Status of $B \to K^{(*)}\nu\nu$

6th Belle II Italian collaboration meeting
Rome, December 14th, 2016

C. Cecchi [1], G. De Nardo[2], E. Manoni[1],
M. Merola[3]

[1] University di Perugia & INFN Perugia
[2] University "Federico II" di Napoli & INFN Napoli
[3] INFN Napoli

Outline

- Theoretical motivation and experimental status
- MC studies with MC5:
  - reconstruction and selection
  - UL estimation @ 500 fb^{-1}
  - first look at bkg characterization
  - comparison with BaBar distributions
- Next steps

Theoretical motivation and experimental status

- $B \to K^{(*)} \nu\nu$ is a potential probe for NP
  - FCNC suppressed in the SM
  - possible non-standard Z-couplings and new sources of missing energy in some NP scenarios
- Experimental searches from B factories:
  - ~ a factor of 4-5 between exp and SM predictions for K^+, K^{*+}, and K^{*0} channels

channel	Exp	Theo [3]
$B^0 \to K^{*0} \nu\nu$	$< 5.5\ 10^{-5}$ [1]	$9.19 \pm 0.86 \pm 0.50$
$B^+ \to K^{*+} \nu\nu$	$< 4.0\ 10^{-5}$ [1]	$9.91 \pm 0.93 \pm 0.54$
$B^0 \to K^0 \nu\nu$	$< 4.9\ 10^{-5}$ [2]	$1.85 \pm 0.20 \pm 0.20$
$B^+ \to K^+ \nu\nu$	$< 1.6\ 10^{-5}$ [2]	$3.98 \pm 0.43 \pm 0.19$

[1] PRD RC 87, 111103(2013)

[2] PRD 87, 112005(2013)

[3] BELLE2-MEMO-2016-007

- If SM holds, BF measurement with full statistics feasible with ~ 20% accuracy (back-of-the-envelop calculation detailed in BELLE2-MEMO-2016-008)

Studies on MC5: samples & reconstruction strategy

- SIGNAL SAMPLES:
  - ~1M events for BGx1 configs (private production with release-00-05-03)
  - generated and reconstructed channels: $K^{*+} \rightarrow K^{+}\pi^{0}$, $K_S\pi^{+}$
- GENERIC MC SAMPLES: (MC5 production, release-00-05-03) corresponding to 500 fb^{-1}
- Reconstruction strategy:
  - Hadronic tag side reconstructed with FEI algorithm
  - dedicated clustering cleaning and PID selection wrt official Belle2 FEI (see back-up for details)
  - B_{tag} signal probability (goodness of hadronic B reconstruction) > 1%
  - Number of tracks not associated to B_{sig} nor to B_{tag} (# extra tracks) = 0
  - Best Y candidate selected according to highest B_{tag} signal probability and K* with smallest $|m_{K^*,reco}-m_{K^*,PDG}|$

- DISCLAIMER: a bug was found in one of the .dec files describing generic B decays (overestimation of some BF), no reweighing has been applied in this study

Selection strategy

- Selection strategy:
  - Apply pre-selection cuts on B_{tag} kinematics (m_{BC}, ΔE)
  - Optimize cuts using S/sqrt(B) as figure of merit on: R_2, m_{KS}, m_{K^*}
  - Apply cuts on $\cos^*\theta_{miss}$, $cp^*_{miss}+E^*_{miss}$

  with $P^*_{MISS} = P^*_{Y4S}-P^*_{Btag}-P^*_{K^*}$

- Define a signal window on the extra energy deposited in the calorimeter, E_{ECL}, and evaluate signal efficiency and expected number of background events
- Estimate Upper Limit @ 90% C.L. with Bayesian approach

Selection summary table

Cut	$K_S\pi^+$ channel	$K^+\pi^0$ channel
m_{BC}	[5.27,5.29] GeV/c^2	[5.27,5.29] GeV/c^2
ΔE	[-0.08,0.05] GeV	[-0.08,0.05] GeV
R_2	<0.3	<0.3
m_{KS}	[0.5476,0.4475] GeV/c^2	
m_{K^*}	[0.842,0.942] GeV/c^2	[0.802,0.982] GeV/c^2
cosθ*miss	[-0.85,0.85]	[-0.85,0.85]
$cp^*_{miss} + E^*_{miss}$	> 4.5 GeV	> 4.5 GeV
E_{ECL}	<0.3 GeV	<0.3 GeV

Selection results and comparison with BaBar and Belle

	Current estimation	BaBar 2008 cut-and-count [*]	BELLE 2013 E_{extra} fit [PRD RC 87, 111103(2013)]
Lumi (fb^{-1})	500	413	711
expected background yield	$K_S\pi^+$:31 ± 6, $K^+\pi^0$: 609 ± 25	$K_S\pi^+$: 9 ± 5, $K^+\pi^0$:19 ± 9	
signal efficiency (10^{-4})	$K_S\pi^+$:1.1 ± 0.1, $K^+\pi^0$: 4.6 ± 0.2	$K_S\pi^+$: ~0.7, $K^+\pi^0$: ~1	1.47

- Statistical errors only
- Main differences between this and BaBar analysis:
  - tighter selection and reconstruction requirements (e.g. K_S and K* reconstruction)
  - no contamination from machine background in BaBar case

[*] NN fit results published for 2008 BaBar analysis (PRD 78, 072007(2008)), cut-and-count analysis in my PHD thesis

Upper limit estimation (I)

- Use Bayesian approach to estimate UL @ 90% C.L. with 500 fb^{-1}
- Inputs:
  - Uncertainties on BB yield at 1% level
  - Statistical uncertainties on signal efficiency and background estimation from this MC study
  - Systematic uncertainties on signal efficiency and background estimation from BaBar cut-and-count analysis

	Cut and Count		
K^* mode	$K^+\pi^0$	$K^0_S\pi^+$	$K^+\pi^-$
	Signal efficiency (%)		
MC statistics	3.5	4.1	3.1
Selection variables	3.4	7.0	6.0
Tracking	0.3	1.0	0.7
K^0_S reconstruction	–	2.5	–
π^0 reconstruction	3.0	–	–
Particle ID	1.5	–	1.6
Model dependence	6.7	6.8	7.2
Total	8.9	11.0	10.0
	Background yield (events)		
$N_{\rm bkg}$	9.0	4.1	2.5

- Correlation on systematic uncertainties among the two channels accounted for
- Relative systematic uncertainties on expected bkg yield at 50% level

Upper limit estimation (II)

- At 500 fb^{-1}:
  - stat errors only: $BF(B \rightarrow K^{*+} \nu\nu) < 3.4 \times 10^{-4}$
  - stat & syst errors: $BF(B \rightarrow K^{*+} \nu\nu) < 4.4 \times 10^{-4}$
- Babar 2008 cut-and-count result (413 fb^{-1}):

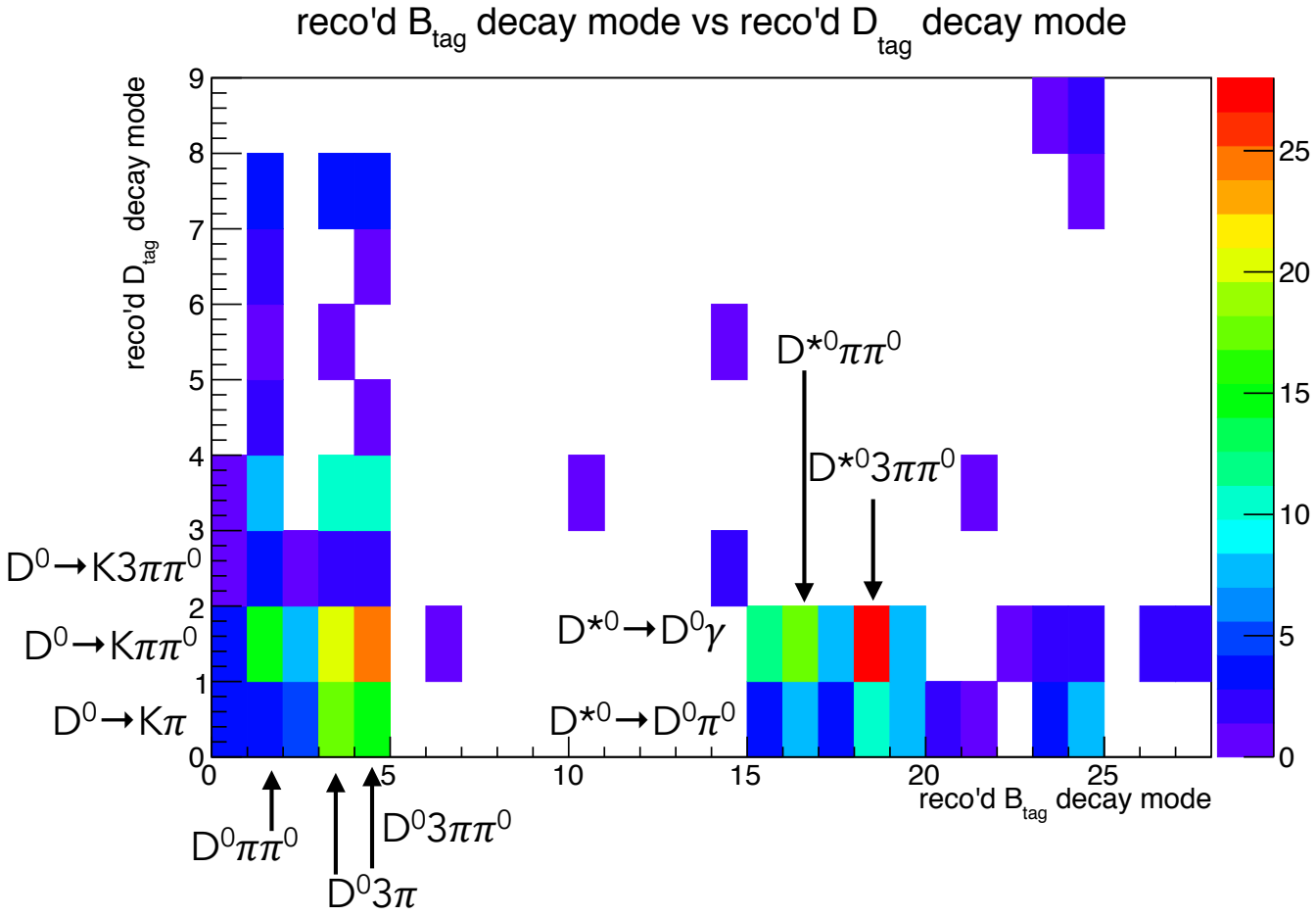
  $BF(B \rightarrow K^{*+} \nu\nu) < 3.3 \times 10^{-4}$

- Room for improvements:
  - refine K_S and K* reconstruction
  - refine background rejection (continuum suppression tools)
  - very conservative systematic error in background estimation applied here → fit to extract signal yield to be implemented

First look at background characterization

- Available info at ntuple-level: reconstructed B and D decay mode (error at reconstruction level)
- Missing: mc truth info on generated decay chain (available for the next iteration of the analysis)
- Consider $K^{*+} \to K^+ \pi^0$ only (~600 evts surviving the final selection)

modes with high π multiplicity dominates



Comparison of variable shapes after event selection

- Will compare distribution for the $K^{*+} \to K^+\pi^0$ channel for some of the variables used in the selection with the following analysis:
  - BaBar 2013 (429 fb^{-1}, PRD RC 87, 111103(2013), for m_{BC} and ΔE distributions: ~ similar hadronic B reconstruction wrt Belle2 FEI
  - BaBar 2008 (413 fb^{-1}) cut-and-count for other vars, similar selection with some known differences:
    - much lower number of modes reconstructed in the tag side (~ factor of 20 lower hadronic reconstruction efficiency)
    - no machine bkg
    - tighter requirements on K*,

    K_S reconstruction, and continuum rejection

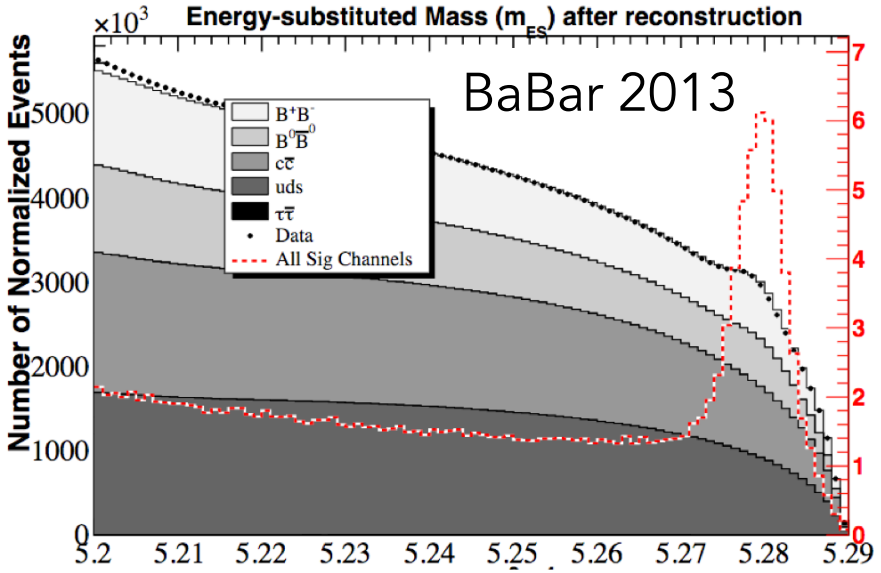
Channel	Selection Criteria
$K^{*+} \to K^+\pi^0$	$0.03 < R_2 < 0.70$
	$0.004 < \lvert\cos\theta^*_{B,\mathrm{T}}\rvert < 0.84$
	$0.84 < m_{K^*} < 0.95\ \mathrm{GeV}/c^2$
	$-0.78 < \cos\theta^*_{\mathrm{miss}} < 0.93$
$K^{*+} \to K^0_S\pi^+$	$0.0 < R_2 < 0.49$
	$0.0 < \lvert\cos\theta^*_{B,\mathrm{T}}\rvert < 0.87$
	$0.86 < m_{K^*} < 0.95\ \mathrm{GeV}/c^2$
	$0.49 < m_{K^0_S} < 0.50\ \mathrm{GeV}/c^2$
	$-0.82 < \cos\theta^*_{\mathrm{miss}} < 0.82$

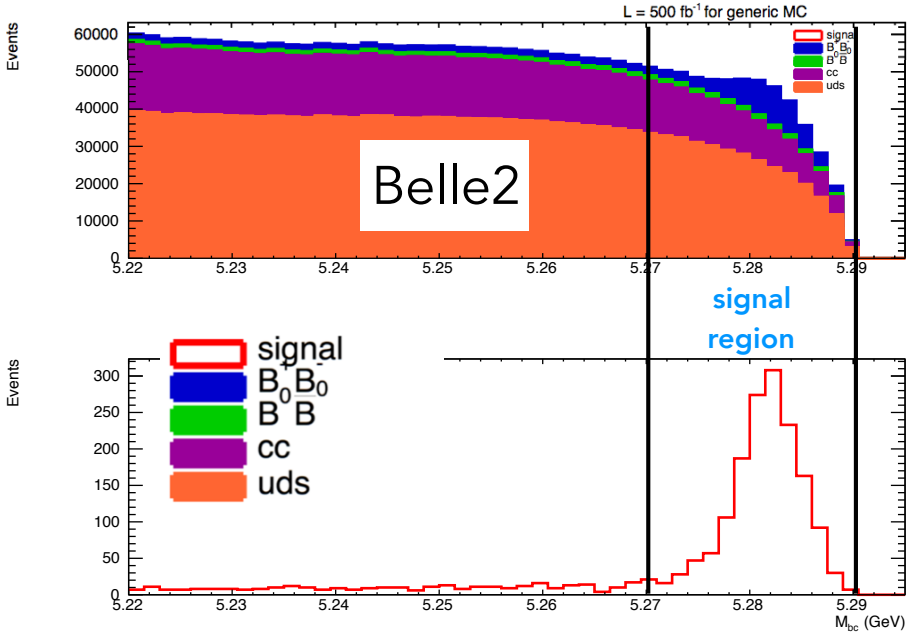
$$E^*_{\mathrm{miss}} + p^*_{\mathrm{miss}} > 4.5\,\mathrm{GeV}\,,$$

$$0 \leq E_{\mathrm{extra}} < 0.3\,\mathrm{GeV}.$$

MBC before selection

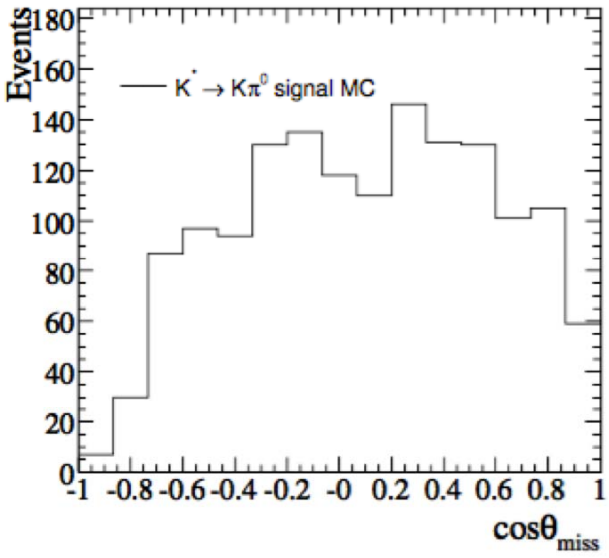
- Selection applied:
  - B_{tag} reconstruction, no requirements on the signal side for BaBar2013
  - B_{tag} + $K^{*+} \rightarrow K^{+}\pi^{0}$ reconstruction (pag 3) for Belle2
- Signal shape: we have lowest tails and sharper peak (due to requirements on K* reconstruction)
- Generic shape: we have a larger amount of continuum wrt generic

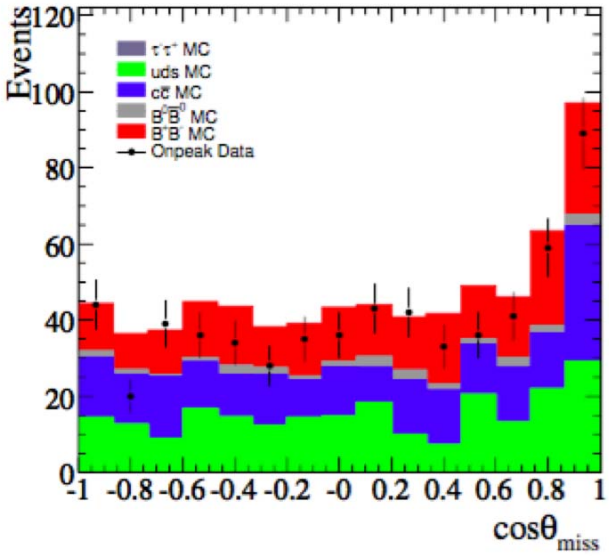




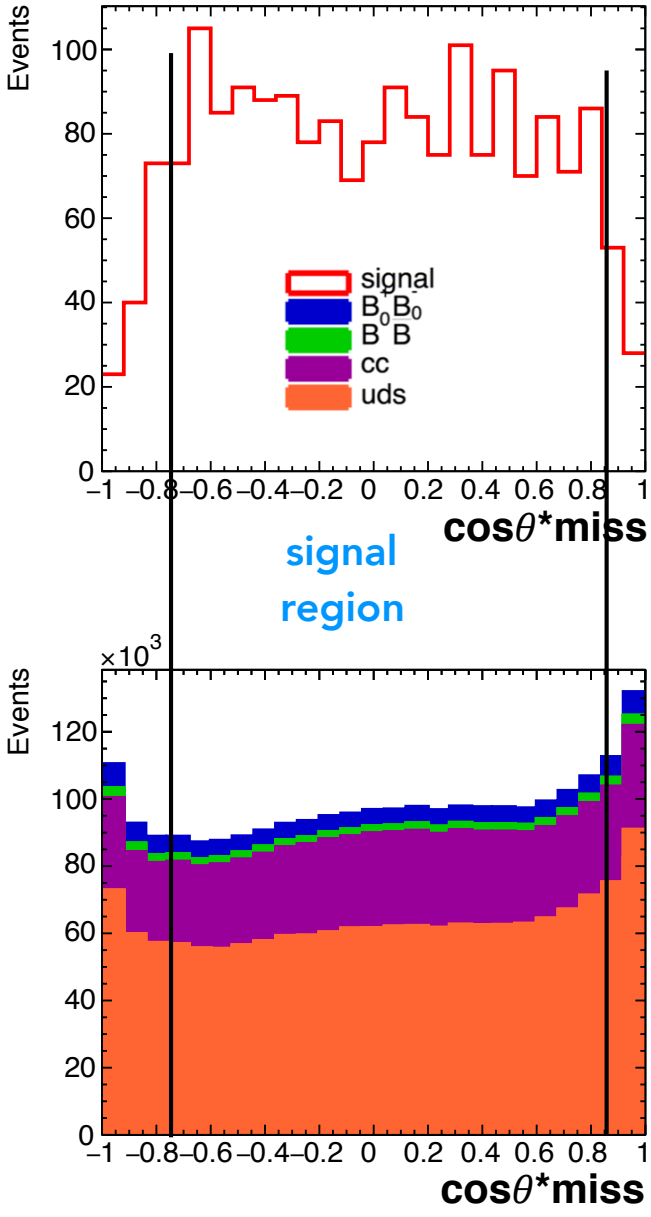
$\cos\theta^*_{miss}$ before selection

BaBar 2008



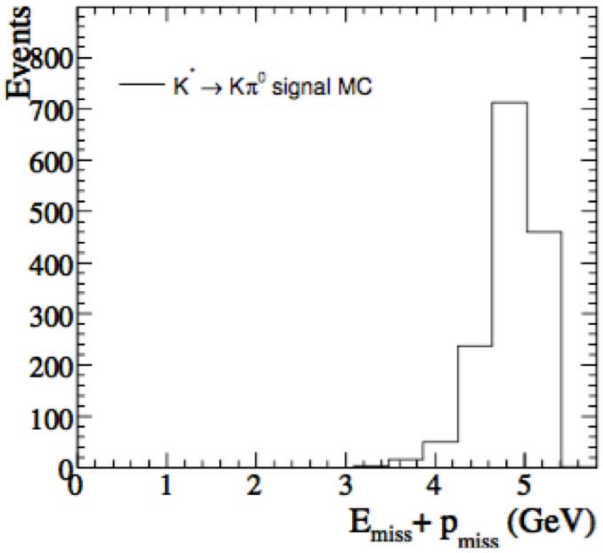


Belle2

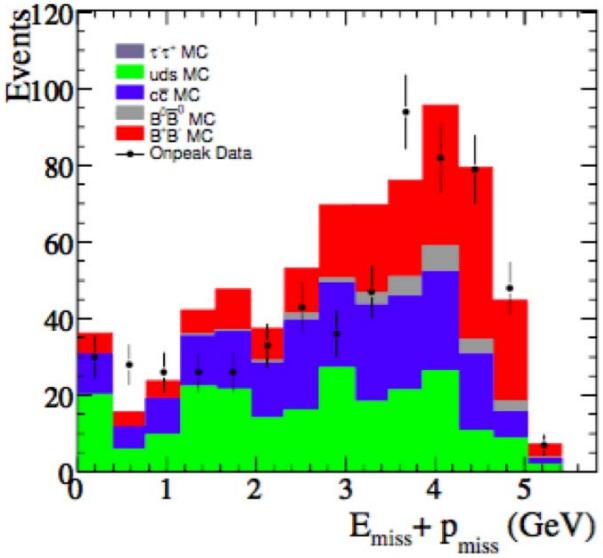


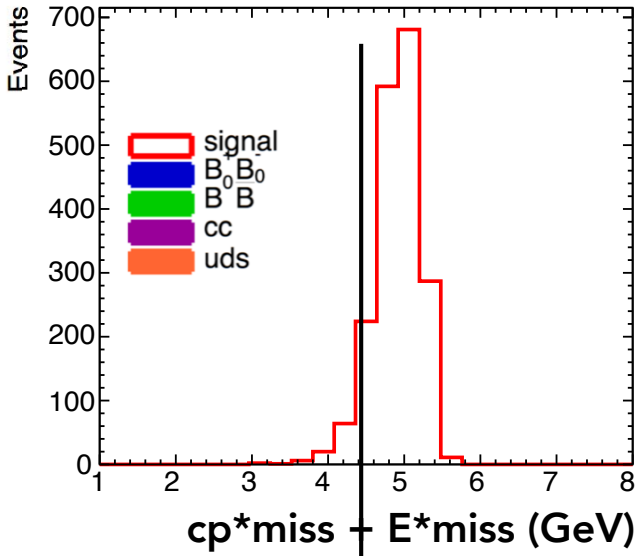
- Selection: in both cases, just cuts at reconstruction level are applied (different B_{tag} reconstruction and K* selection)
- Similar signal shapes, Generic shape pushed in the fwd region in the BaBar2008 case (due to the larger boost?)

cp^*_{miss} + E^*_{miss} before and after selection

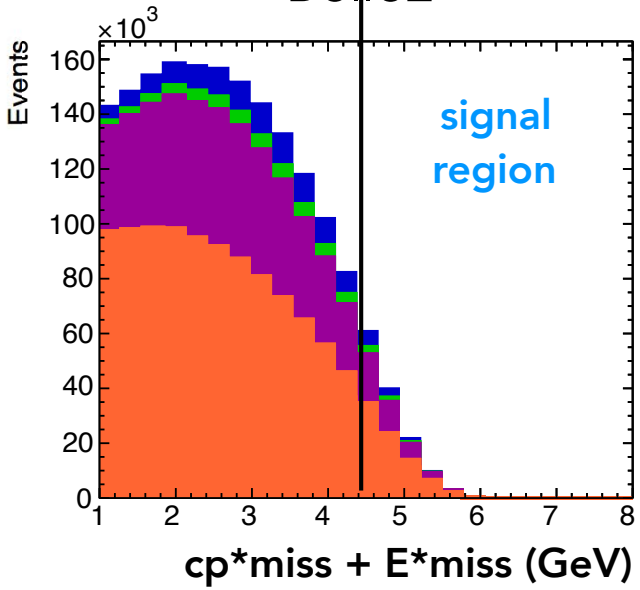


BaBar 2008



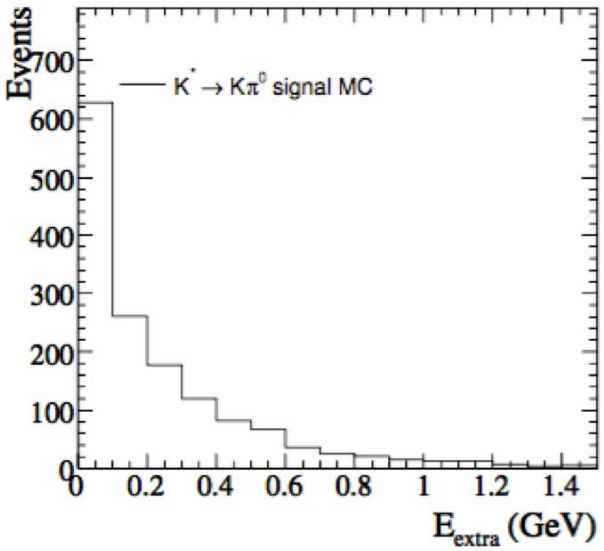


Belle2

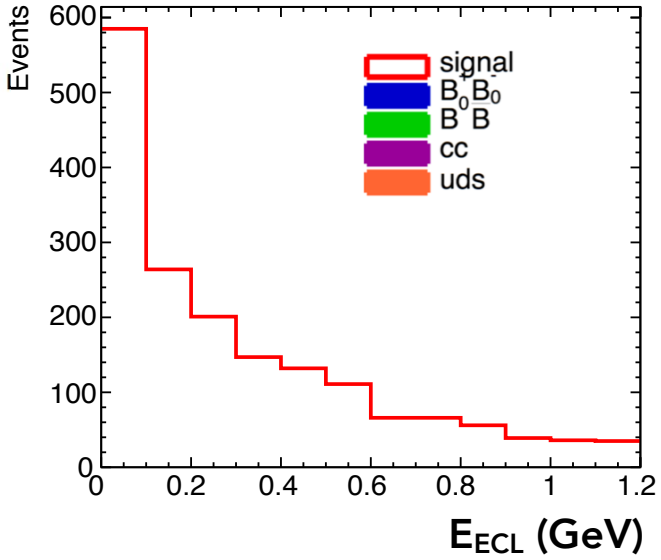


- Selection: in both cases, just cuts at reconstruction level are applied (different B_{tag} reconstruction and K* selection)
- Similar shape for signal samples, very different distribution for the Generic MC (under investigation)

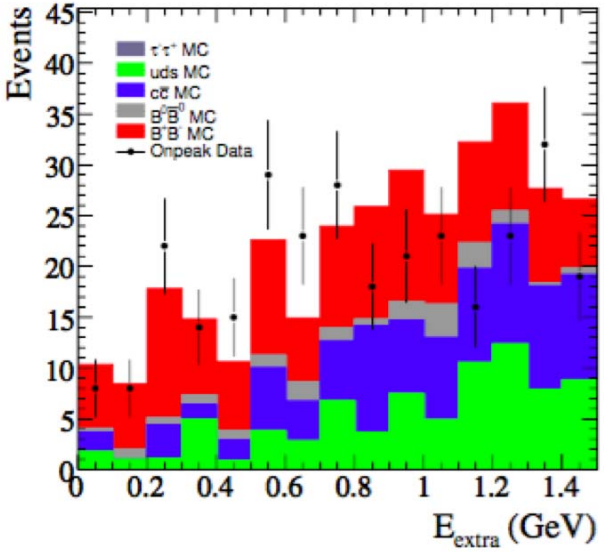
E_{ECL} before selection

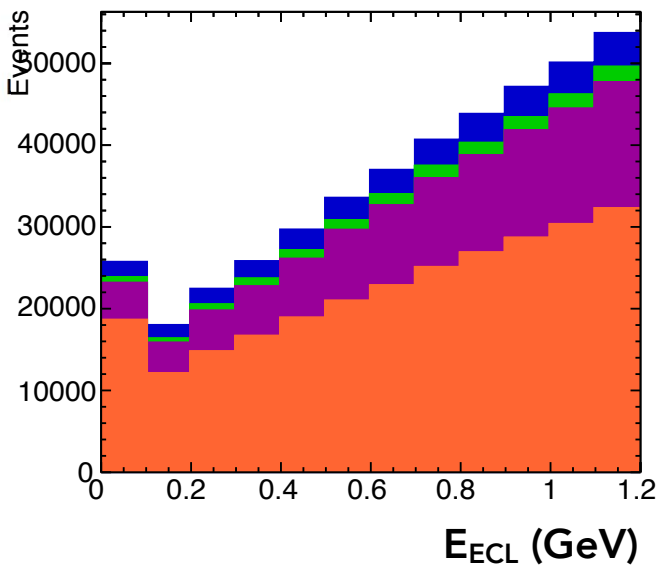


BaBar 2008



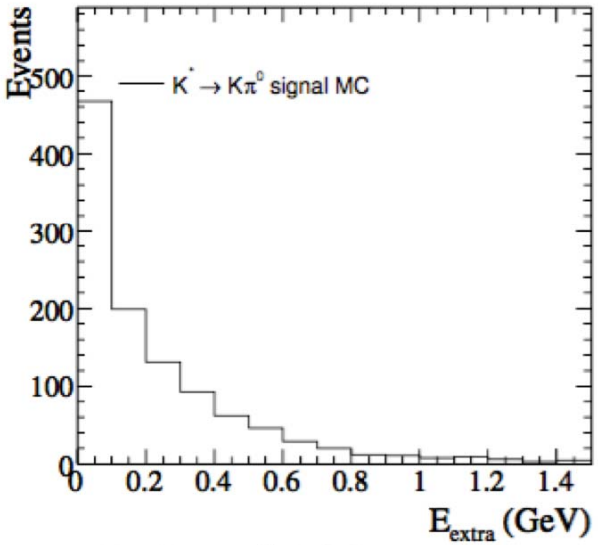
Belle2



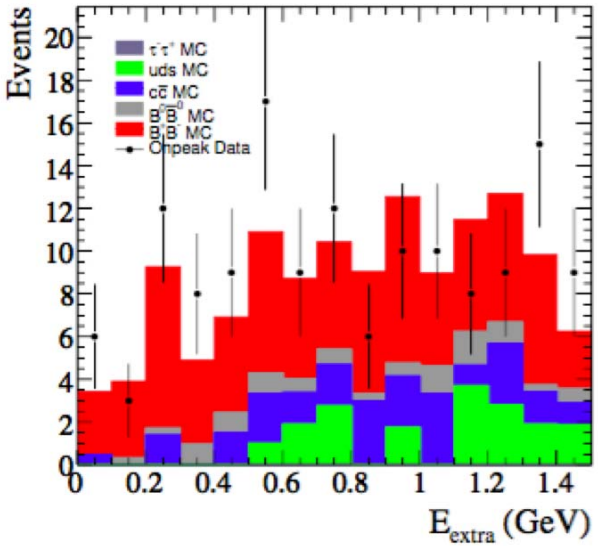


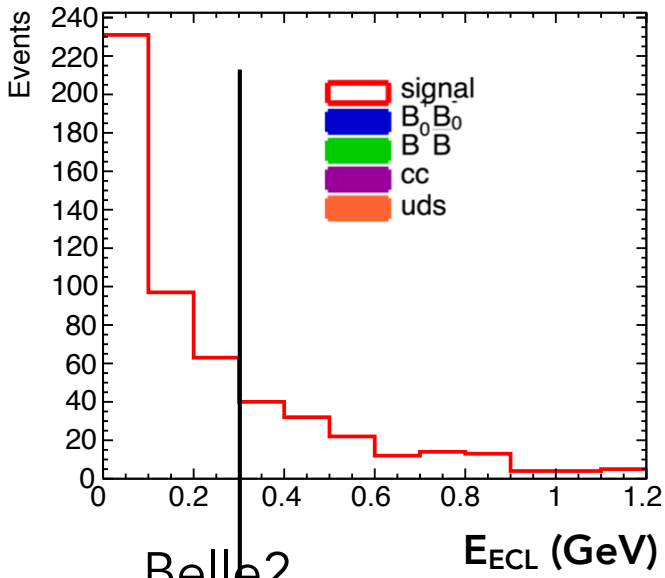
- Selection: in both cases, just cuts at reconstruction level are applied (different B_{tag} reconstruction and K* selection)
- Larger peak at low E_{ECL} values, probably due to machine bkg

E_{ECL} after selection (but Eextra cut) (I)

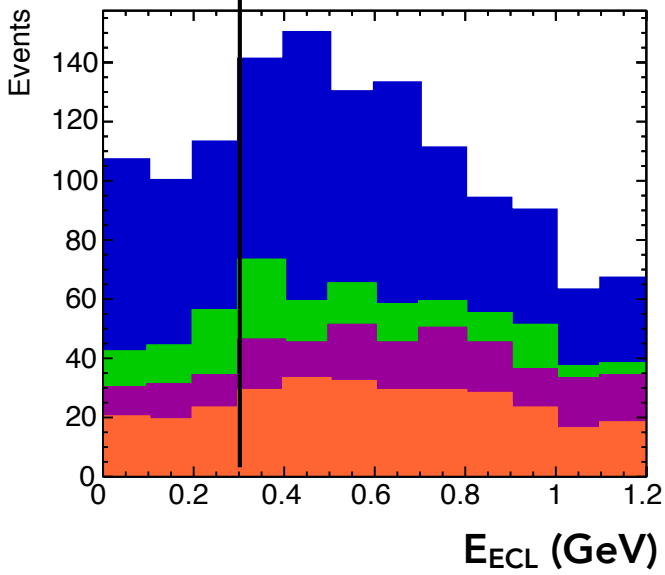


BaBar 2008



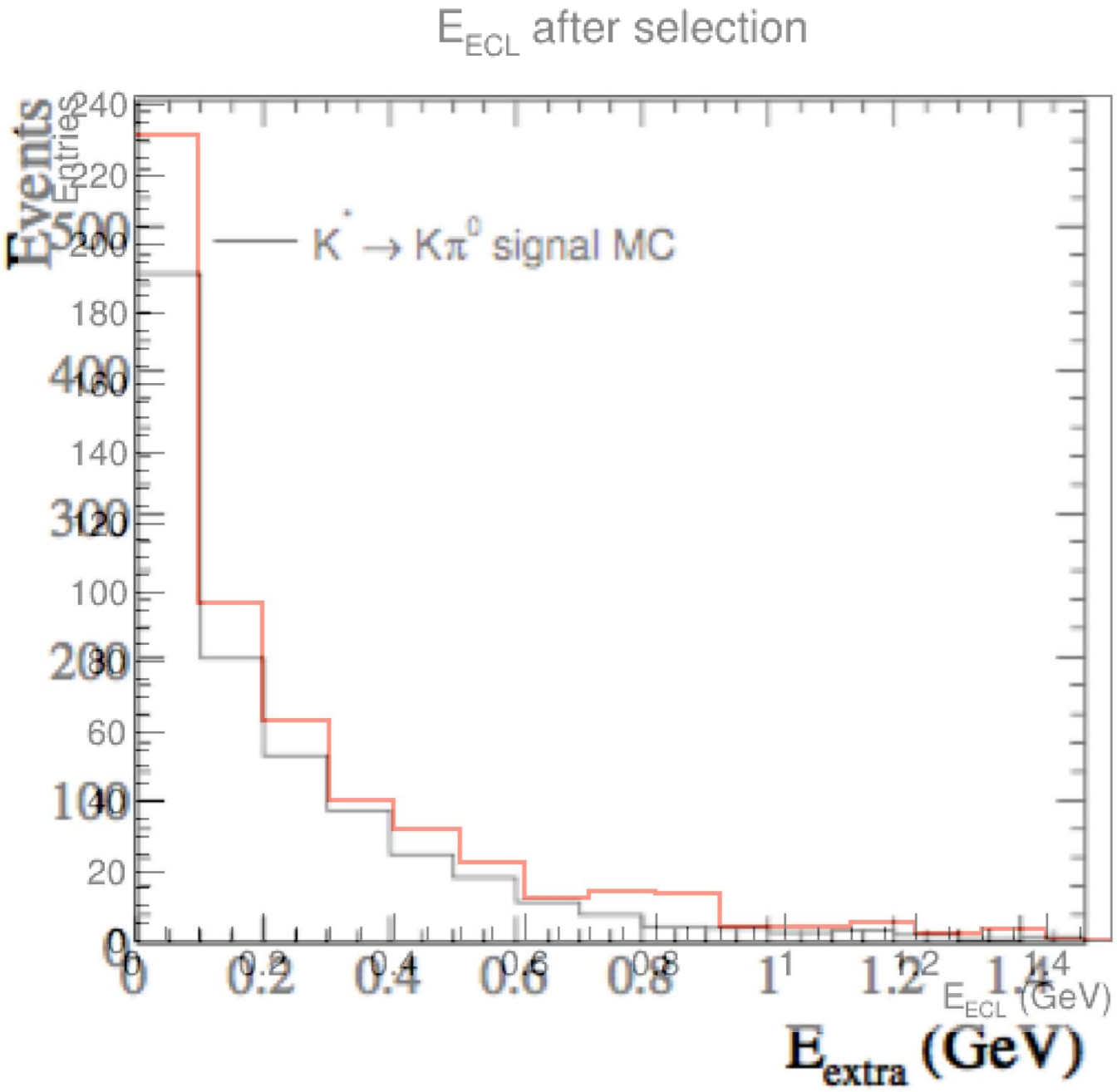


Belle2



- Selection: in both cases, full selection but E_{ECL} cut applied (pag 5 for Belle2 and page 10 for BaBar 2008)
- More evident difference at low E_{ECL} values in the generic sample, probably due to machine bkg

E_{ECL} after selection (but Eextra cut) (II)



BaBar 2008

Belle2

- Selection: in both cases, full selection but E_{ECL} cut applied (pag 5 for Belle2 and page 10 for BaBar 2008)
- Very similar **signal shapes**

Conclusions and outlook (I)

- Cut-And-Count analysis of Belle2 generic MC5 + private signal MC production performed on $B^+ \to K^{*+}\nu\nu$
  - preselection on tag side variables
  - cut optimization for continuum rejection and strange meson masses
  - loose selection on missing angle, sum of missing energy and momentum and E_{ECL}
- Selection efficiencies and expected background yields estimated, Upper limit estimation at 500 fb^{-1} ~ compatible with BaBar cut-and-count

- First look at bkg characterization: modes with high π multiplicity dominates, need additional mctruth info to complete the study

Conclusions and outlook (II)

- Comparison of selection variables distributions with BaBar analyses
  - known differences in reconstruction and may explain some discrepancy
  - cp*miss + E*miss distribution needs a closer look
  - comparison with BGx0.0 would be helpful

- Next steps, on MC7:
  - tune selection, e.g. using multivariate tools for continuum rejection, K_S and K* reconstruction
  - complete bkg characterization and comparison with BaBar and Belle
  - perform signal yield extraction with 1-DIM (E_{extra}) or 2-DIM (E_{extra} vs $cp^*_{miss}+E^*_{miss}$)
  - extrapolate expected UL at higher luminosities

EXTRA SLIDES

Efficiencies in 10^{-4} units for $K^{*+} \to K^{+}\pi^{0}$ mode

cut/sample	signal MC	B+B-	B0B0bar	ccbar	uubar	ddbar	ssbar
m_{BC}	15.6 +/−0.4	2.570 +/− 0.001	0.640 +/− 0.005	2.027 +/− 0.006	28.282 +/− 0.006	28.847 +/−0.012	23.14 +/−0.011
ΔE	13.2 +/−0.4	2.219 +/− 0.001	0.517 +/− 0.004	1.605 +/− 0.005	22.539 +/− 0.005	23.010 +/−0.011	17.95 +/− 0.01
R2	9.8 +/−0.3	1.925 +/− 0.0008	0.455 +/− 0.004	0.418 +/− 0.003	0.493 +/− 0.002	0.506 +/− 0.005	0.386 +/− 0.005
m_{K^*}	6.3 +/−0.3	0.5800 +/− 0.0005	0.176 +/− 0.002	0.181 +/− 0.002	0.184 +/− 0.002	0.193 +/− 0.003	0.148 +/− 0.003
$\cos\theta^*_{miss}$	5.9 +/−0.2	0.4695 +/− 0.0004	0.145 +/− 0.002	0.150 +/− 0.002	0.1458 +/− 0.0002	0.155 +/− 0.003	0.126 +/− 0.003
cp^*_{miss} + E^*_{miss}	5.5 +/−0.2	0.02750 +/− 0.0001	0.0061 +/− 0.0005	0.0037 +/− 0.0002	0.0029 +/− 0.0002	0.0037 +/− 0.0004	0.005 +/− 0.0005
E_{ECL}	4.6 +/−0.2	0.012608 +/− 0.00007	0.0031 +/− 0.0003	0.0009 +/− 0.0002	0.0009 +/− 0.0001	0.0009 +/− 0.0002	0.0028 +/− 0.0003
$N_{exp,\ bkg}$		337 +/− 18	88 +/− 9	62 +/− 8	71 +/− 8	18 +/− 4	33 +/− 6

Efficiencies in 10^{-4} units for $K^{*+} \to K_S \pi^+$ mode

cut/sample	signal MC	B+B-	B0B0bar	ccbar	uubar	ddbar	ssbar
m_{BC}	4.61 +/−0.21	10.876 +/− 0.006	0.296 +/− 0.003	1.272 +/− 0.004	1.654 +/− 0.005	1.642	1.504 +/− 0.009
ΔE	3.94 +/−0.20	9.443 +/− 0.006	0.241 +/− 0.003	1.002 +/− 0.004	1.306 +/− 0.004	1.300 +/− 0.008	1.162 +/− 0.008
R2	2.76 +/−0.17	8.310 +/− 0.006	0.218 +/− 0.003	0.247 +/− 0.002	0.282 +/− 0.002	0.281 +/− 0.004	0.222 +/− 0.003
m_{KS}	2.16 +/−0.15	4.683 +/− 0.005	0.123 +/− 0.002	0.137 +/− 0.001	0.151 +/− 0.001	0.154 +/− 0.003	0.123 +/− 0.003
m_{K^*}	1.31 +/−0.11	0.029 +/− 0.001	0.0105 +/− 0.0006	0.0010 +/− 0.0004	0.0100 +/− 0.0004	0.0103 +/− 0.0007	0.0008 +/− 0.0007
$\cos\theta^*_{miss}$	1.28 +/−0.11	0.0229 +/− 0.0009	0.0008 +/− 0.0005	0.0008 +/− 0.0004	0.0008 +/− 0.0003	0.0008 +/− 0.0006	0.0007 +/− 0.0006
cp^*_{miss} + E^*_{miss}	1.19 +/−0.11	0.0013 +/− 0.0002	0.0003 +/− 0.0001	0.00012 +/− 0.00004	0.00025 +/− 0.00006	0.0002 +/− 0.0001	0.0003 +/− 0.0001
E_{ECL}	1.10 +/−0.10	0.0005 +/− 0.0001	0.0002 +/− 0.00009	0.00003 +/− 0.00002	0.00007 +/− 0.00003	0.00010 +/− 0.00007	0.00010 +/− 0.00007
$N_{exp,\ bkg}$		13 +/− 4	6.0 +/− 2.4	2.0 +/− 1.4	6.0 +/− 2.4	2.0 +/− 1.4	2.0 +/− 1.4

Cluster selection & PID

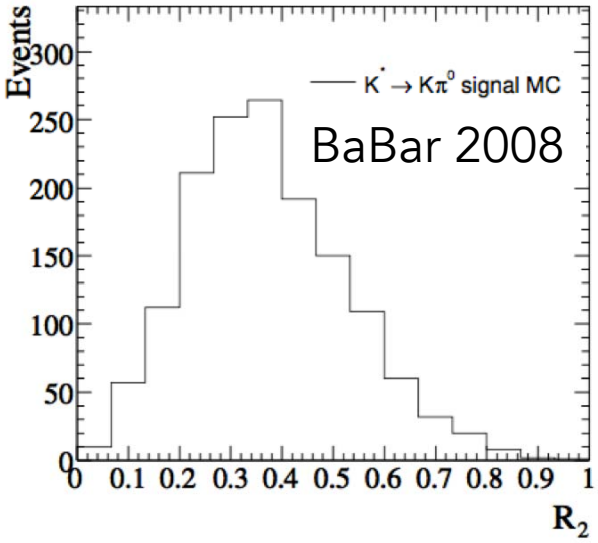
PID selection

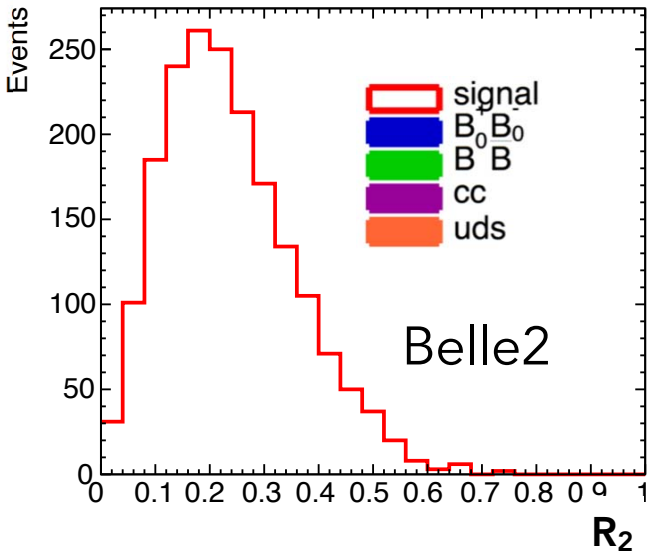
- Likelihood function based on E/p (energy loss in the calorimeter divided by particle momentum) and dE/dx (energy loss in the tracking system)
- Cut on the LR = L(particle) / (L(e) + L(mu) + L(pi))

Photon selection

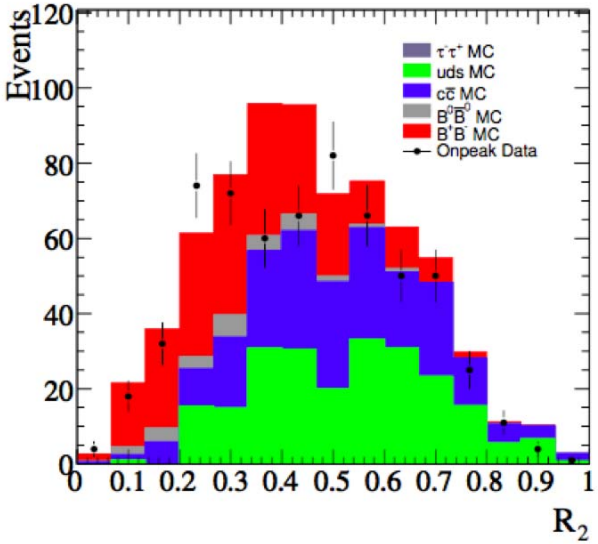
- cluster cleaning (to reject photons from beam background) with cuts on photon energy, cluster timing, E9/E25 and minimum distance between the cluster and tracks in the event (separately in forward, barrel and backward detector regions)

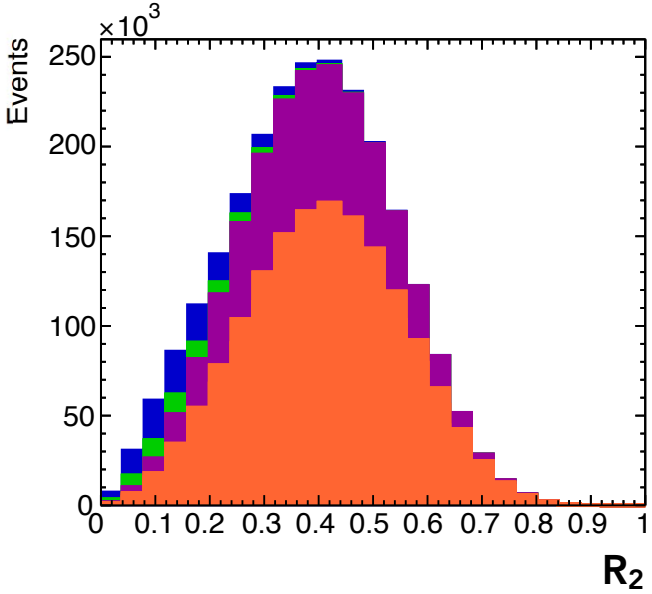
R_2 before selection





- Selection: in both cases, just cuts at reconstruction level are applied (different B_{tag} reconstruction and K* selection)





- Signal shape: our distribution peaked at slightly low values, may depend on tag side modes (?)

ΔE before selection

- Selection applied:
  - B_{tag} reconstruction, no requirements on the signal side for BaBar2013
  - B_{tag} + $K^{*+} \rightarrow K^{+}\pi^{0}$ reconstruction (pag 3) for Belle2

- Different structure probably due to different mode-by-mode cuts at reconstruction level