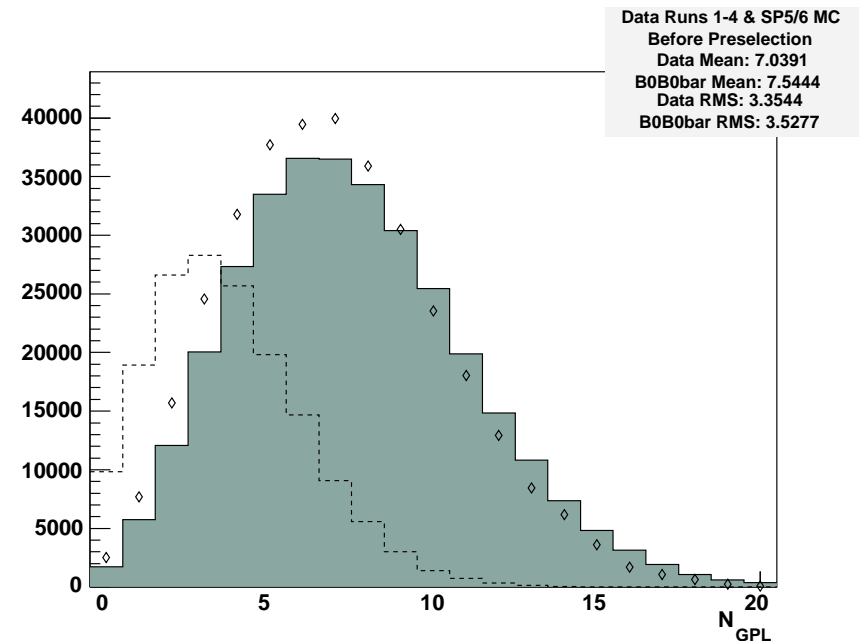
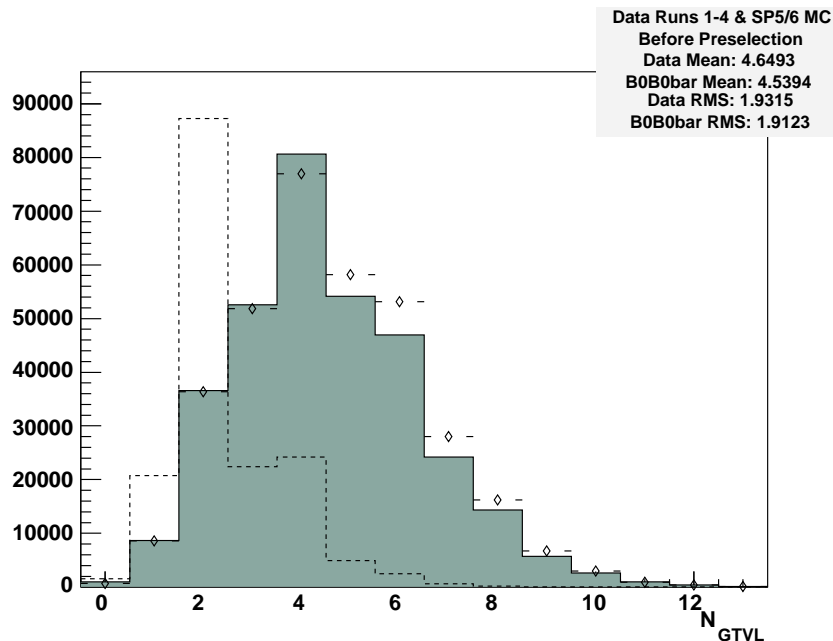
At left, the reconstructed mass of the seed D or D^{*} used in reconstructing the tag B . At right, the ΔE of the tag B . Only the *peaking components* of data (dots), generic neutral B (solid) and the signal cocktail (dashed) are plotted.

Tag B Yield



- We added the combinatorial (*nonpeaking*) component of the neutral B distribution with the continuum and charged B distributions. The normalization has been selected to minimize the mean square error in the region $m_{ES} \in [5.23, 5.25]$ GeV.
- We also fitted the background m_{ES} distribution with the sum of four Argus functions in a region far below the peak. The four Argus shape parameters a are free, but the cutoff parameter m_c is fixed at 5.29 GeV. The fit is performed only in the region $m_{ES} \in [5.20, 5.23]$, well below the peak tail.
- The discrepancy is approximately 9%, and is used as the systematic error on the tag B yield.

Event Preselection

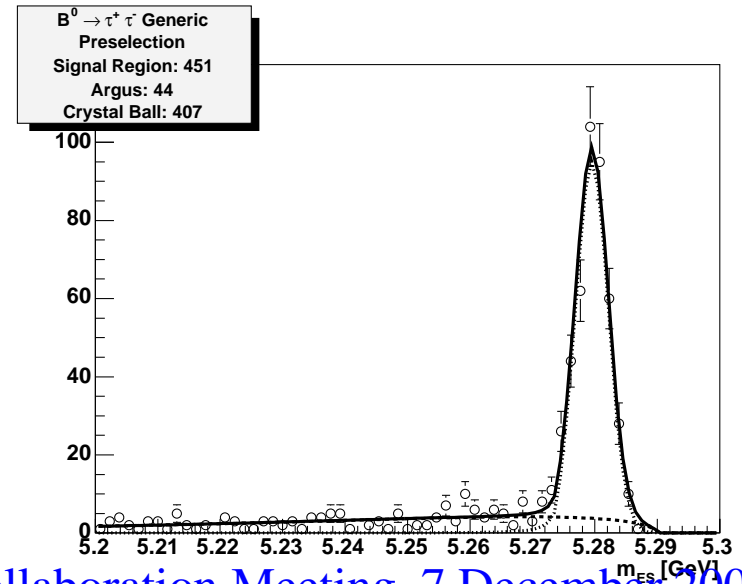
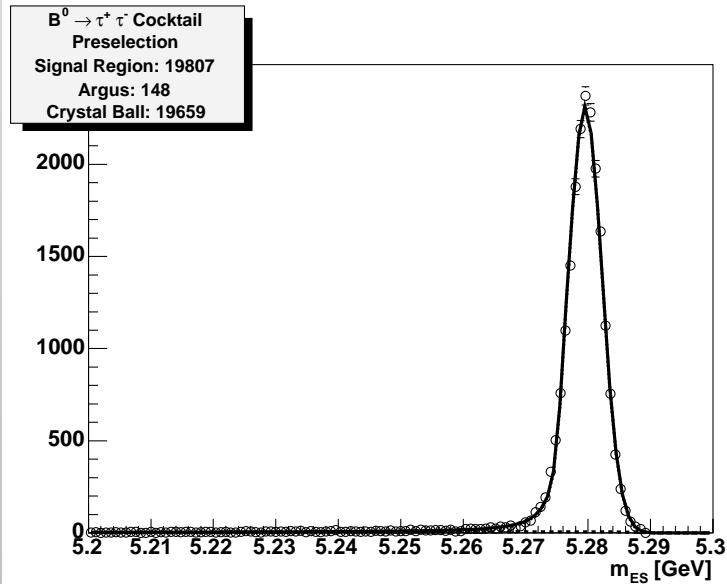
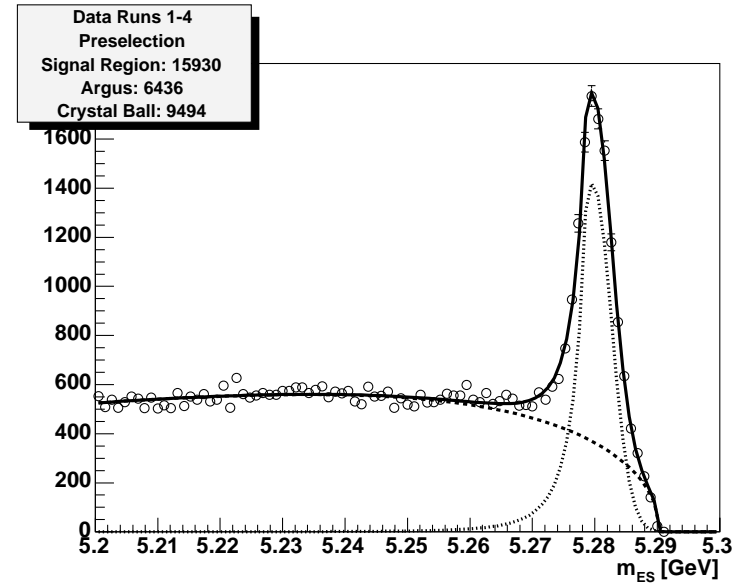
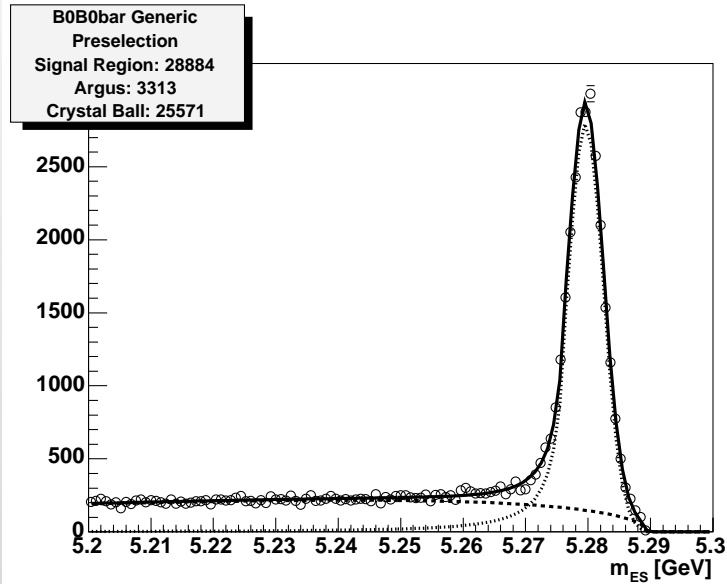


At left, the very loose track multiplicity on the signal side. At right, the loose photon multiplicity on the signal side. The distributions in data and Monte Carlo simulation do not match. Therefore two requirements are imposed on the samples before beginning this analysis:

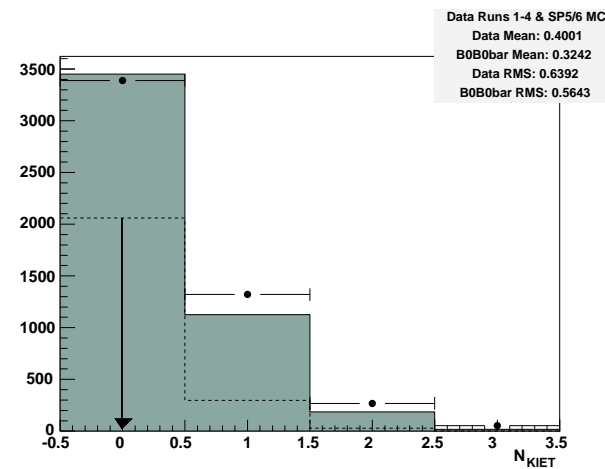
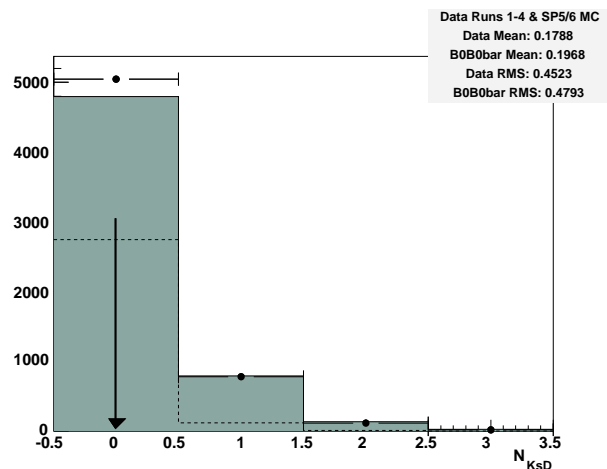
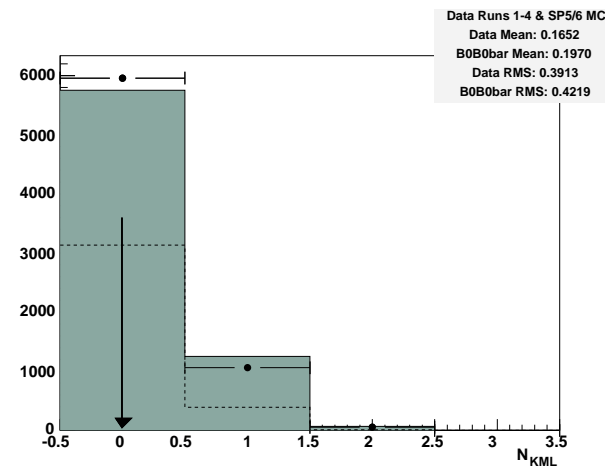
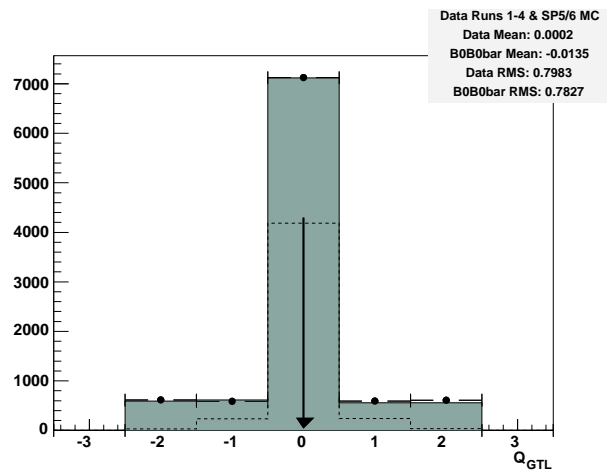
- two very loose track candidates reconstructed opposite the tag B
- four or fewer loose photons reconstructed opposite the tag B

After imposing these requirements, the Monte Carlo simulation and data distributions came into better agreement.

m_{ES} Distributions after Preselection

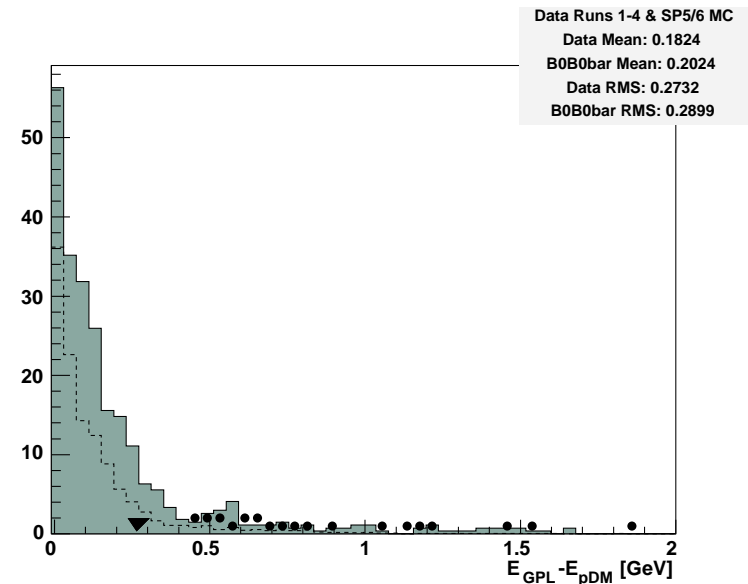
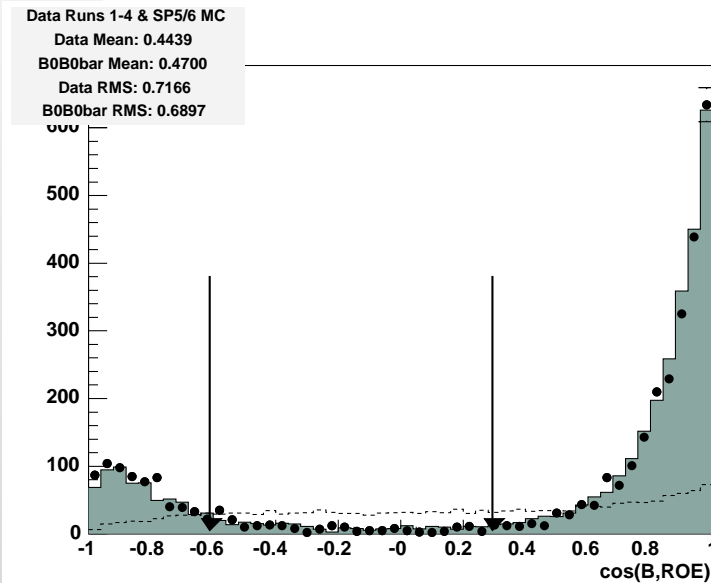


Background Rejection



Clockwise from top left, the net loose track charge on the signal side, loose kaon, default K_S and tight K_L multiplicity on the signal side after all preceding requirements in the analysis chain have been imposed.

Signal Selection: $\cos(B, S)$ and E_{res}



On the left, the cosine of the angle between the reconstructed tag B and the rest of the event. On the right, remaining neutral energy after neutral pion reconstruction. Preceding requirements in the analysis chain have been imposed.

- The angle between the tag B momentum and the rest of the event momentum (all tracks and photons) provides a discriminant between signal and background. Signal side momentum in the signal samples is nearly isotropically distributed.
- The existence of any neutral energy which is not reconstructed in a neutral pion from the signal tau pair or in the reconstructed tag B is a strong indication that unreconstructed neutral pions are present.

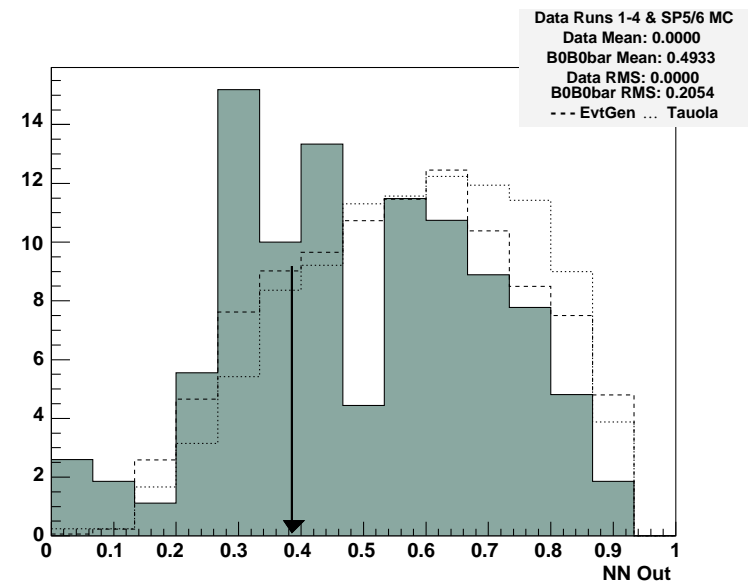
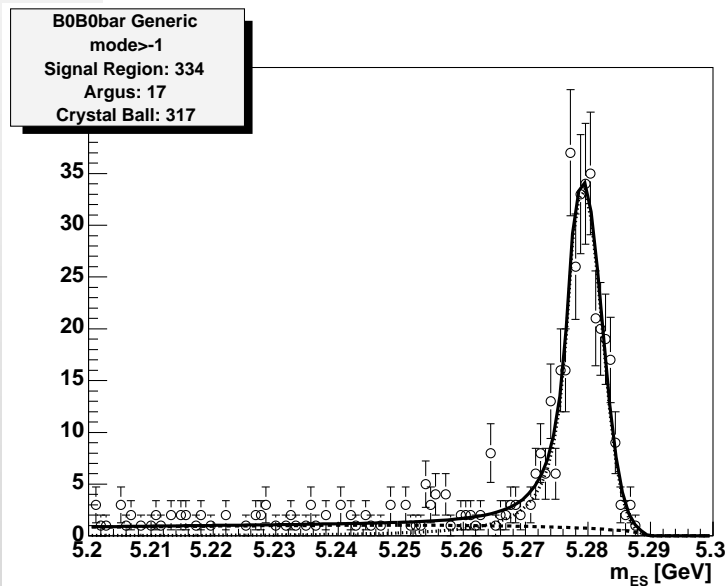
Signal Selection: Decay Mode



Selection Mode	BR [?]	$N_e + N_\mu$	N_{π^0}	$m_{(\pi\pi^0)}$	Efficiency	Composition
0: $l'l'4\nu$	0.124	2	0	na	0.47	0.74
1: $l\pi3\nu$	0.078	1	0	na	0.64	0.34
2: $l\rho3\nu$	0.177	1	1	[0.6, 1.0] GeV	0.36	0.70
3: $2\pi2\nu$	0.012	0	0	na	0.78	0.15
4: $\pi\rho2\nu$	0.056	0	1	[0.6, 1.0] GeV	0.49	0.35
5: $2\rho2\nu$	0.063	0	2	[0.6, 1.0] GeV	0.29	0.53

- Branching ratio, signal mode requirements, reconstruction efficiencies and sample purity with respect to all tau pair decay modes in the signal cocktail with a tag B reconstructed with the exclusive method. The reconstruction is verified with Monte Carlo truth.
- In order to best exploit correlations in selection mode, candidate tau daughter momenta and remaining neutral energy, five parameters were used as inputs in a neural network analysis.

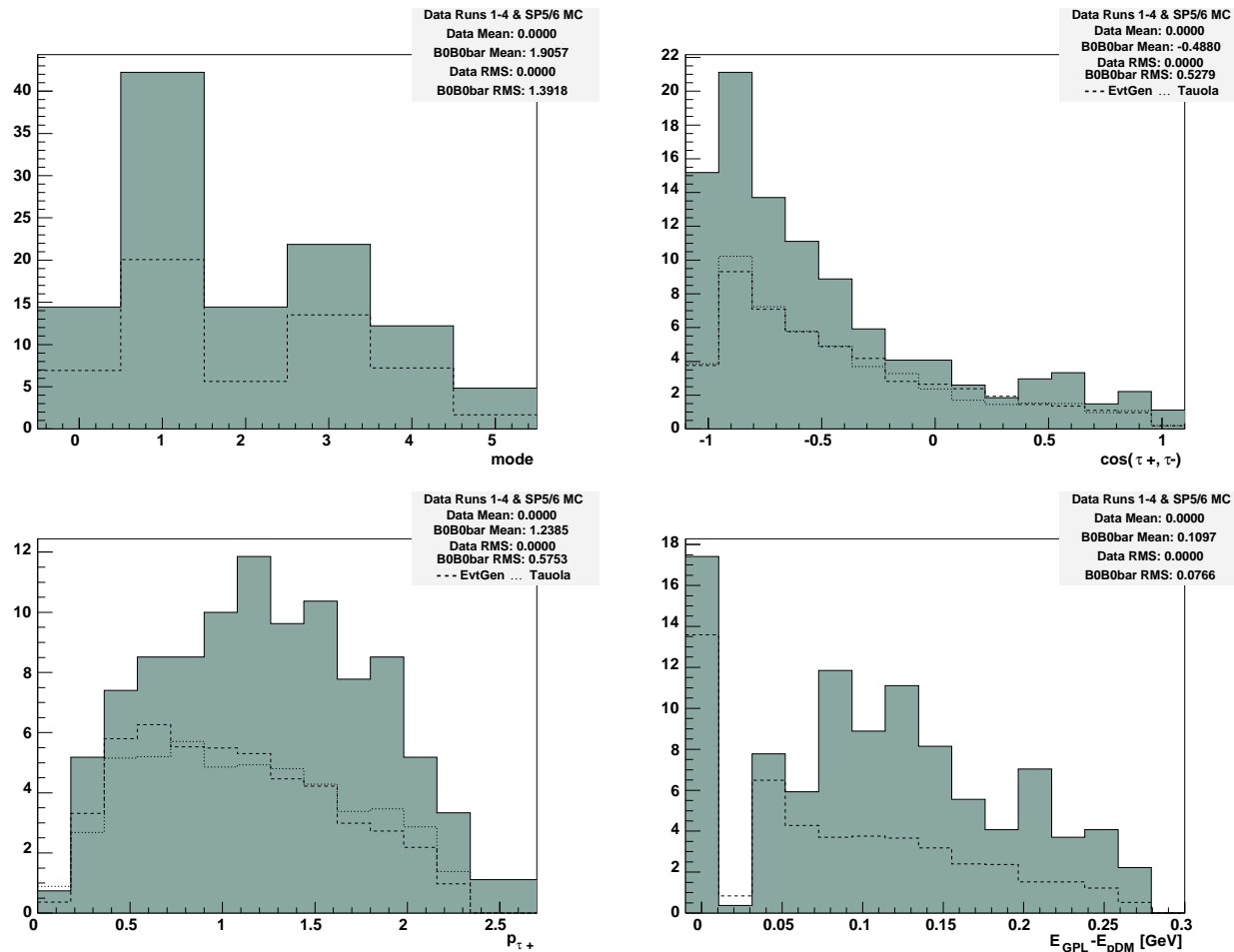
Signal Selection: Neural Network



The selection for $B \rightarrow \tau^+ \tau^-$. At left, the m_{ES} distribution in Monte Carlo simulation. At right, the neural network output in Monte Carlo simulation. The analysis is still blind in data.

- The neural network was implemented on the Stuttgart Neural Network Simulator (SNNSv4.2) in a 5 – 10 – 1 topology. We separated each of the signal and background cocktail Monte Carlo simulation into two disjoint subsamples, one for purposes of training the neural network and the other for evaluating the neural network performance.
- The truth tagged sample provided the neural network training patterns and the BRecoUser tagged sample provided the evaluation patterns. We stopped the neural network training after the minimum root mean square error (RMSE) obtained.

Signal Selection: NN Inputs



Inputs to the neural network for the $B \rightarrow \tau^+ \tau^-$ selection. Clockwise from top left are the signal multiplicity mode, cosine subtended by tau daughter candidate momenta, remaining neutral energy and magnitude of the tau daughter candidate momentum. The analysis is still blind in data.

Efficiencies: Data and B0B0bar



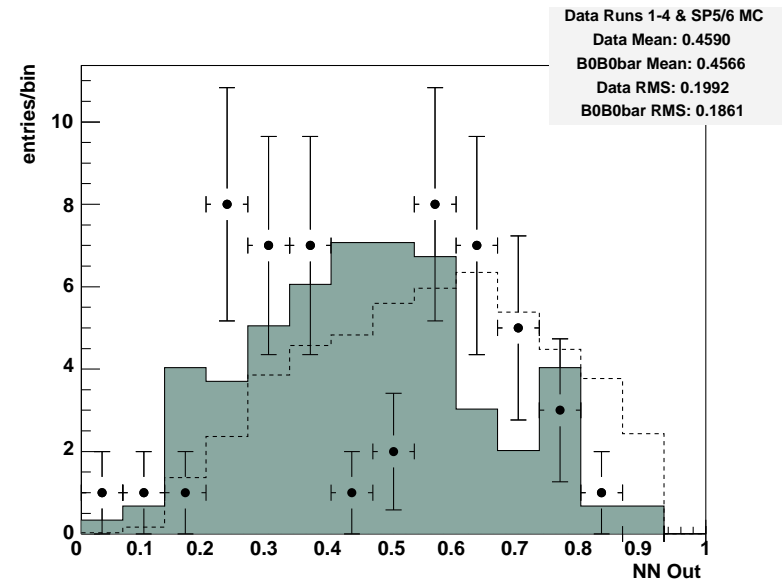
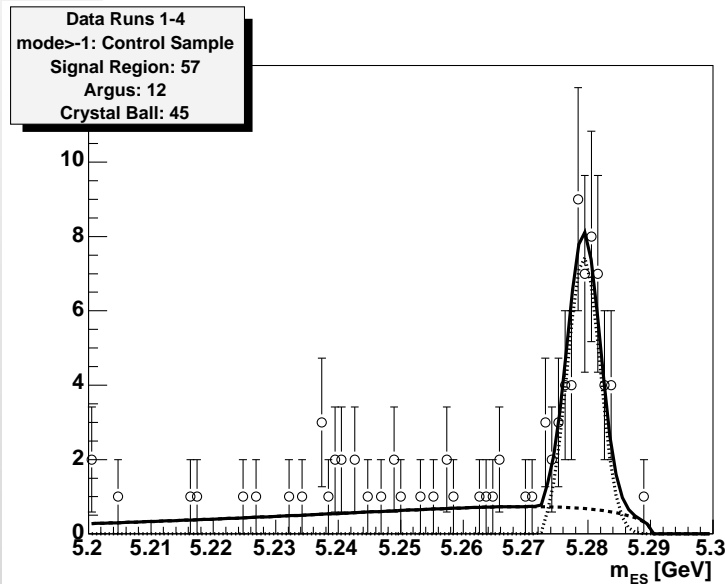
Requirement	B0B0bar Monte Carlo		Data Runs 1-4	
	Peak Yield	Efficiency	Peak Yield	Efficiency
Preselection	25571 ± 164	100.0 ± 0.0	9494 ± 730	100.0 ± 0.0
$Q_{GTL} = 0$	19222 ± 150	75.2 ± 0.4	7149 ± 214	75.3 ± 6.2
$N_{GTL} = 2$	19099 ± 149	74.7 ± 0.4	7113 ± 178	74.9 ± 6.1
$N_{KML} = 0$	15566 ± 129	60.9 ± 0.4	5995 ± 130	63.1 ± 5.0
$N_{KsD} = 0$	12961 ± 125	50.7 ± 0.4	5060 ± 115	53.3 ± 4.3
$N_{KIET} = 0$	9323 ± 97	36.5 ± 0.3	3396 ± 36	35.8 ± 2.8
$-0.60 < \cos(B, ROE) < 0.30$	709 ± 32	2.8 ± 0.1	244 ± 12	2.6 ± 0.2
$E_{GPL} - E_{pDM} < 0.27 \text{ GeV}$	527 ± 26	2.1 ± 0.1	<i>blind</i>	<i>blind</i>
$mode > -1$	317 ± 19	1.2 ± 0.1	<i>blind</i>	<i>blind</i>
$N_{out} > 0.20$	297 ± 18	1.2 ± 0.1	<i>blind</i>	<i>blind</i>

Efficiencies: Signal



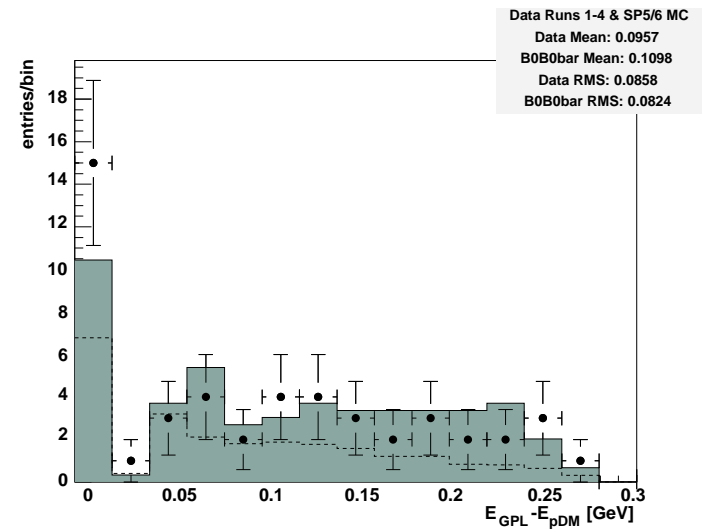
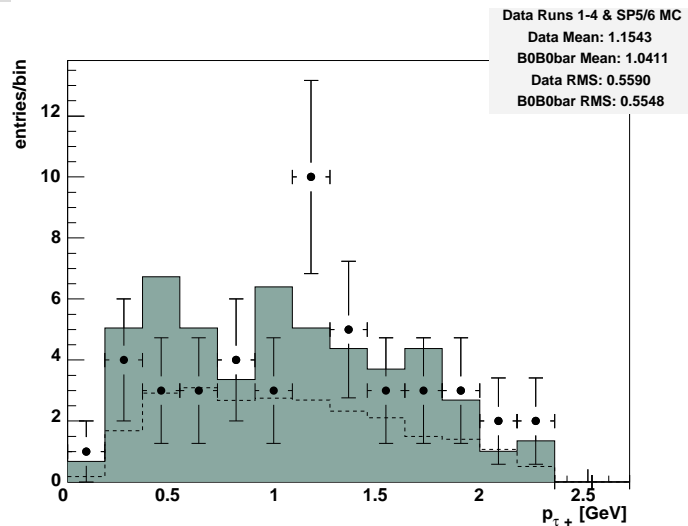
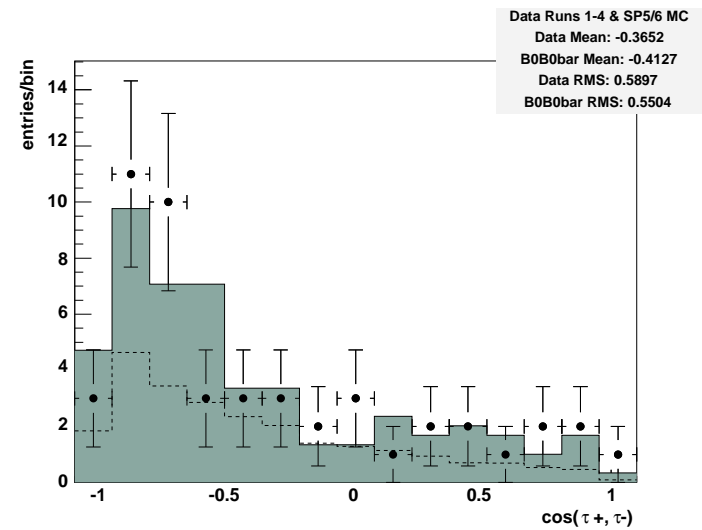
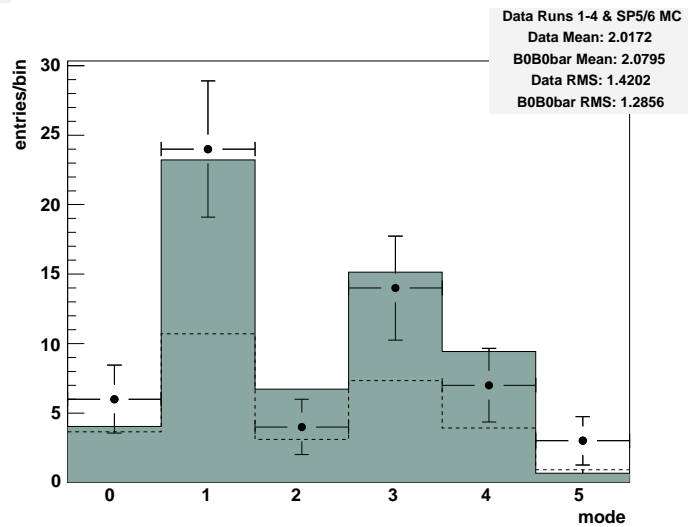
Requirement	Signal Cocktail		Signal Generic	
	Peak Yield	Efficiency	Peak Yield	Efficiency
Tag B Yield	54832 ± 236	100.0 ± 0.0	1476 ± 38	100.0 ± 0.0
Preselection	19659 ± 142	35.9 ± 0.2	407 ± 21	27.6 ± 1.3
$Q_{GTL} = 0$	17413 ± 132	31.8 ± 0.2	376 ± 20	25.5 ± 1.2
$N_{GTL} = 2$	17351 ± 132	31.6 ± 0.2	375 ± 19	25.4 ± 1.2
$N_{KML} = 0$	15393 ± 124	28.1 ± 0.2	333 ± 18	22.6 ± 1.2
$N_{KsD} = 0$	14657 ± 121	26.7 ± 0.2	318 ± 18	21.5 ± 1.1
$N_{KIET} = 0$	12636 ± 112	23.0 ± 0.2	252 ± 15	17.1 ± 1.0
$-0.60 < \cos(B, ROE) < 0.30$	5260 ± 72	9.6 ± 0.1	124 ± 11	8.4 ± 0.7
$E_{GPL} - E_{pDM} < 0.27 \text{ GeV}$	4479 ± 66	8.2 ± 0.1	112 ± 10	7.6 ± 0.7
$mode > -1$	3483 ± 58	6.4 ± 0.1	84 ± 9	5.7 ± 0.6
$N_{out} > 0.20$	3372 ± 58	6.1 ± 0.1	81 ± 8	5.5 ± 0.6

Control Sample: NN Output



- The selection for the extra K_S control sample. At left, the m_{ES} distributions in data. At right, the neural network output in data and Monte Carlo samples. Only the *peaking components* of data (dots), B0B0bar (solid) and the signal cocktail (dashed) are plotted.
- The observed number of events in the control sample is 44 ± 5 . From Monte Carlo simulation, the expected number of events in the control sample is 46.4 ± 4.0 , yielding a relative discrepancy of 5.52%. Modulo error, the observed number of events in the extra K_S control sample agrees with the expected number.

Control Sample: Inputs



Clockwise from top left are the signal multiplicity mode, cosine subtended by tau daughter candidate momenta, remaining neutral energy and magnitude of the tau daughter candidate momentum.

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	1.6	10.5	6.0
Fit PDF Choice	1.8	4.1	0.4
Electron Particle ID	0.3	1.2	0.9
Muon Particle ID	0.2	3.6	0.7
Kaon Particle ID	2.9	7.1	5.4
Photon Energy Resolution	0.3	7.1	1.0
Signal Decay Model	0.6	3.6	0.0
Tracking Efficiency	2.6	2.6	2.6
Remaining Photon Energy	5.5	5.5	5.5
Total Error	7.2	17.1	10.3

Relative systematic errors $\delta\epsilon/\epsilon$ for the signal cocktail, signal generic and B0B0bar efficiencies.

- Remaining neutral energy systematic: relative discrepancy between control sample observation and expectation.
- Signal decay systematic: relative difference between EvtGen and Tauola kinematic parameters.

Limit Setting Procedure



To obtain the 90% confidence level upper limit R_{ul}^{90} on the branching ratio R , we determine the corresponding upper limit n_{ul}^{90} on the number of observed events

$$n_{ul}^{90} = R_{ul}^{90} N_{B^0 \bar{B}^0} \epsilon_{sig} + B$$

where n follows a Poisson distribution. We do so by finding R_{ul}^{90} such that $\sum_{n=0}^{n_{obs}} P(n; n_{ul}^{90}) = 0.1$. We follow the approach taken by Cousins and Highland (and Barlow) and imagine N_{exp} experiments in which $N_{B^0 \bar{B}^0}$, ϵ_{sig} , B and n fluctuate according to their parent distributions.

- We first fix a low hypothesis R_0 for the branching ratio. Then for each experiment, we sample $N_{B^0 \bar{B}^0}$, ϵ_{sig} , B and n .
- After N_{exp} such experiments, the fraction of experiments for which $\tilde{n} \leq n_{obs}$ is calculated. If it is larger than 10%, the hypothesis R_0 is increased and another N_{exp} experiments are carried out.
- The procedure repeats until the fraction of experiments with $\tilde{n} \leq n_{obs}$ is, to within a small tolerance, 10%.

Upper Limit Optimization (1)

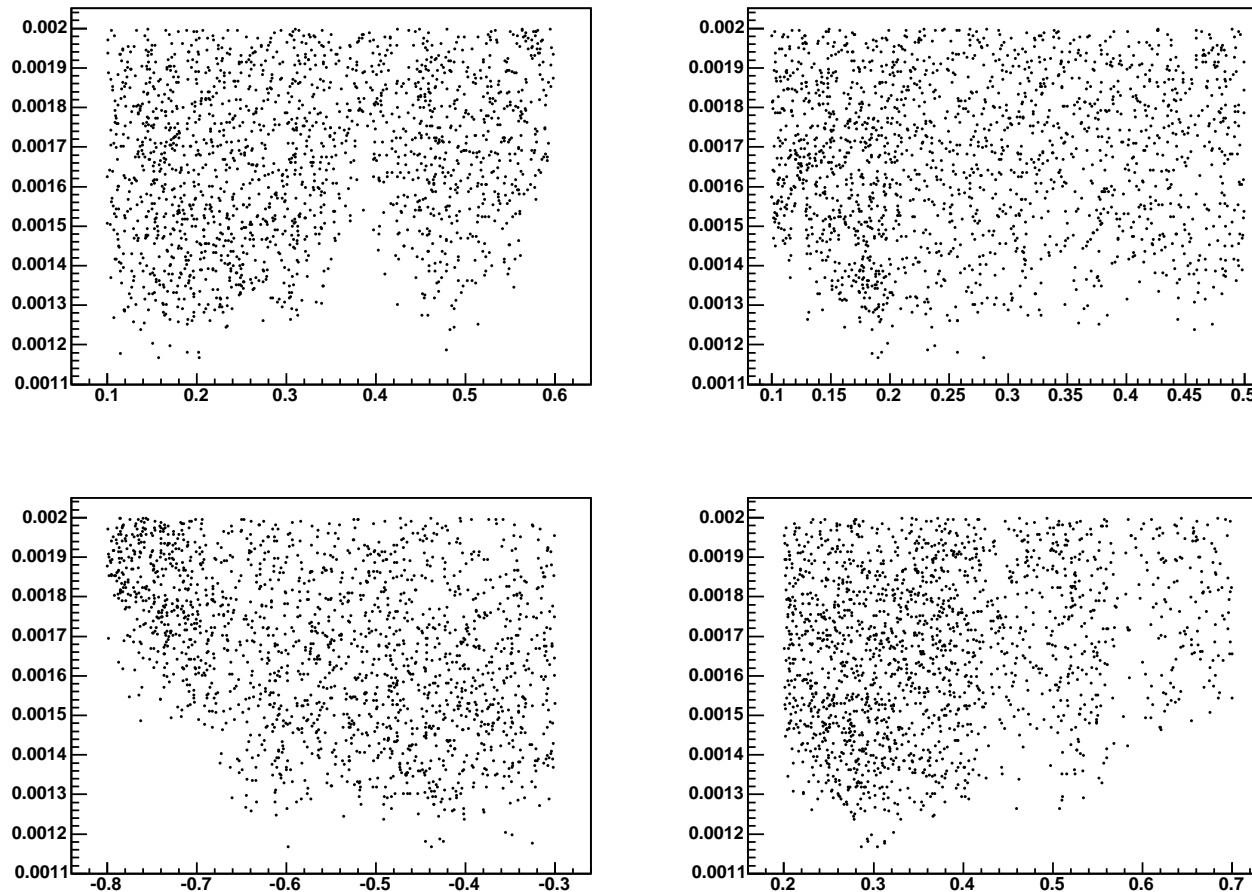


- The optimization proceeds by sampling each cut value from a uniform distribution on an interval appropriate for the parameter.
- The systematic errors on the signal efficiency and background expectation for this set of cut values is computed.
- Assuming that the number of observed data events is equal to the background expectation, the upper limit R_{ul}^{90} is determined.
- We sampled 5×10^3 sets of cut values. For each set of cut values, the number of trial experiments N_{exp} is 10^4 .

The cut values which minimize the upper limit over the sampled set are

$$\begin{aligned} N_{out} &> 0.20 \\ E_{GPL} - E_{pDM} &< 0.27 \\ \cos(B, ROE) &> -0.60 \\ \cos(B, ROE) &< 0.30 \end{aligned}$$

Upper Limit Optimization (2)



The 90% confidence level upper limit R_{ul}^{90} plotted versus cut values for (clockwise from top left) lower bound for the neural network output, upper bound for unassigned photon energy, upper bound for $\cos(B, ROE)$ and lower bound for $\cos(B, ROE)$

Results



We are still blind for the last three analysis chain requirements. Below, the upper limit R_{ul}^{90} for a range of outcomes n_{obs} . We assume the values

$$\begin{aligned}N_{B^0 \bar{B}^0} &= 297275 \pm 26807 \\ \epsilon_{sig} &= 0.055 \pm 0.00941 \\ B &= 110 \pm 14.1\end{aligned}$$

The range of n_{obs} below does not cover many outcomes. See BAD 542 v4 for $\pm 1.6\sigma$ coverage.

n_{obs}	R_{ul}^{90}	n_{obs}	R_{ul}^{90}
110	0.00146	110	0.00146
109	0.0014	111	0.00155
108	0.00134	112	0.0016
107	0.00127	113	0.00162
106	0.00119	114	0.00176
$\epsilon_{sig} = 0.055 \pm 0.00941, B = 110 \pm 14.1$			

Outlook



- We will fix known problems and incorporate feedback received this week.
- We will then release version 5 of BAD 542, hopefully early next week.
- We hope to have an AWG BAD reading next week.
- We would like to move the analysis to the Review Committee as soon as we have AWG approval.