Hadronic Recoil Analysis and $B \to K^{(*)} \nu\nu$ at SuperB

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Outline

* Theoretical and Experimental status of $B \to K^{(*)} \nu\nu$
* Hadronic Recoil Analysis Method and Implementation in Superb Fast Simulation

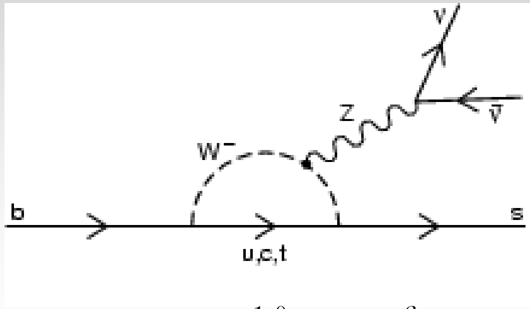
* BaBar Full Simulation vs Fast Simulation in the BaBar configuration

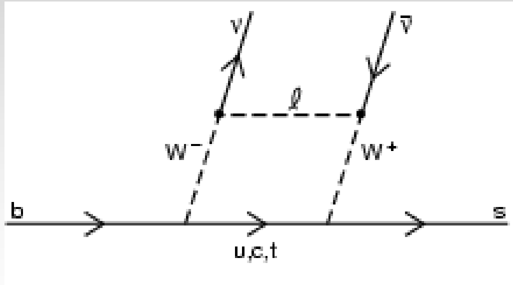
* Comparison between SuperB Detector geometry # 1 (DG_1) and SuperB Detector geometry # 4 (DG_4)
  - Breco side
  - $B \to K^{(*)} \nu\nu$ signal side analysis

* SuperB expected sensitivity on $B \to K^{(*)} \nu\nu$ branching fractions

Theoretical status

* Standard Model diagrams



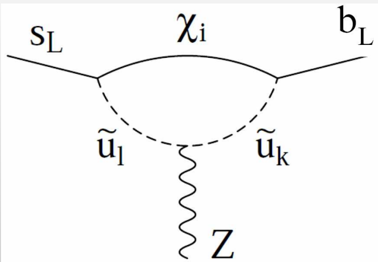


$$BR_{SM}(B \to K^* \nu\nu) = (6.8^{+1.0}_{-1.1})x10^{-6}$$
$$BR_{SM}(B \to K \nu\nu) = (4.5 \pm 0.7)x10^{-6}$$

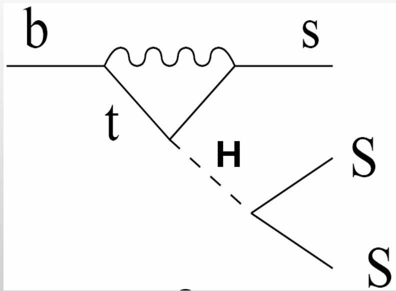
G.Altmannshofer et al., TUM-HEP-709-09

* New physics effects: some examples

Non Standard Z - couplings



New sources of missing energy



Buchalla et al. hep-ph/0006136;
Bird et al. hep-ph/0401195;
Aliev et al. arXiv:0705.4542;
Neubert at LLWI '09;
Kim et al. arXiv:0904.0318;

* BR enhanced up to a factor 50 with respect to the SM expectations

Experimental Status

- Belle experiment (Had Recoil, 535 million BB pairs)[1]:

$$\mathcal{B}(B^{\pm} \to K^{\pm}\nu\bar{\nu}) < 1.4x10^{-5}$$

$$\mathcal{B}(B^{0} \to K^{0}_{S}\nu\bar{\nu}) < 1.6x10^{-4}$$

$$\mathcal{B}(B^{\pm} \to K^{*\pm}\nu\bar{\nu}) < 1.4x10^{-4}$$

$$\mathcal{B}(B^{0} \to K^{*0}\nu\bar{\nu}) < 3.4x10^{-4}$$

All the measurements are still consistent with the SM expectation ($O(10^{-6})$)

- BaBar (Had Recoil, 351 million BB pairs)[2]:

$$\mathcal{B}(B^{\pm} \to K^{\pm}\nu\bar{\nu}) < 4.2x10^{-5}$$

- BaBar (Had+SL Recoil 454 million BB pairs)[3]:

$$\mathcal{B}(B^{\pm} \to K^{*\pm}\nu\bar{\nu}) < 8x10^{-5}$$

$$\mathcal{B}(B^{0} \to K^{*0}\nu\bar{\nu}) < 12x10^{-5}$$

$$\mathcal{B}(B \to K^{*}\nu\bar{\nu}) < 8x10^{-5}$$

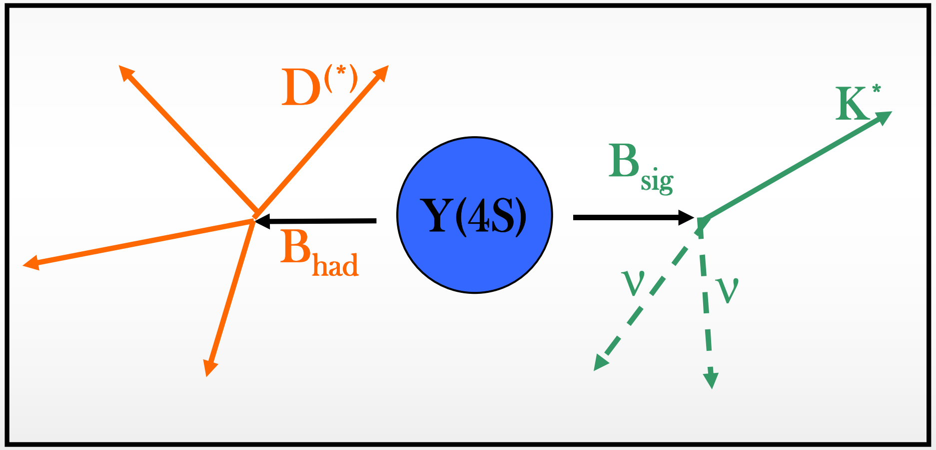
[1] K. F. Chen et al. [BELLE Collaboration], Phys. Rev. Lett. 99, 221802 (2007).
[2] H.Kim on behalf of the BaBar collaboration, arXiv:hep-ex/08052365 (2008).
[3] B. Aubert et al. [BaBar collaboration], Phys.Rev.D78:072007,2008

Hadronic Recoil Analysis: method

$e^+e^- \to \Upsilon(4S) \to B\overline{B}$

1. B_{had} reconstruction: Full reconstruction of one B meson in hadronic (or semileptonic) decays

2. B_{sig} reconstruction: look for the signal B signature, i.e. a K^* not accompanied by additional (charged or neutral) particles + missing energy



RECOIL TECHNIQUE @ b-FACTORIES

→ search for rare decay with MISSING ENERGY

(NOT FEASIBLE @ HADRONIC MACHINE)

→ two examples of SuperB benchmark channels: $B \to \tau\nu$, $B \to K^{(*)}\nu\nu$

Hadronic Breco reconstruction philosophy

* Aim: collect as many as possible fully reconstructed B mesons in order to study the property of the recoil
* SemiExclusive reconstruction: search for $B \to D(^*)X$, with $X = n\pi\ mK\ pK_s\ q\pi^0$ and $n+m+r+q<6$, without making requirements on intermediate resonances
* Reoconstruction steps:
  - reconstruct $D \to$ hadrons

$D^{*+} \to D^0\pi^+$	$D^0 \to K^-\pi^+$	$D^+ \to K^-\pi^+\pi^-$
$D^{*0} \to D^0\pi^0$	$D^0 \to K^-\pi^+\pi^0(\gamma\gamma)$	$D^+ \to K^-\pi^+\pi^-\pi^0$
$D^{*0} \to D^0\gamma$	$D^0 \to K^-\pi^+\pi^+\pi^-$	$D^+ \to K^0_S\pi^+$
	$D^0 \to K^0_S\pi^+\pi^-$	$D^+ \to K^0_S\pi^+\pi^-\pi^+$
		$D^+ \to K^0_S\pi^+\pi^0$

  - use D as a seed and add X to have a system compatible with the B hypotesys
* Signal box defined by using:

$$m_{ES} = \sqrt{E^{*2}_{beam} - p^{*2}_B}$$

$$\Delta E = E^*_B - E^*_{beam}$$

* Sample of 1100 B decay modes, ordered by purity.
* In events with multiple candidates, the best one is selected according to the smallest ΔE

Hadronic Recoil Analysis in FastSim

* use BaBar code, adapted to FastSim framework

* Breco side: limit the number of reconstructed modes channels according to their purity
  - Breco mode classification: neat : purity > 80% , $\varepsilon_{neat} \approx O(10^{-4})$
    clean : 50% < purity < 80% , $\varepsilon_{clean} \approx O(10^{-3}\text{-}10^{-2})$
    dirty : 8%<purity<50% , $\varepsilon_{dirty} \approx O(10^{-2})$
  - in some BaBar analysis (i.e. $B \to \tau\nu$) only the cleanest Breco modes are used; same will be probably done with the high SuperB statistics

$\to$ reconstruct only neat+clean modes

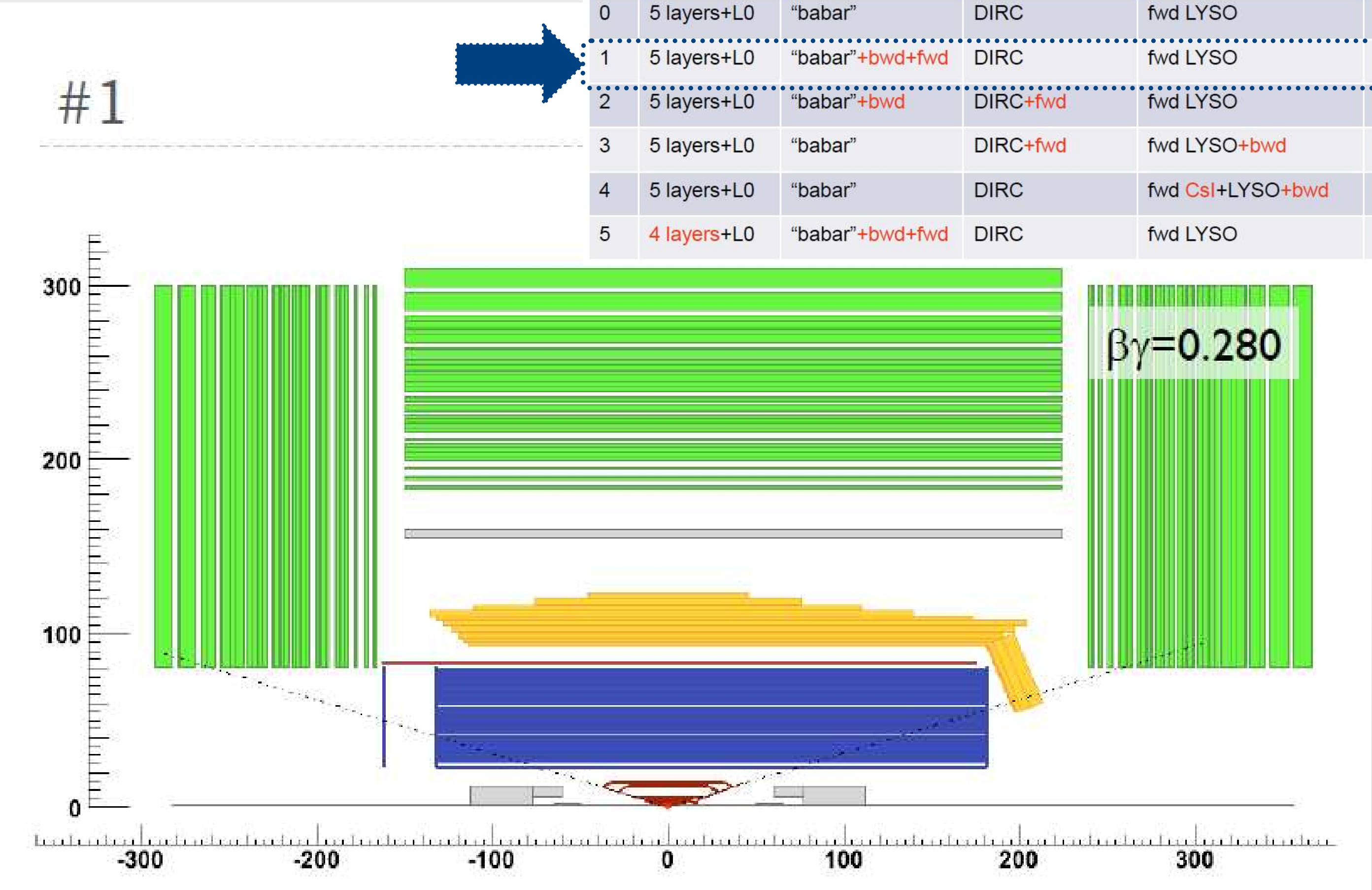
* Bsig side:
  - $K^+\nu\nu$
  - $K_s(\pi^+\pi^-)\nu\nu$
  - $K^{*+}(K_s\pi^+, K^+\pi^0)\nu\nu$
  - $K^{*0}(K^+\pi^-)\nu\nu$
  - $\tau^+\nu$, with $\tau^+ \to e^+\nu\nu$, $\mu^+\nu\nu$, $\pi^+\nu$, $\rho^+(\pi^+\pi^0)\nu$, $a_1^+(\rho^0\pi^+)\nu$

discussed in this talk ($K^+\nu\nu$, K^{*+}, K^{*0})

SuperB detector geometry : example I

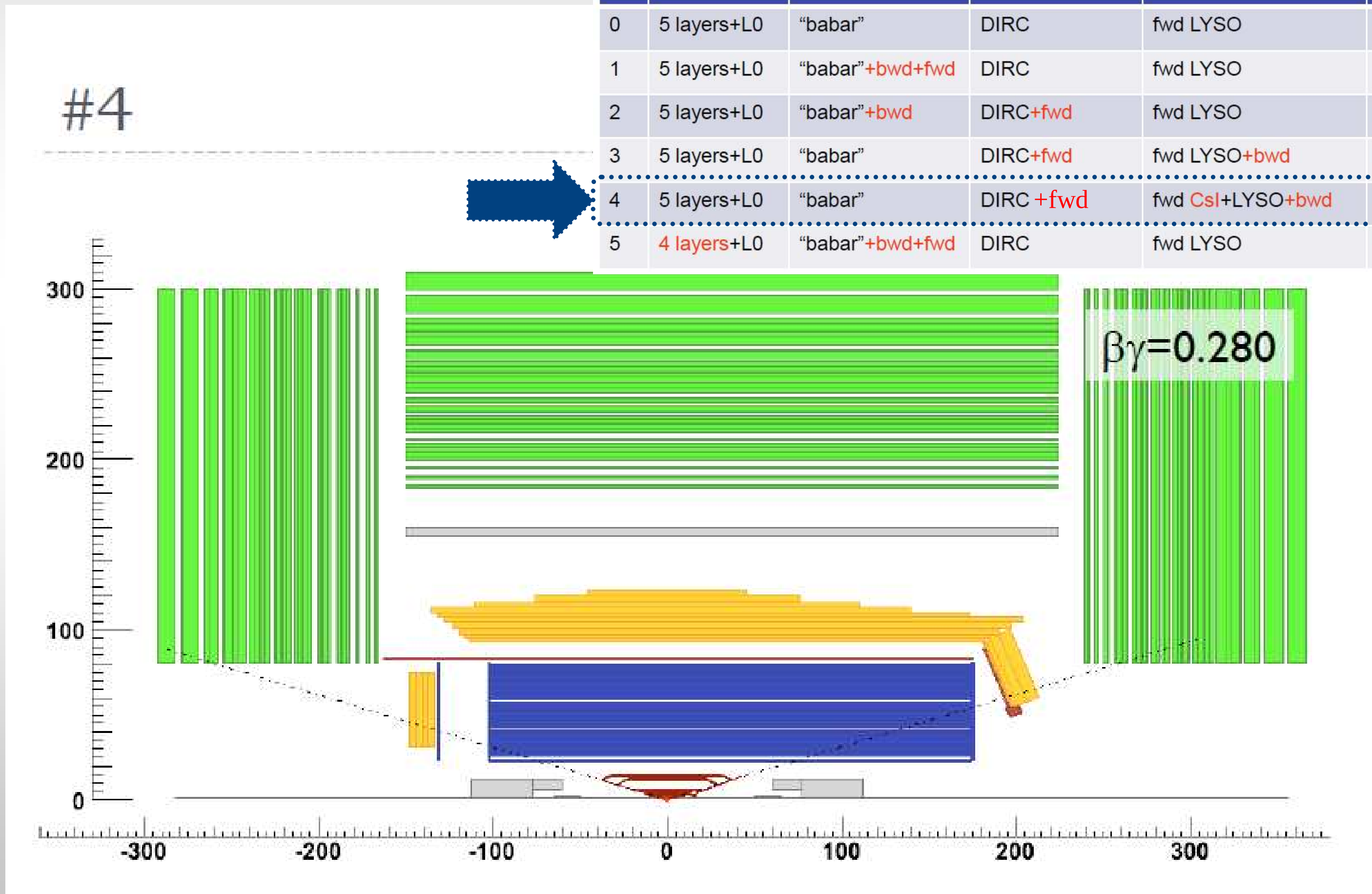
* DetectorGeometry_1
  - SVT_L0 + bwd and fwd DCH: gain in tracking and Breco reconstruction efficiencies

	SVT	DCH	PID	EMC	IFR
0	5 layers+L0	"babar"	DIRC	fwd LYSO	baseline
1	5 layers+L0	"babar"+bwd+fwd	DIRC	fwd LYSO	baseline
2	5 layers+L0	"babar"+bwd	DIRC+fwd	fwd LYSO	baseline
3	5 layers+L0	"babar"	DIRC+fwd	fwd LYSO+bwd	baseline
4	5 layers+L0	"babar"	DIRC	fwd CsI+LYSO+bwd	baseline
5	4 layers+L0	"babar"+bwd+fwd	DIRC	fwd LYSO	baseline



SuperB detector geometry :example II

- DetectorConfiguration_4
  - SVT_L0 + fwd DIRC + bwd EMC: higher angular coverage and better K-π separation



	SVT	DCH	PID	EMC	IFR
0	5 layers+L0	"babar"	DIRC	fwd LYSO	baseline
1	5 layers+L0	"babar"+bwd+fwd	DIRC	fwd LYSO	baseline
2	5 layers+L0	"babar"+bwd	DIRC+fwd	fwd LYSO	baseline
3	5 layers+L0	"babar"	DIRC+fwd	fwd LYSO+bwd	baseline
4	5 layers+L0	"babar"	DIRC +fwd	fwd CsI+LYSO+bwd	baseline
5	4 layers+L0	"babar"+bwd+fwd	DIRC	fwd LYSO	baseline

Data Sample for this analysis

* Hadronic Breco reconstruction implemented in SuperB Fast Simulation

* Background production (run in parallel for several analysis):
  - generic MC samples,
  - some machine background included
  - 3 detector geometry: DG_BaBar, DG_1, DG_4

* Signal MC ("private") production:
  - $B^+ \to K^+ \nu\nu$, $B^+ \to K^{*+} \nu\nu$, $B^0 \to K^{*0} \nu\nu$
  - 3 detector geometry
  - 10^6 generated events for each sample, for each DG

Detector Geometry	Generator	N requested	Analysis	Requestor	Status	N produced
DG_1	B0B0bar_generic	50x10^6	All	Dave	Complete	53.1 x10^6
DG_1	B+B-_generic	50x10^6	All	Dave	Complete	49.4x10^6
DG_1	ccbar	50x10^6	DstD0ToKspipi, HadRecoil	Rolf, Elisa	Complete	49.9x10^6
DG_1	uds	100x10^6	HadRecoil	Elisa	Complete	49.9x10^6
DG_1	B+B-_tau_DX	1x10^6	BtoTauNu	Chih-hsiang	Complete	1x10^6
DG_4	B0B0bar_generic	50x10^6	All	Dave	Complete	48.3x10^6
DG_4	B+B-_generic	50x10^6	All	Dave	Complete	48.7x10^6
DG_4	ccbar	50x10^6	HadRecoil	Elisa	Complete	49.8x10^6
DG_4	uds	100x10^6	HadRecoil	Elisa	Complete	49.3x10^6
DG_4	B+B-_tau_DX	1x10^6	BtoTauNu	Chih-hsiang	Complete	1x10^6
DG_BaBar	B0B0bar_generic	50x10^6	HadRecoil	Elisa	Complete	50x10^6
DG_BaBar	B+B-_generic	50x10^6	HadRecoil	Elisa	Complete	50x10^6
DG_BaBar	ccbar	50x10^6	DstD0ToKspipi, HadRecoil	Rolf, Elisa	Complete	50x10^6
DG_BaBar	B+B-_tau_DX	1x10^6	BtoTauNu	Chih-hsiang	Complete	1x10^6

BaBaf Full Simulation

vs

SuperB Fast Simulation

Samples used

* SuperB FastSim:
  - B+B-, B0B0bar, ccbar MC samples (see slide 10)
  - BaBar beams and detector geometry
* BaBar FullSim, Run3:
  - B+B- : 49766000 gen. events
  - B0B0bar : 50556000 gen. events
  - ccbar : 83974000 gen. events
* Differences in reconstructed Breco modes
  - BaBar FullSim: additive modes wrt FastSim, i.e. $B \rightarrow J/\psi\ X$, new D modes as seeds → cut on B and D mode to reject most of them
  - BaBar FullSim: neat+clean+dirty sample → cut on purity
* Selection applied:
  - at least one reconstructed Breco; if #Breco > 1, best candidate ↔ $|\Delta E|$min
  - $-0.09<\Delta E<0.05$ GeV
  - $5.270<m_{ES}<5.288$ GeV/c^2

Hadronic Recoil Analysis: FastSim vs FullSim (I)

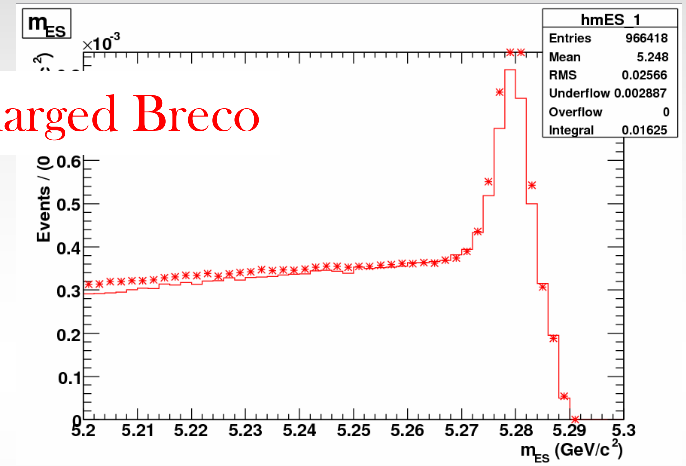
charged Breco	B0B0bar		BpBm		ccbar	
	FullSim	FastSim	FullSim	FastSim	FullSim	FastSim
≥ 1 Breco	0.0037	0.0054	0.0100	0.0115	0.0088	0.0079
deltaE cut	0.0028	0.0043	0.0081	0.0093	0.0063	0.0057
mES cut	0.0004	0.0007	0.0034	0.0032	0.0008	0.0007
$\varepsilon_{Fast}/\varepsilon_{Full}$	1.66		0.95		0.94	

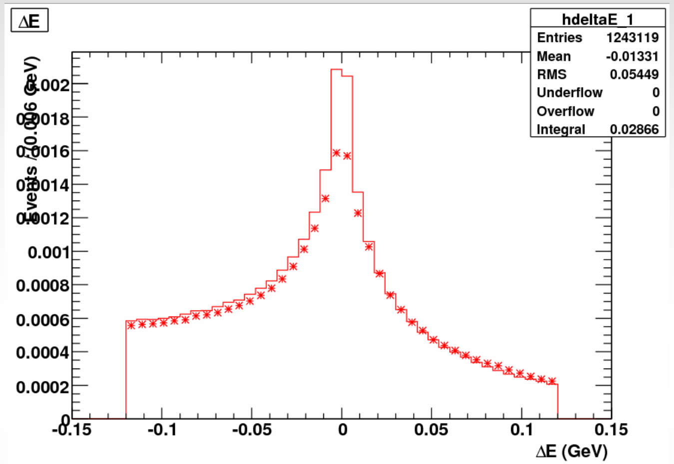
neutral Breco	B0B0bar		BpBm		ccbar	
	FullSim	FastSim	FullSim	FastSim	FullSim	FastSim
≥ 1 Breco	0.0083	0.0133	0.0031	0.0057	0.0038	0.0054
deltaE cut	0.0070	0.0116	0.0025	0.0048	0.0029	0.0043
mES cut	0.0020	0.0028	0.0003	0.0006	0.0003	0.0005
$\varepsilon_{Fast}/\varepsilon_{Full}$	1.40		1.92		1.57	

Hadronic Recoil Analysis: FastSim vs FullSim (II)

* m_{ES} and ΔE before the selection

charged Breco

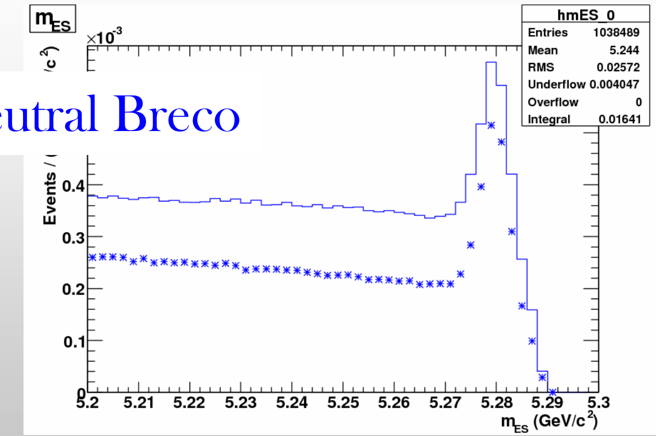


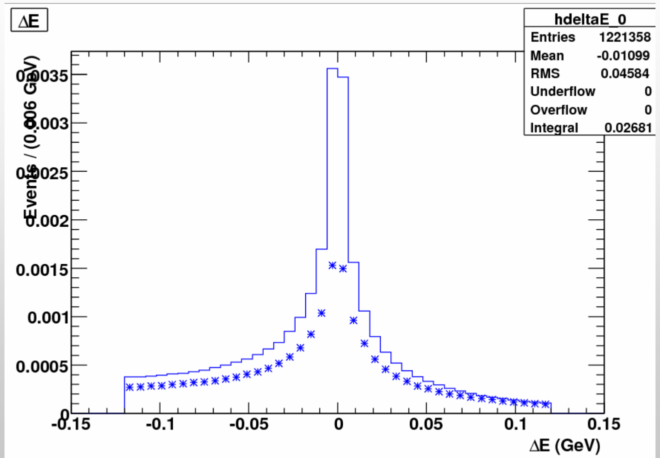


* BaBar FullSim
— FastSim DG_BaBar

♦ ccbar + B0B0 + B+B-

neutral Breco





♦ ccbar + B+B- +B0B0

SuperB Fast Simulation: DG_1 and DG_4

Hadronic Recoil Analysis: SuperB configs(I)

* Efficiency table for charged reconstructed Breco

charged Breco	B0B0bar		BpBm		ccbar		uds	
	DG_1	DG_4	DG_1	DG_4	DG_1	DG_4	DG_1	DG_4
$\geq$ 1 Breco	0.0084	0.0089	0.0165	0.0174	0.0113	0.0120	0.0055	0.0058
deltaE cut	0.0067	0.0072	0.0135	0.0143	0.0081	0.0087	0.0038	0.0040
mES cut	0.0010	0.0011	0.0042	0.0043	0.0011	0.0012	0.0006	0.0006
$(\varepsilon_{DG4}-\varepsilon_{DG1})/\varepsilon_{DG1}$	+5.92		+3.70%		+5.61%		+3.03%	

Hadronic Recoil Analysis: SuperB configs(II)

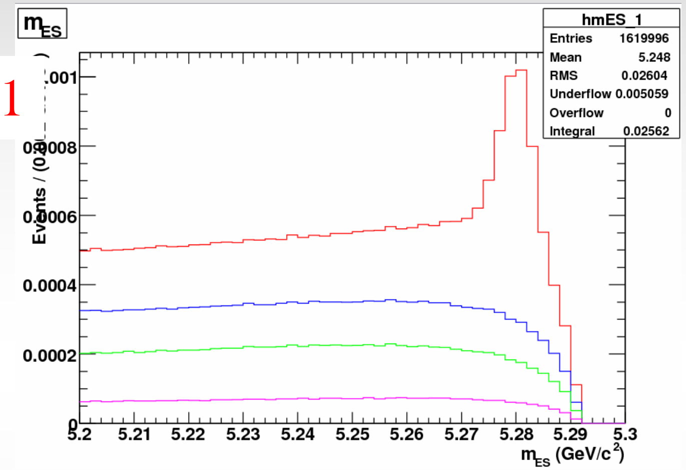
* Efficiency table for neutral reconstructed Breco

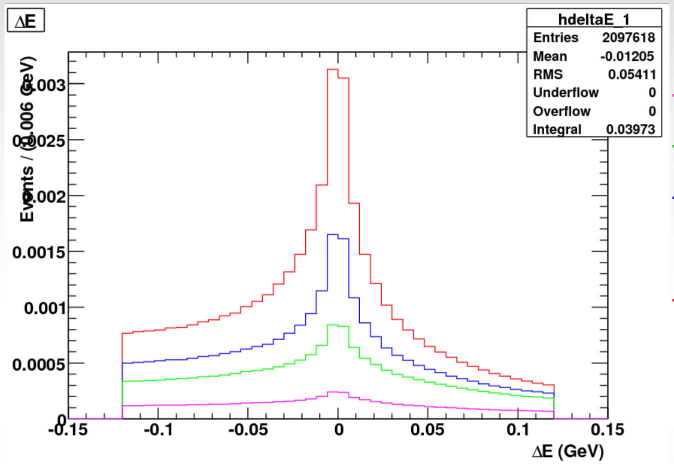
neutral Breco	B0B0bar		BpBm		ccbar		uds	
	DG_1	DG_4	DG_1	DG_4	DG_1	DG_4	DG_1	DG_4
≥ 1 Breco	0.0198	0.0202	0.0090	0.0092	0.0084	0.0086	0.0015	0.0015
deltaE cut	0.0174	0.0178	0.0077	0.0079	0.0068	0.0071	0.0011	0.0011
mES cut	0.0039	0.0039	0.0009	0.0009	0.0007	0.0007	0.0001	0.0001
$(\varepsilon_{DG4}-\varepsilon_{DG1})/\varepsilon_{DG1}$	+1.76%		+1.45%		+2.16%		+2.79%	

Hadronic Recoil Analysis: SuperB configs(III)

* charged Breco, ΔE before selection, and m_{ES} after ΔE selection

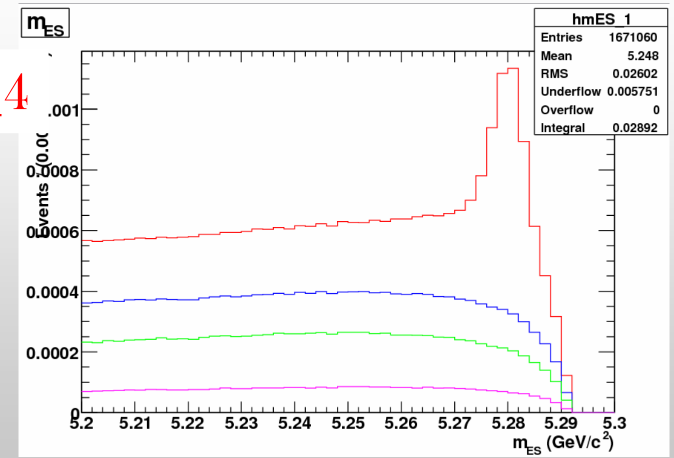
DG_1

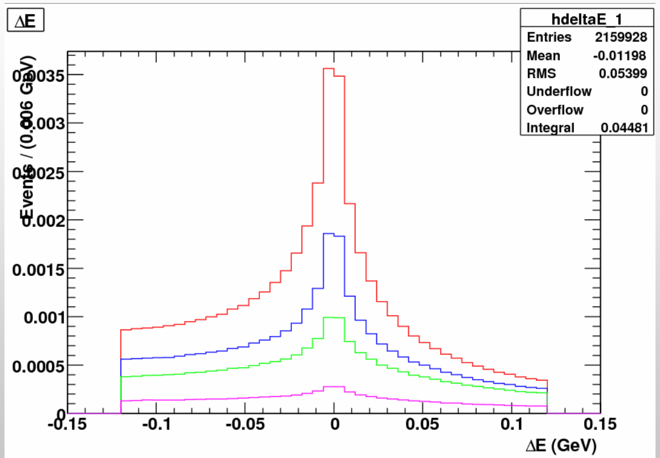




— uds
— uds + ccbar
— uds + ccbar + B0B0
— uds + ccbar + B0B0 + B+B-

DG_4



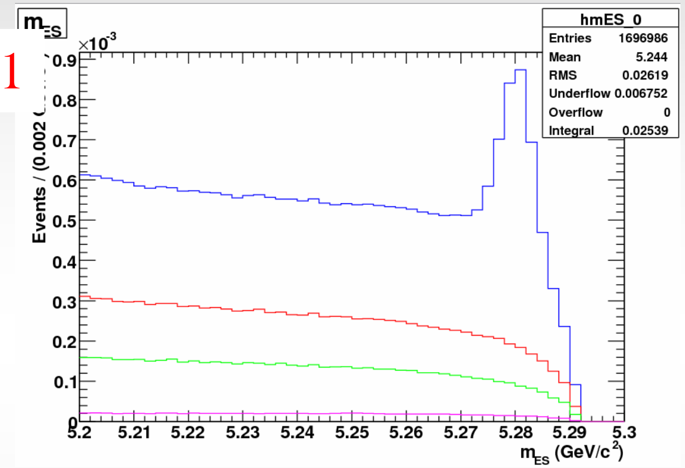


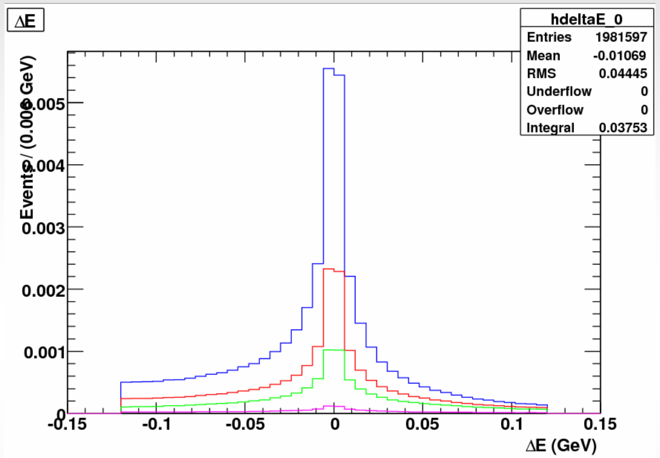
— uds
— uds + ccbar
— uds + ccbar + B+B-
— uds + ccbar + B+B- + B0B0

Hadronic Recoil Analysis: SuperB configs(IV)

* neutral Breco, ΔE before selection, and m_{ES} after ΔE selection

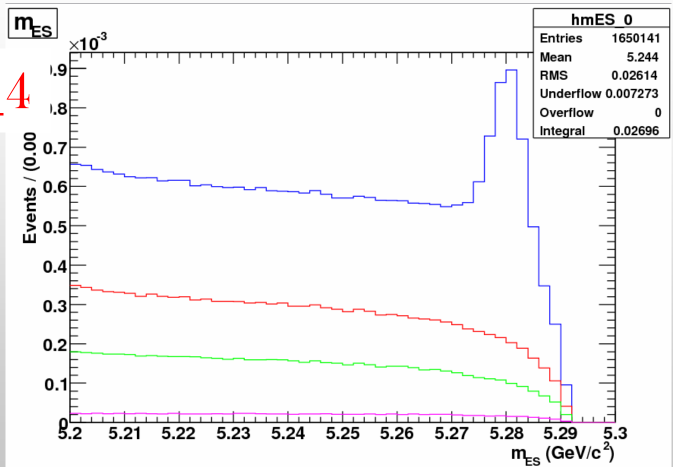
DG_1

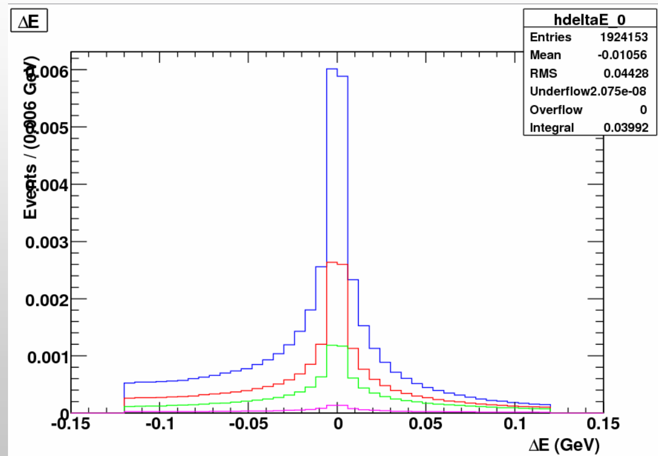




— uds
— uds + ccbar
— uds + ccbar + B0B0
— uds + ccbar + B0B0 + B+B-

DG_4





— uds
— uds + ccbar
— uds + ccbar + B+B-
— uds + ccbar + B+B- + B0B0

Signal Side Analysis

$B \to K\nu\nu$: efficiency studies

* BaBar cut and count analysis
  - Selection:

$Q_{tag} = \pm 1$
$5.270 < m_{ES} < 5.288$ GeV/c^2
$|\cos\theta_{Breco,Thrust}| < 0.85$

K candidate from Bsig
$|\cos\theta^*_{trk}| < 0.85$
$N_{extraTrk} < 3$
$E_{extra} < 0.4$ GeV
$N_{\pi 0} = 0$
$p_K^B > 1.1$Gev/c
$-0.85 < \cos\theta_{pmiss} < 0.9$

$\varepsilon_{TOT} = 7.2 \times 10^{-4}$
(no systematics or corrections included)

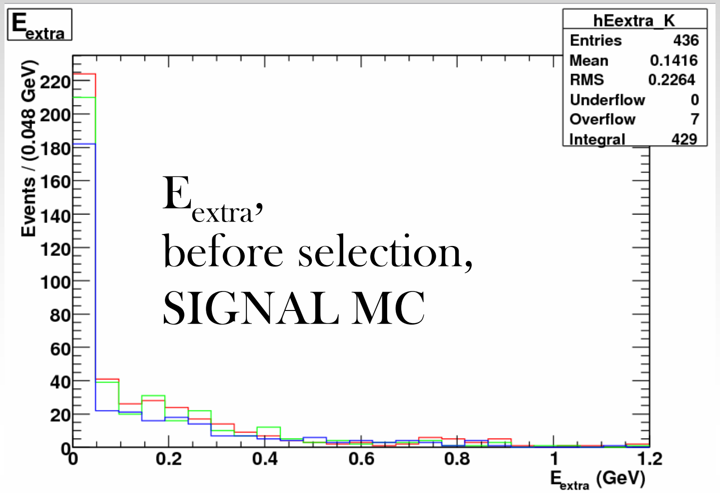
  - reconstructed Breco modes = neat + clean + dirty

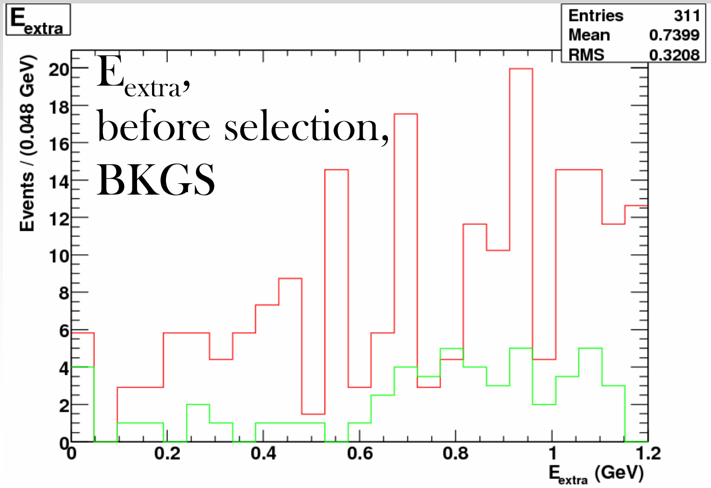
* SuperB: applying BaBar cuts BUT $N_{extraTrk}$==0

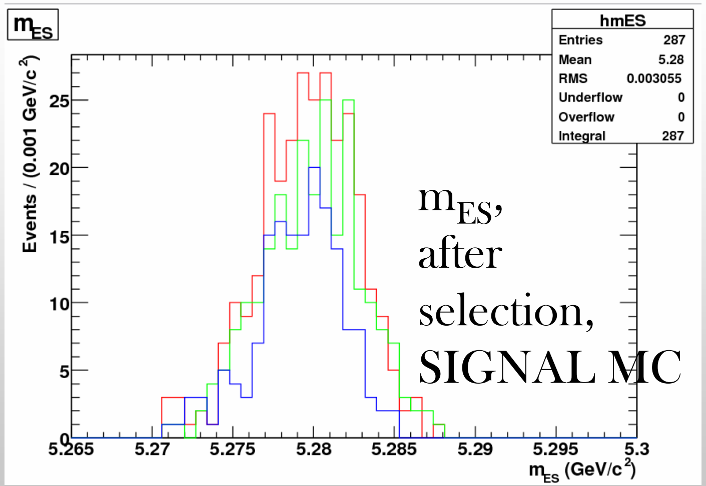
	DG_BaBar	DG_1	DG_4
$\varepsilon_{tot, K}$	$(1.63 \pm 0.13) \times 10^{-4}$	$(2.36 \pm 0.15) \times 10^{-4}$	$(2.87 \pm 0.17) \times 10^{-4}$
ε gain wrt DG_BaBar		+44.8%	+76.1%

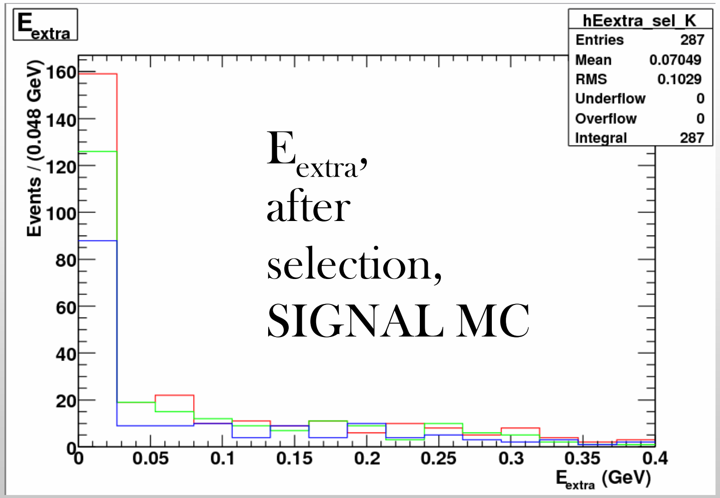
B→Kνν: some distributions

— DG_BaBar
— DG_1
— DG_4









B→K*νν: efficiency studies (I)

- BaBar cut and count analysis
  - Selection:

B_{sig}-B_{reco} charge correlation
$5.270 < m_{ES} < 5.288$ GeV/c²
$-0.09 < \Delta E < 0.05$ GeV
$|\cos\theta_{Breco,Thrust}| < 0.85$

channel	selection criteria
$K^{*\pm} \to K^{\pm}\pi^0$	$0.03 < R_2 < 0.70$ $0.004 < \lvert\cos\theta^*_{thrust}\rvert < 0.84$ $0.84 < m_{K^*} < 0.95$ GeV/c^2 $-0.78 < \cos\theta^*_{miss} < 0.93$
$K^{*\pm} \to K^0_S(\pi^+\pi^-)\pi^{\pm}$	$0.0 < R_2 < 0.49$ $0.0 < \lvert\cos\theta^*_{thrust}\rvert < 0.85$ $0.86 < m_{K^*} < 0.95$ GeV/c^2 $0.49 < m_{K^0_S} < 0.50$ GeV/c^2 $-0.82 < \cos\theta^*_{miss} < 0.82$
$K^{*0} \to K^-\pi^+$	$0.06 < R_2 < 0.53$ $0.002 < \lvert\cos\theta^*_{thrust}\rvert < 0.85$ $0.85 < m_{K^*} < 0.97$ GeV/c^2 $-0.86 < \cos\theta^*_{miss} < 0.90$

E*miss+cp*miss>4.5GeV
Eextra<0.3GeV

  - reconstructed Breco

modes = neat + clean + dirty

ε_{TOT} $(B^+ \to K^{*+}(K^+\pi^0)\nu\nu) = 1.01 \times 10^{-4}$
ε_{TOT} $(B^+ \to K^{*+}(K_S\pi^+)\nu\nu) = 0.74 \times 10^{-4}$
ε_{TOT} $(B^0 \to K^{*0}(K^+\pi^-)\nu\nu) = 1.74 \times 10^{-4}$
(no systematics or corrections included)

$B \to K^* \nu\nu$: efficiency studies (I)

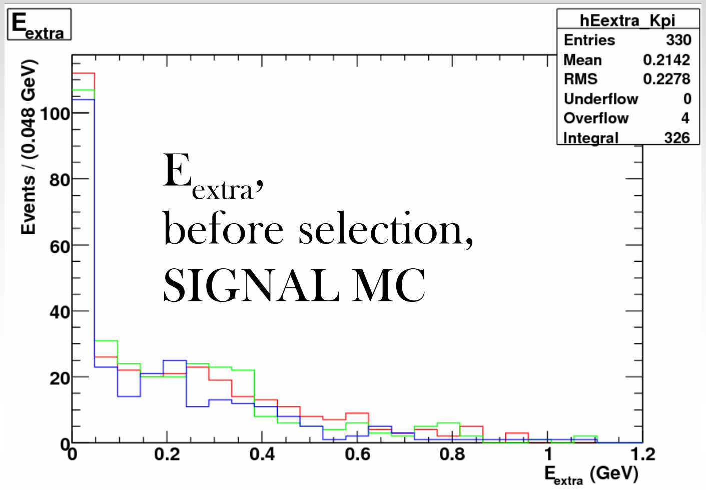
- SuperB: applying BaBar cuts BUT R_2, m_{Ks} (not filled correctly at rootuple level)

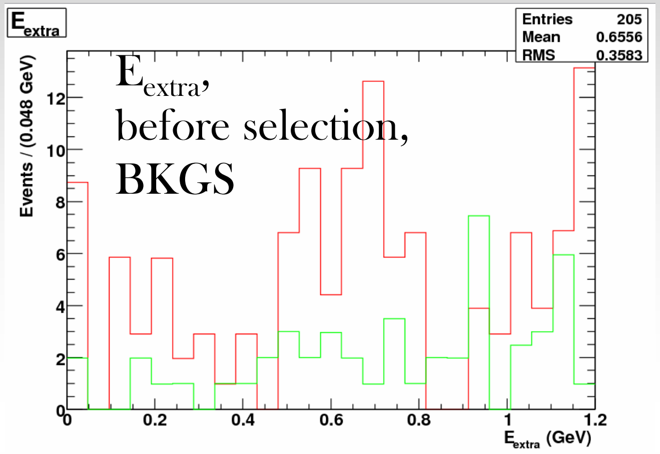
	DG_BaBar	DG_1	DG_4
$\varepsilon_{tot,\, K^*0(K+\pi-)}$	$(0.82\pm0.09)\times10^{-4}$	$(1.18\pm0.10)\times10^{-4}$	$(1.20\pm0.11)\times10^{-4}$
ε gain wrt DG_BaBar		+42.7%	+45.2%
$\varepsilon_{tot,\, K^*+(K+\pi0)}$	$(0.40\pm0.06)\times10^{-4}$	$(0.46\pm0.07)\times10^{-4}$	$(0.50\pm0.07)\times10^{-4}$
ε gain wrt DG_BaBar		+15.0%	+25.0%
$\varepsilon_{tot,\, K^*+(Ks\pi+)}$	$(0.43\pm0.07)\times10^{-4}$	$(0.55\pm0.07)\times10^{-4}$	$(0.64\pm0.08)\times10^{-4}$
ε gain wrt DG_BaBar		+27.9%	+48.8%

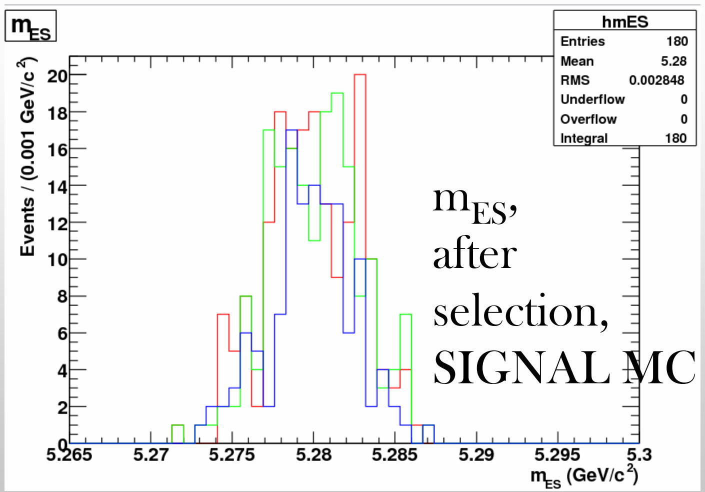
$B \to K^* \nu\nu$: some distributions (I)

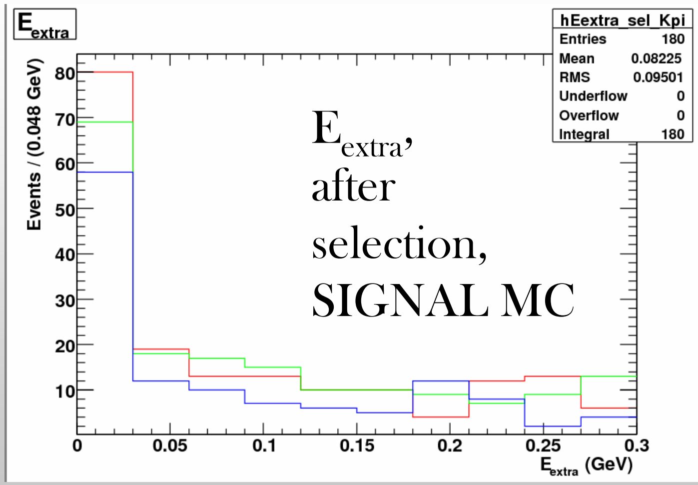
— DG_BaBar
— DG_1
— DG_4

$K^{*0} \to K^+\pi^-$



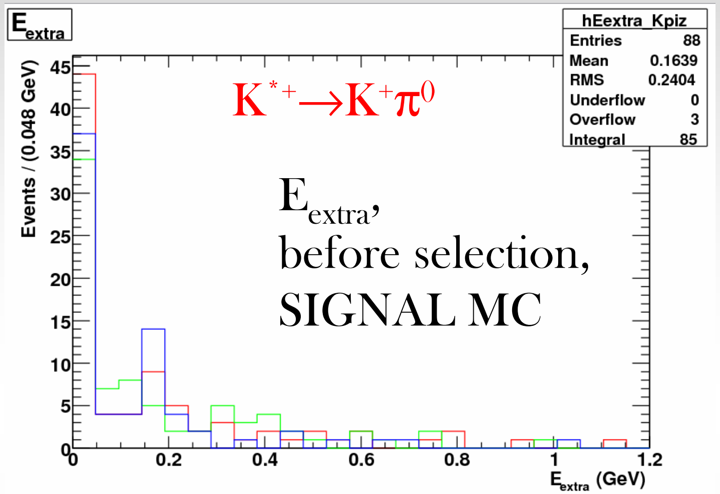


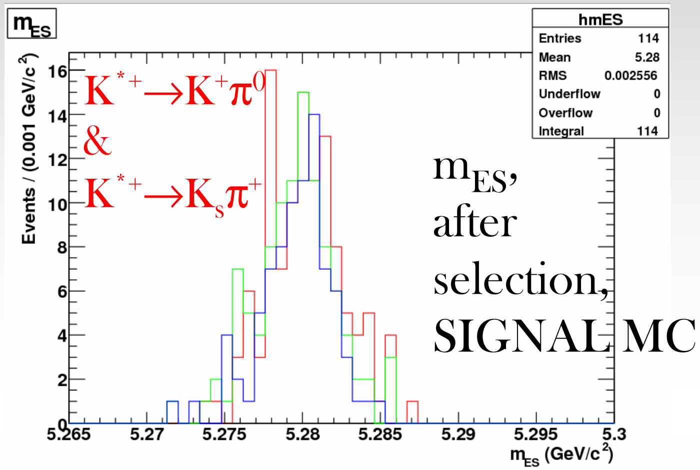


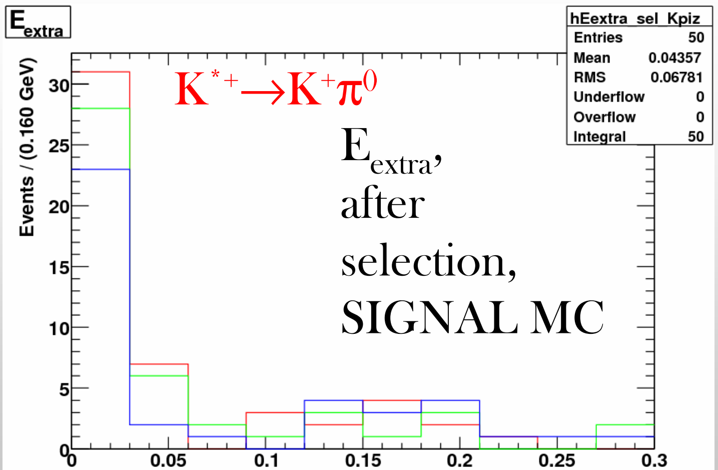


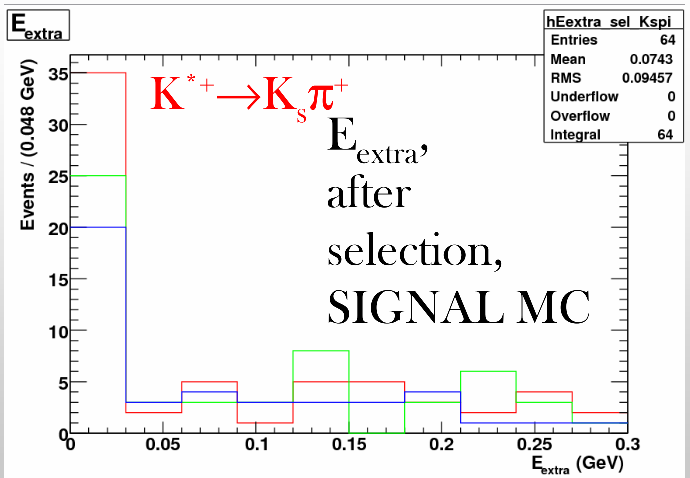
B→K*νν: some distributions (I)

— DG_BaBar
— DG_1
— DG_4









SuperB expected sensitivity

Method and uncertainties treatment

* K*nunu:
  - FastSim : cut and count analysis (optimization done in BaBar)
  - BaBar published result: results extracted by fitting Neural Network output

  → not straightforward to extrapolate BaBar results in SuperB scenario

* Knunu: applied same cut and count analysis as done in BaBar

* Compare:
  - BaBar results, scaling with lumi
  - SuperB DG_1 configuration
  - SuperB DG_4 configuration

* start from BaBar efficiencies & Backgrounds, BaBar analysis technique
* estimate a background reduction of 10%, use the efficiency gain evaluated by comparing DG_BaBar and DG_1/DG_4

* Systematic uncertainties

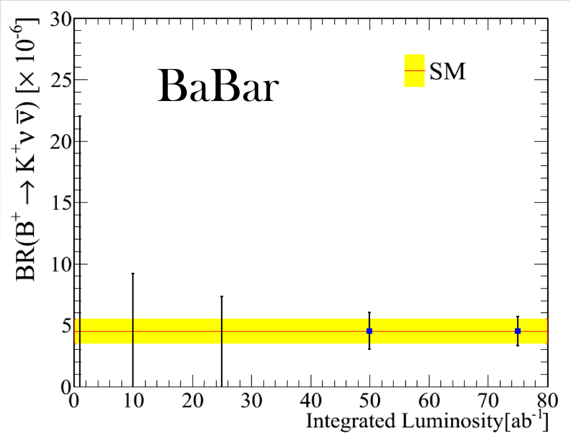
  BaBar: systematics largely dominated by MC statistics; Syst. error expected to go down with: 1/sqrt(MC stat) ~ 1/sqrt(Luminosity)

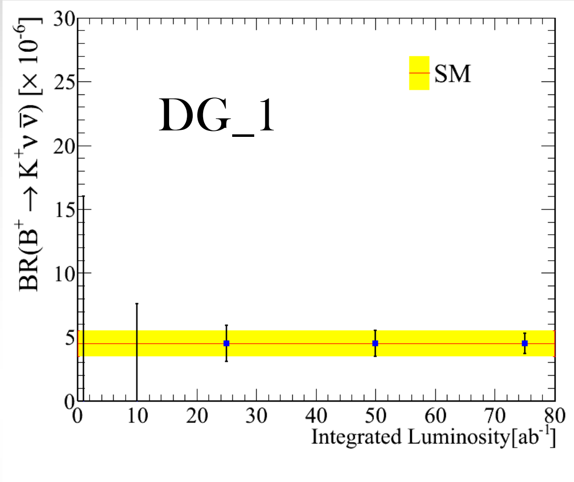
  SuperB: assume a syst. error equal to the stat. error;

BR(B→Kνν) Expected sensitivity

Preliminary

* BR as a function of luminosity





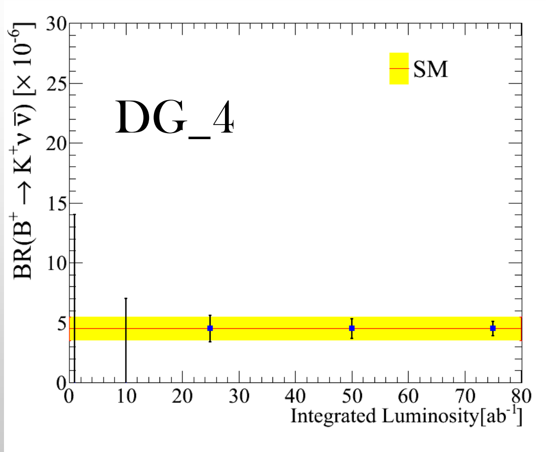
* statistics needed for signal evidence @ 3σ significance (just few scanned points)

BaBar config → 50 ab^{-1}

DG_1 → 25 ab^{-1}

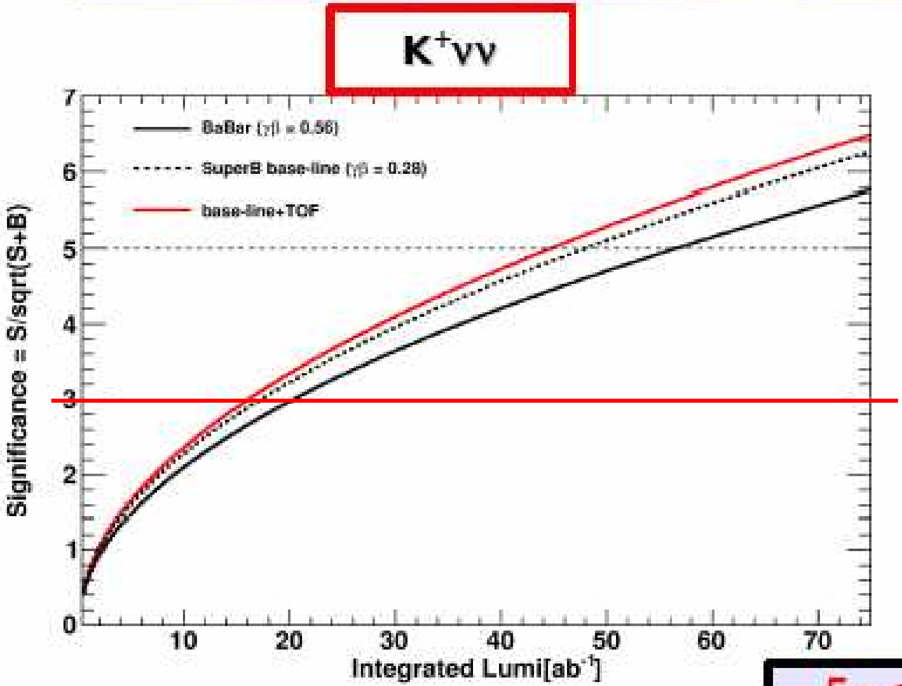
DG_4 → 25 ab^{-1} (smaller error wrt DG_1)

* better can be done by improving the analysis and combining with SL recoil



BR(B→Kνν) SL recoil, expected sensitivity

B⁺→K⁺νν (SL): Extrapolation



5σ significance (stat-only):

- BaBar: ~55ab⁻¹
- SuperB-base line: ~48ab⁻¹
- +TOF: ~44ab⁻¹

Alejandro Perez, Frascati SuperB Workshop Dec. 2nd 2009

Conclusions

* Hadronic Breco reconstruction provide high statistic and clean samples
  → searches of Bsig channels with invisible particles feasible in the recoil
* $B \to K^{(*)}\nu\nu$: one of theSuperB benchmark channels

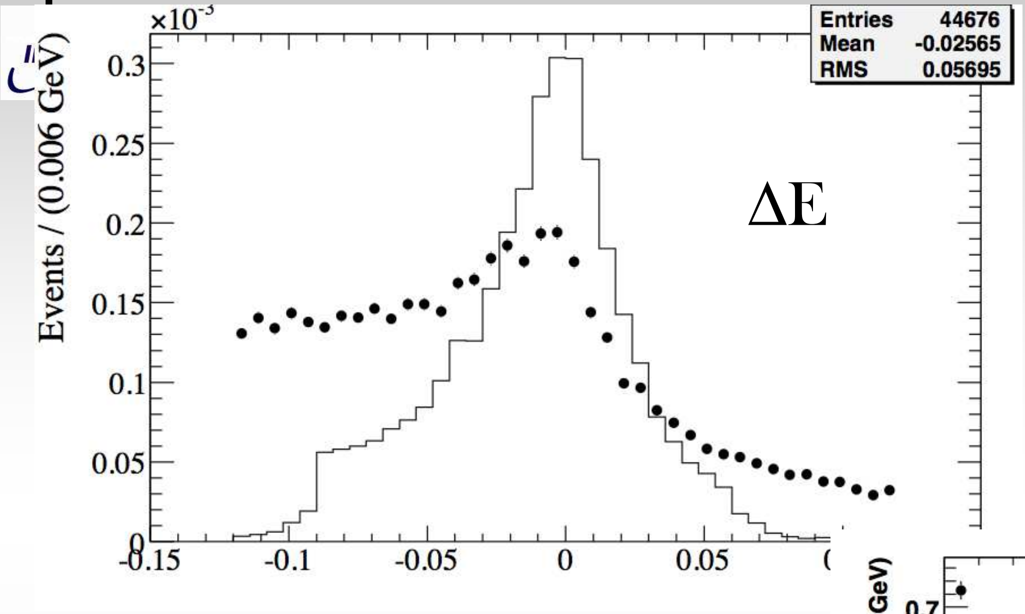
* Hadronic Recoil Analysis Method and Superb Fast Simulation
* Generic background and signal MC samples production performed

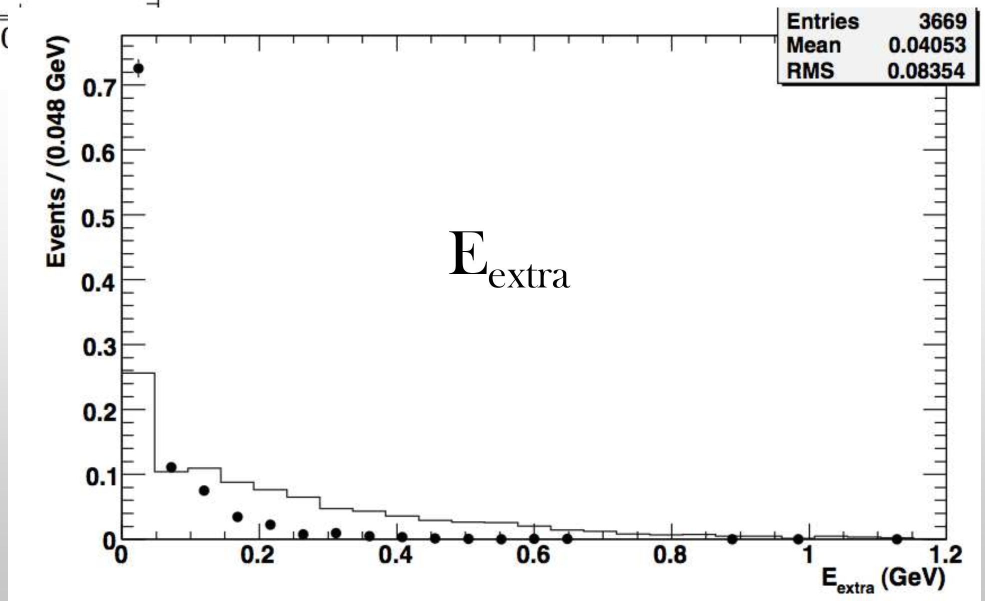
* comparison with BaBar FullSim:
  - quite good agreement for charged Breco, still some wok to do for the neutral
* test SuperB detector geometry configuration
  - DG_4 gives higher statistics wrt DG_1, but also higher background contamination
  - DG_4 selection variables may be more discriminant → more statistics needed

* SuperB expected sensitivity on $B \to K^{(*)}\nu\nu$ branching fractions
  - extrapolation for $K^*\nu\nu$ not straightforward
  - evidence for $B \to K\nu\nu$ signal @ $25ab^{-1}$ (assuming SM BR, HAD cut and count analysis only)

Back-up slides

FastSim V.0.0.3 vs BaBar FullSim





Bkg efficiency, before signal side selection

* Knunu
  - BRR) bz = 5e-07 bp : 5.44e-06 cc : 5.8e-07
  - DG1) bz = 3.59848e-07(-28%) bp = 4.87854e-06 (-10%) cc = 8.4e-07 (+45%)
  - DG4) bz = 3.52697e-07 (-29%) bp = 5.23614e-06 (-4%) cc = 7.83133e-07 (+35%)
* Kstar0nunu
  - BRR) bz = 1.88e-06 bp : 3.5e-06 cc : 3e-07
  - DG1) bz = 1.36364e-06 (-27%) bp = 1.78138e-06 (-49%) cc = 4.4e-07 (+47%)
  - DG4) bz = 1.53527e-06 (-19%) bp = 2.25873e-06 (-35%) cc = 4.21687e-07 (+40%)
* Kstarpnunu
  - Kspi

    BRR) bz = 9.4e-07 bp : 6.6e-06 cc : 8e-07

    DG1) bz = 1.00379e-06 (+7%) bp = 6.33603e-06 (-4%) cc = 9.4e-07 (+17%)

    DG4) bz = 1.20332e-06 (+28%) bp = 6.55031e-06 (-1%) cc = 1.1245e-06 (+40%)
  - Kpiz

    BRR) bz = 9.4e-07 bp : 6.6e-06 cc : 8e-07

    DG1) bz = 1.13636e-07 (-88%) bp = 9.7166e-07 (-85%) cc = 2.4e-07 (-70%)

    DG4) bz = 1.24481e-07 (-87%) bp = 1.00616e-06 (-84%) cc = 3.21285e-07 (-60%)