Results $B^0 \longrightarrow K_s K_s K_s$ - **Time Dependent Analysis**

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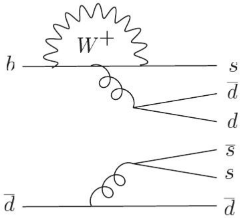
Overview

- Introduction (Motivation And Previous Measurements)
- Reconstruction And Selection
- Likelyhood PDF
  - Signal And Continuum
  - B Backgound
- Fit Validation
- Systematic Uncertainties
- Results
- Perspectives
- Summary

Theoretical Motivation

- Measurement of time-dependent CP-asymmetry



- In SM: pure b $\longrightarrow$ s penguin (up to small corrections)
- $\propto V_{ts}V_{tb}^{*}$
  - $V_{us}V_{ub}^{*}$ doubly Cabbibo suppressed
  - Final state CP-even

- SM prediction (as $b \longrightarrow c\bar{c}s$): $S \cong -sin(2\beta)$, $C \cong 0$
- Any deviation is sign of NP (e.g. squarks in penguin)
- Experimental challenge: No charged particles come from primary vertex

Previous Analyses

- BarBar (384 M $B\bar{B}$): Run 1-4 (BAD 948,1140), update Run 1-5 (BAD 1486)
  $\rightarrow$ S=-0.71 $\pm$ 0.24 $\pm$ 0.04
  $\rightarrow$ C=0.02 $\pm$ 0.21 $\pm$ 0.05
- Belle (535 M $B\bar{B}$)
  $\rightarrow$ S=-0.30 $\pm$ 0.32 $\pm$ 0.08
  $\rightarrow$ C=-0.31 $\pm$ 0.20 $\pm$ 0.07
- HFAG average
  $\rightarrow$ S=-0.58 $\pm$ 0.20
  $\rightarrow$ C=-0.14 $\pm$ 0.15
- All measurements compatible within 1σ with SM prediction

B Candidate Reconstruction And Selection

- Analysis of 2 modes: $B^0 \to 3K_S^0(\pi^+\pi^-)$, $B^0 \to 2K_S^0(\pi^+\pi^-)K_S^0(\pi^0\pi^0)$
- `AllEventsSkim` (R22d), TreeFitter for vertexing
- Loose cuts:
  - $5.22 GeV < m_{ES} < 5.29 GeV$
  - $-0.18 GeV < \Delta E < 0.12 GeV$
  - $P(\chi^2 Bvertex) > 0$
- Muliple candidates choose the one with the best:

$$\chi^2 = \sum_{i=1}^{3} \left(\frac{M_{K_S,i} - M_{K_S}^{PDG}}{\sigma_{M_{K_S}}} \right)^2$$

- Average number of candidates:
  - 1.005 for $B^0 \to 3K_S^0(\pi^+\pi^-)$
  - 1.123 for $B^0 \to 2K_S^0(\pi^+\pi^-)K_S^0(\pi^0\pi^0)$
- Small Self Cross Feed:
  - 1.59 % for $B^0 \to 3K_S^0(\pi^+\pi^-)$
  - 2.30 % for $B^0 \to 2K_S^0(\pi^+\pi^-)K_S^0(\pi^0\pi^0)$
- Apply veto on allowed charmonium mode $\chi_{c0}\ K_s^0$ to avoid "SM-pollution"

K_s^0 selection

- General Selection

	$K_S \to \pi^+\pi^-$	$K_S \to \pi^0\pi^0$
α	$\alpha < 0.2$	
$r_{dec}(K_{S,\pi^+\pi^-})$ $m(K_{S,\pi^+\pi^-})$	$0.2 < r_{dec} < 40cm$ $\lvert m_{K_S} - m_{PDG}\rvert < 0.012GeV$	$0.15 < r_{dec} < 60cm$ $\lvert m_{K_S} - m_{PDG}\rvert < 0.011GeV$
$\tau_{K_S^0}$ $(K_s^0 \to \pi^0\pi^0)$ $m(K_{S,\pi^0\pi^0})$ LAT $m(\pi^0)$ E_γ	$\frac{\tau}{\sigma(\tau)} > 5$	$0.48GeV < m_{K_S} < 0.52GeV$ $LAT < 0.55$ $m_{pi^0} < 0.141$ $E_\gamma > 0.05$

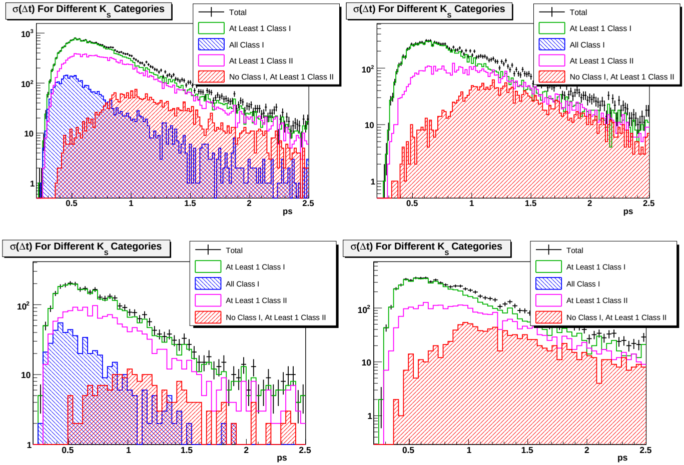
- Vertex Quality
  - Very few losses by requireing at least one K_s^0 to decay in the 2 inner SVT layer
    - 0.4 % for $B^0 \to 3K_S^0(\pi^+\pi^-)$
    - 2.1 % for $B^0 \to 2K_S^0(\pi^+\pi^-)K_S^0(\pi^0\pi^0)$
- Reconstruction Efficiencies
  - 7.3 % for $B^0 \to 3K_S^0(\pi^+\pi^-)$, 6.7% with charmonium veto
  - 3.4 % for $B^0 \to 2K_S^0(\pi^+\pi^-)K_S^0(\pi^0\pi^0)$, 3.0% with veto

Errors On Δt For Different SVT Categories

$B^0 \to 3K_s^0(\pi^+\pi^-)$ $\qquad$ $B^0 \to 2K_s^0(\pi^+\pi^-)K_s^0(\pi^0\pi^0)$

MC

Onpeak



Class 1: Both pions have at least 1 hits in ϕ and z in the 3 inner layers

Class 2: Both pions have at least 1 hits in ϕ and z but K_s^0 is not in category 1

Signal And Continuum

Signal

- m_{ES}: Cruijff
- ΔE: Cruijff
- NN: RooKeysPDF splitted by tagging category
- Δt: BCPGenDecay_Sig
  - BReco resolution parameters

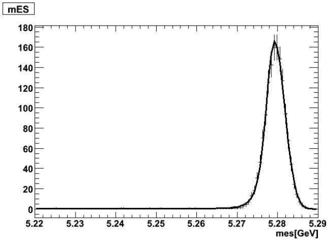
Continuum

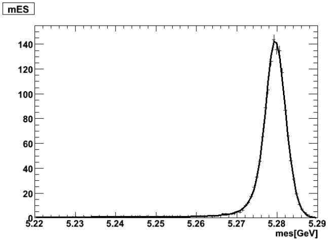
- m_{ES}: ARGUS
- ΔE: 1st order polynom
- NN: Sum of power-functions $f(x) = \sum_3 N_i x^{a_i}(1-x)^{b_i}$
- Δt: BCPGenDecay_Bkg
  - prompt decay, resolution parameters floating
  - S=C=0

Signal (m_{ES} And ΔE)

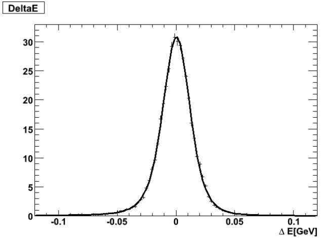
$B^0 \rightarrow 3K_s^0(\pi^+\pi^-)$ $\qquad$ $B^0 \rightarrow 2K_s^0(\pi^+\pi^-)K_s^0(\pi^0\pi^0)$

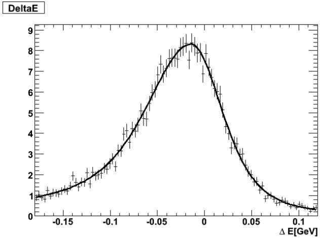
m_{ES}





ΔE

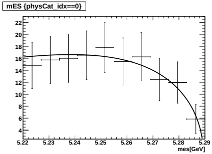


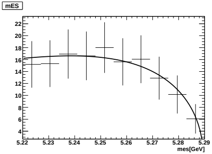


Continuum PDF's

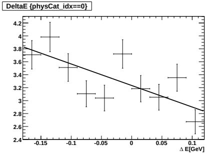
$B^0 \to 3K_s^0(\pi^+\pi^-)$ $\quad$ $B^0 \to 2K_s^0(\pi^+\pi^-)K_s^0(\pi^0\pi^0)$

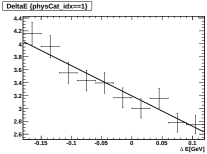
m_{ES}



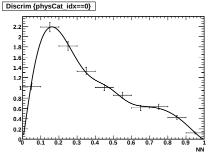


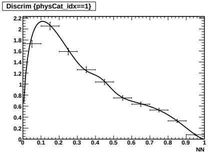
ΔE





ΔNN





B-Background

- Used neutral and charged generic MC to study the B-bkg modes
- Isolated main contributions and treat them separately (exclusive MC)
- Yields are fixed for the separately treated components
- Yields are floated for generic components (filtered for signal and separately treated modes)
- Branching fractions of some exclusively treated modes are not measured $\rightarrow$ estimated conservatively
- PDF's: RooKeysPDF for m_{ES},ΔE and the NN, signal for Δt with C=S=0 (variated for systematics)

Neutral Generics

Sub Mode	Event Type	Decay Mode	# Events	SP Mode
$3K_s^0(\pi^+\pi^-)$	Signal	$K_s^0 K_s^0 K_s^0$	601	—
		$f_0(K_s^0 K_s^0)\ K_s^0$	15	—
	Allowed charmonium	$\chi_{c0}(K_s^0 K_s^0)K_s^0$	27	—
		$\chi_{c2}(K_s^0 K_s^0)K_s^0$	1	—
	Forbidden charmonium	$\eta_c(K_s^0 K_s^0)K_s^0$	34	—
		$\eta_c(2S)(K_s^0 K_s^0)K_s^0$	16	—
	$b \to s$ B backgrounds	$K_s^0 K_s^0 K_l^0$	15	SP8997
		$K_s^0 K_s^0 K_s^{0*}$	23	SP8998

Sub Mode	Event Type	Decay Mode	# Events	SP Mode
$2K_s^0(\pi^+\pi^-)$ $K_s^0(\pi^0\pi^0)$	Signal	$K_s^0 K_s^0 K_s^0$	299	—
		$f_0(K_s^0 K_s^0)\ K_s^0$	6	—
	Allowed charmonium	$\chi_{c0}(K_s^0 K_s^0)K_s^0$	16	—
		$\chi_{c0}(K_s^0 K_s^0)K_s^0$	1	—
	Forbidden charmonium	$\eta_c(K_s^0 K_s^0)K_s^0$	17	—
		$\eta_c(2S)(K_s^0 K_s^0)K_s^0$	5	—
	$b \to s$ B backgrounds	$K_s^0 K_s^0 K_l^0$	18	SP8997
		$K_s^0 K_s^0 K_s^{0*}$	19	SP8998
		$K_s^0 K_l^0 K_s^{0*}$	5	SP8999

filtered vetoed treated exclusively

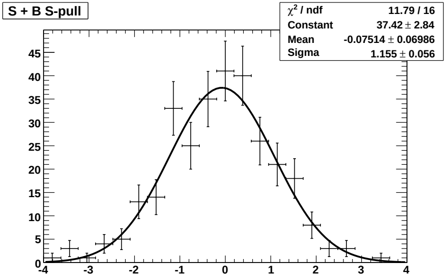
Charged Generics

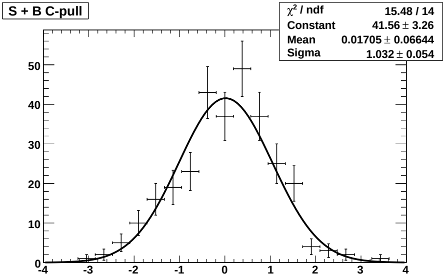
Exlusively treated modes

Sub Mode	Event Type	Decay Mode	# Events	SP Mode
$3K_s^0(\pi^+\pi^-)$	$b \to s$ B backgrounds	$K_s^0 K_s^0 K^+$	9	SP9000
$2K_s^0(\pi^+\pi^-)$ $K_s^0(\pi^0\pi^0)$	$b \to s$ B backgrounds	$K_s^0 K_s^0 K^+$	11	SP9000
		$K_s^0 K_s^{0+*}$	5	SP9001

Embedded Toy Studies

- Generate continuum and B background with analysis tool
- Signal from Monte Carlo (SP 8996)
- Treat fit bias as systematic





Systematics 1

- The uncertainty in the PDF parameters
  preliminary $\rightarrow$ will be done with control sample ($J/\Psi K_s^0$)
- The uncertainty in the CP-content and the branching fraction of the B-background.
- Error due to the vertexing technique
- Fit bias
- Bias due to the charmonium vetoes.
- Detector misalignment, beam spot position,the boost of the $\Upsilon(4s)$-resonance and doubly Cabbibo suppressed decays taken from charmonium analysis

Systematics 2

Contribution	S	C
PDF	$^{+0.0349}_{-0.0245}$	$C^{+0.0104}_{-0.0234}$
B-bkg	$^{+0.0256}_{-0.0123}$	$C^{+0.0069}_{-0.0062}$
Vertexing	± 0.0036	± 0.0093
Fit bias	± 0.020	± 0.0119
Vetoes	± 0.0051	± 0.0036
Other	± 0.004	± 0.015
Sum	$^{+0.043}_{-0.027}$	$^{+0.024}_{-0.032}$

Table: Systematics summary

Fit Results

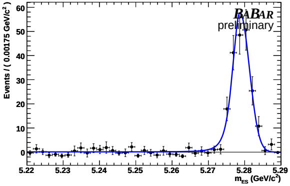
- S= $-0.906^{+0.203}_{-0.189}$ (stat) $^{+0.043}_{-0.027}$ (sys)
- C= $-0.165^{+0.174}_{-0.173}$ (stat) $^{+0.024}_{-0.032}$ (sys)

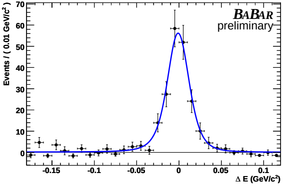
Parameter	combined Fit	separated Fit	combined prev.	separated prev.
$N_{sig,pm}$	$207.3^{+16.1}_{-15.7}$	$206.6^{+16.0}_{-15.7}$	125 ± 13	125 ±13
$N_{sig,00}$	$66.8^{+13.8}_{-13.3}$	$71.1^{+13.6}_{-13.1}$	64±12	64±12
S	$-0.906^{+0.203}_{-0.189}$	-	-0.71±0.24	-
C	$-0.165^{+0.174}_{-0.173}$	-	0.02 ±0.21	-
S_{pm}	-	$-1.425^{+0.239}_{-0.215}$	-	$-1.06^{+0.25}_{-0.16}$
C_{pm}	-	$-0.127^{+0.160}_{-0.166}$	-	$-0.08^{+0.23}_{-0.22}$
S_{00}	-	$0.343^{+0.539}_{-0.539}$	-	0.24 ± 0.52
C_{00}	-	$0.185^{+0.411}_{-0.418}$	-	0.23 ± 0.38

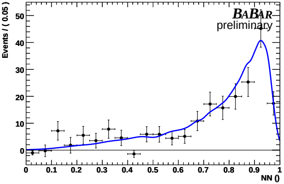
- Within 1 σ of SM prediction
- Compatible within less than 2 σ with previous analysis, assuming same reconstructed events in runs 1-5:
  $\Delta S = -0.196 \pm 0.138$ and $\Delta C = 0.185 \pm 0.12$

sPlots Signal m_{ES}, ΔE, NN

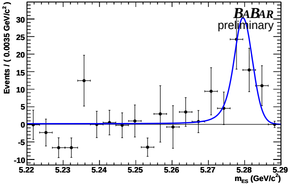
$$B^0 \longrightarrow 3K_s^0(\pi^+\pi^-)$$

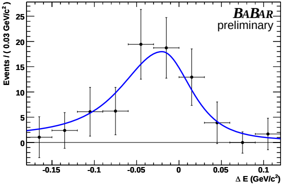


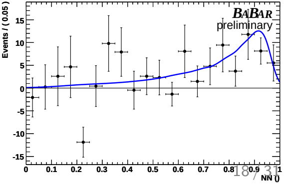




$$B^0 \longrightarrow 2K_s^0(\pi^+\pi^-)K_s^0(\pi^0\pi^0)$$

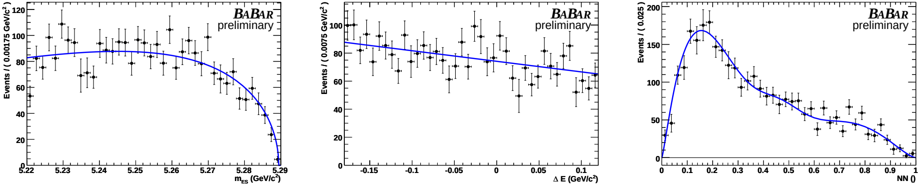




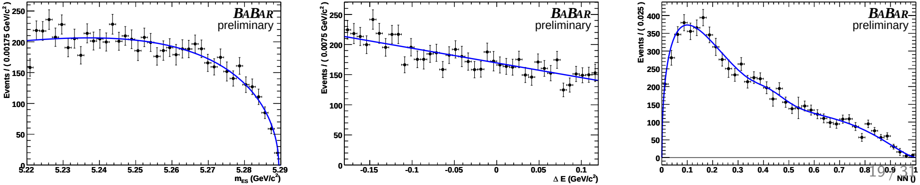


sPlots Continuum m_{ES},ΔE, NN

$$B^0 \rightarrow 3K_s^0(\pi^+\pi^-)$$

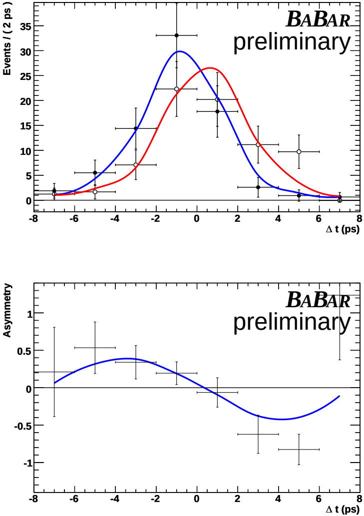


$$B^0 \rightarrow 2K_s^0(\pi^+\pi^-)K_s^0(\pi^0\pi^0)$$

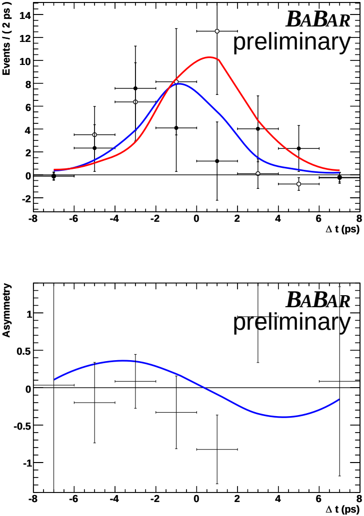


sPlots Δt And Asymmetry

$B^0 \rightarrow 3K_s^0(\pi^+\pi^-)$



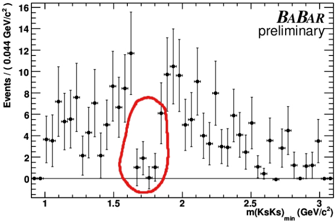
$B^0 \rightarrow 2K_s^0(\pi^+\pi^-)K_s^0(\pi^0\pi^0)$

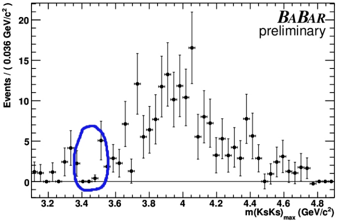


Perspectives

- Results have been presented at CKM-workshop
- For journal publication:
  - More detailed systematics studies
  - Measure branching fraction
  - Study of Dalitz-model to check if branching-fraction of $f^0 \to K_s^0 K_s^0$ can be measured

sPlots of invariant masses $\mathrm{min}(\mathrm{m}_{K_s^0 K_s^0})$, $max(m_{K_s^0 K_s^0})$





Interference?

Veto

Summary

- Measured time-dependent CP-asymmetry

$$S = -0.906^{+0.203}_{-0.189}\ (\text{stat})\ ^{+0.043}_{-0.027}\ (\text{sys})$$
$$C = -0.165^{+0.174}_{-0.173}\ (\text{stat})\ ^{+0.024}_{-0.032}\ (\text{sys})$$

- Consistent within 1 σ with SM prediction
- Consistent with previous BaBar measurement in less than 2 σ
- Perspectives: branching fraction, Dalitz study/analysis
- Documentation: BAD #2025, physics note BAD #2090

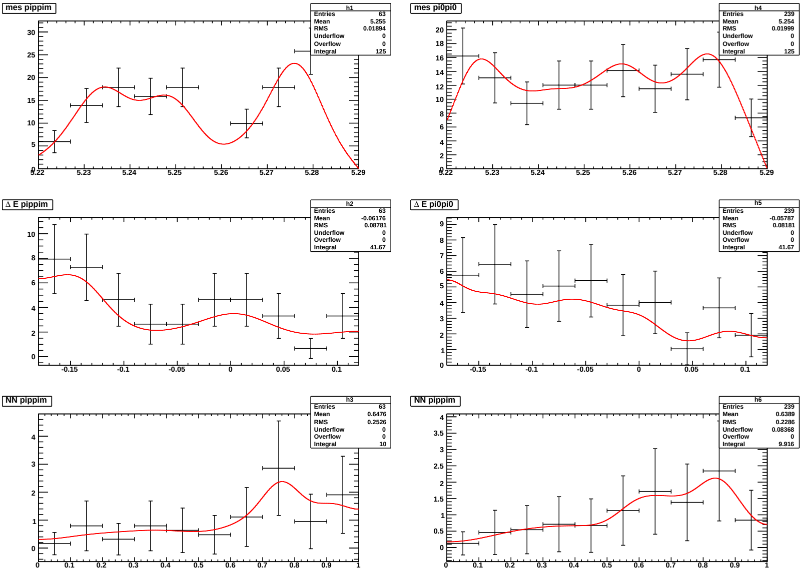


Figure: Neutral generic B background for $B^0 \to 3K_s^0(\pi^+\pi^-)$ (left) and $B^0 \to 2K_s^0(\pi^+\pi^-)K_s^0(\pi^0\pi^0)$ (right).

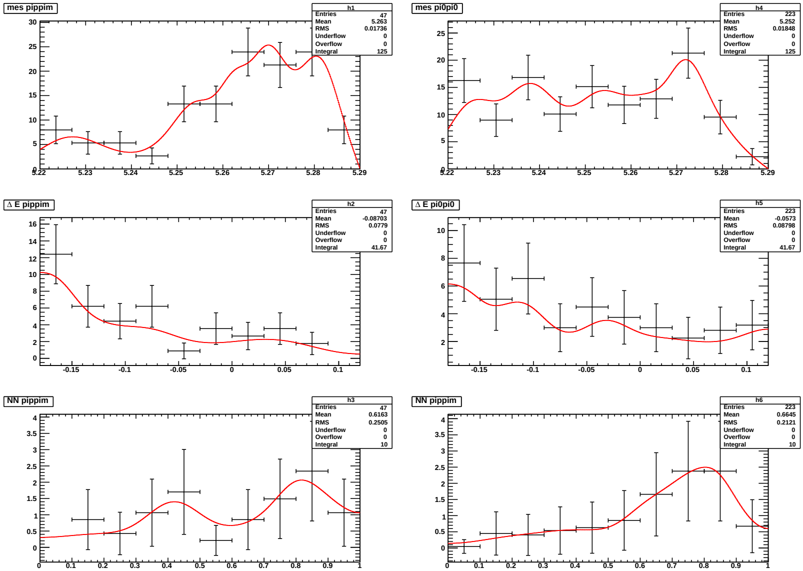


Figure: Charged generic B background for $B^0 \to 3K_s^0(\pi^+\pi^-)$ (left) and $B^0 \to 2K_s^0(\pi^+\pi^-)K_s^0(\pi^0\pi^0)$ (right).

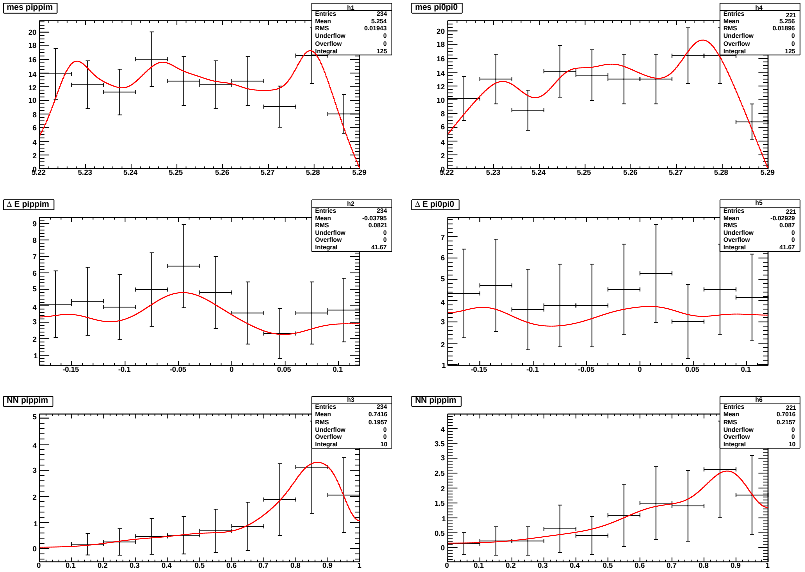


Figure: $K_s^0 K_s^0 K_l^0$ B background for $B^0 \to 3K_s^0(\pi^+\pi^-)$ (left) and $B^0 \to 2K_s^0(\pi^+\pi^-)K_s^0(\pi^0\pi^0)$ (right).

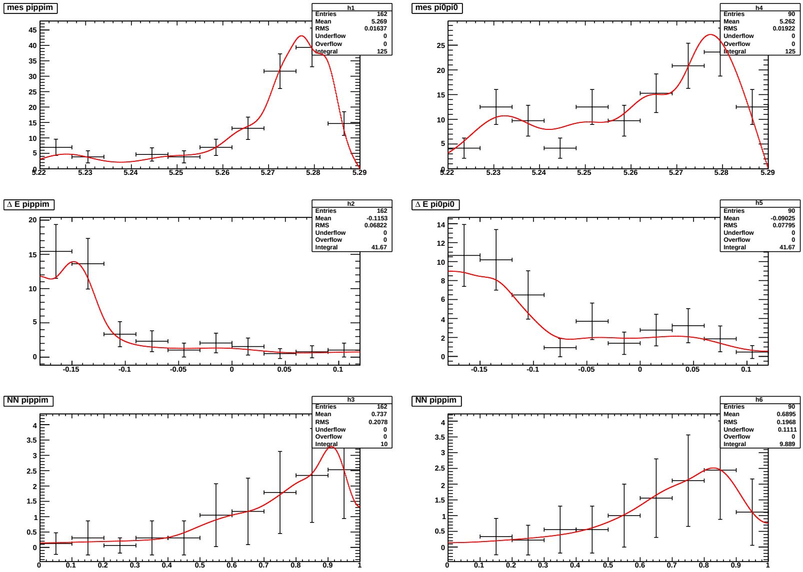


Figure: $K_s^0 K_s^0 K^{0*}$ B background for $B^0 \to 3K_s^0(\pi^+\pi^-)$ (left) and $B^0 \to 2K_s^0(\pi^+\pi^-)K_s^0(\pi^0\pi^0)$ (right).

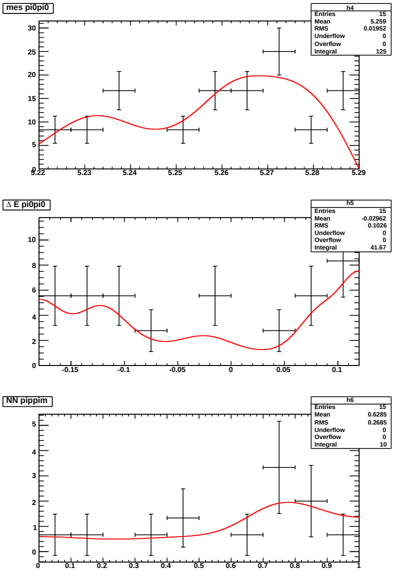


Figure: $K_s^0 K_l^0 K^{0*}$ B background for $B^0 \to 2K_s^0(\pi^+\pi^-)K_s^0(\pi^0\pi^0)$.

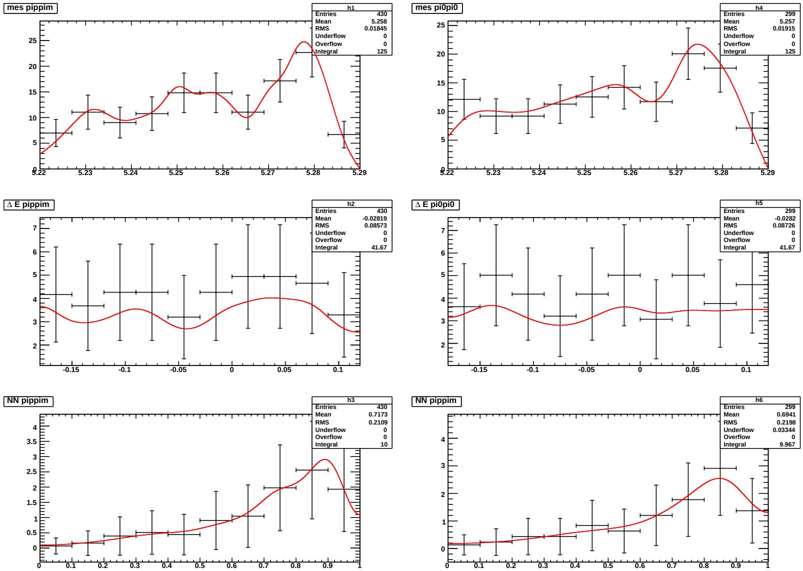


Figure: $K^+K_s^0K_s^0$ B background for $B^0 \to 3K_s^0(\pi^+\pi^-)$ (left) and $B^0 \to 2K_s^0(\pi^+\pi^-)K_s^0(\pi^0\pi^0)$ (right).

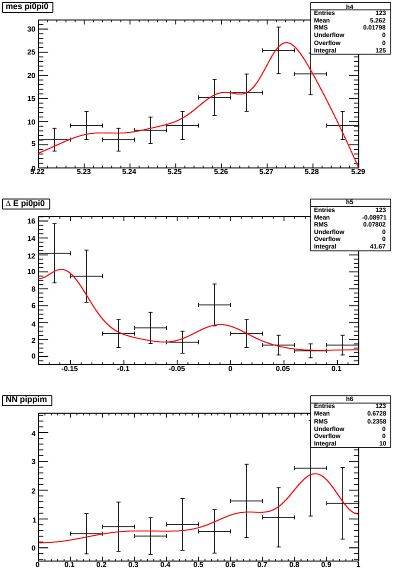


Figure: $K^{+*}K_s^0K_s^0$ B background for $B^0 \to 2K_s^0(\pi^+\pi^-)K_s^0(\pi^0\pi^0)$.

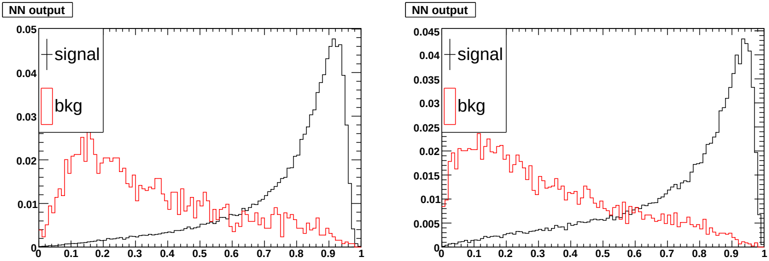


Figure: Transformed output of the NN trained for $K_S \to \pi^+\pi^-$ (left) and $K_S \to \pi^0\pi^0$ (right).