$B \to K^{(*)}\nu\nu$ UPDATE: FEI AND SENSITIVITY STUDIES FOR B2TIP REPORT

Eighth Belle II Italian collaboration meeting

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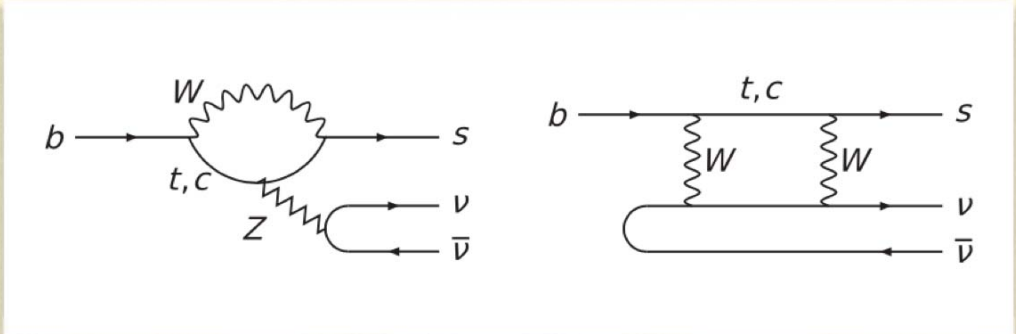
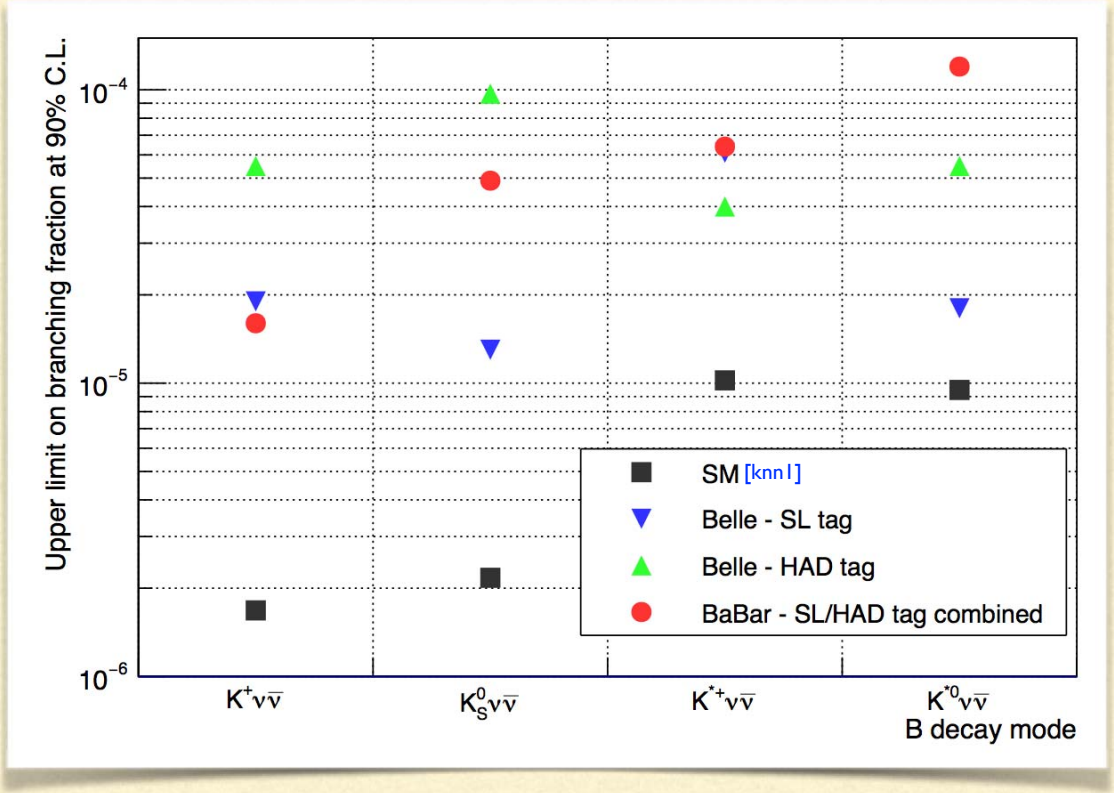
Theoretical and experimental status

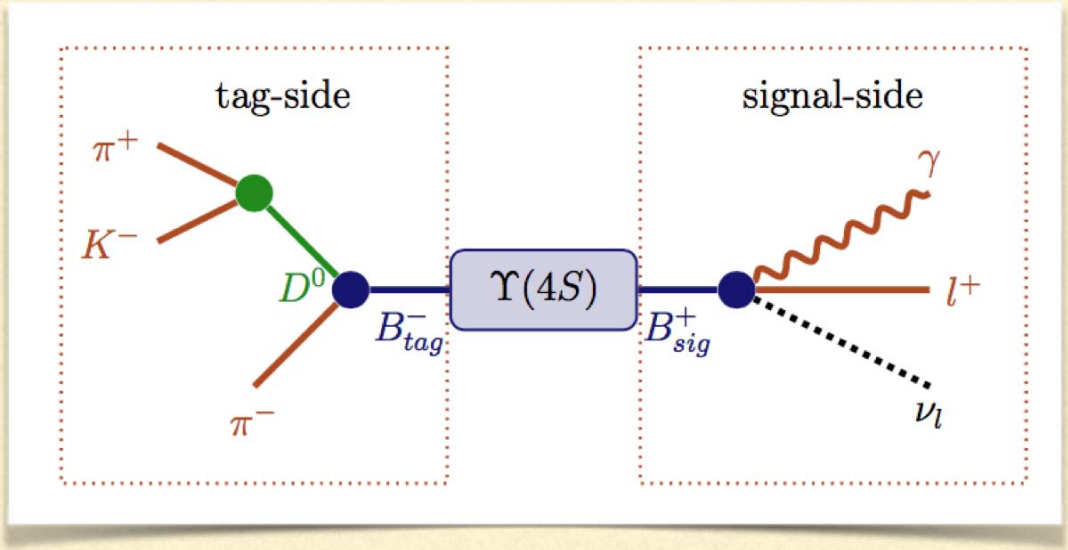
- Flavour changing neutral current, prohibited at tree level in the SM
  - NP contribution (from new mediators or sources of missing energy) may be comparable to SM ones
  - free of uncertain long-distant hadronic effects, theoretically clean
  - in the framework of the Operator Product Expansion, the decay is sensitive to the so called C_L and C_R Wilson coefficients [knn1]
  - Experimental searches from BaBar and Belle on both HAD and SL recoil[knn2]
    - no signal evidence, UL less than 1 order of magnitude away from SM predictions for K* channels





FEI PERFORMANCE STUDIES

B meson decays with missing energy: how to



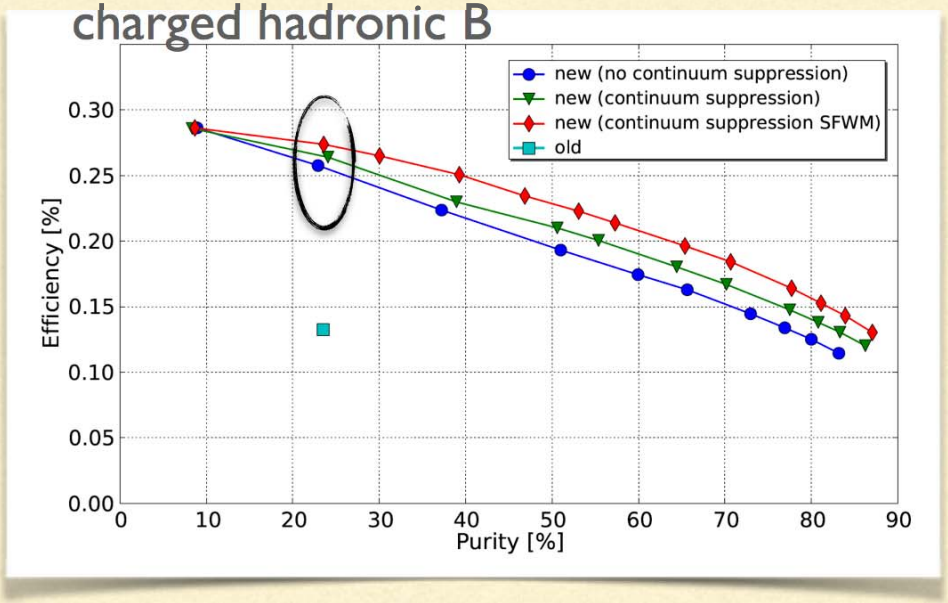
- Clean event environment and well defined initial state.
- Good and efficient reconstruction of decays with neutrals
- Full solid angle detector, lower boost wrt Belle/BaBar ↔ higher detector hermeticity

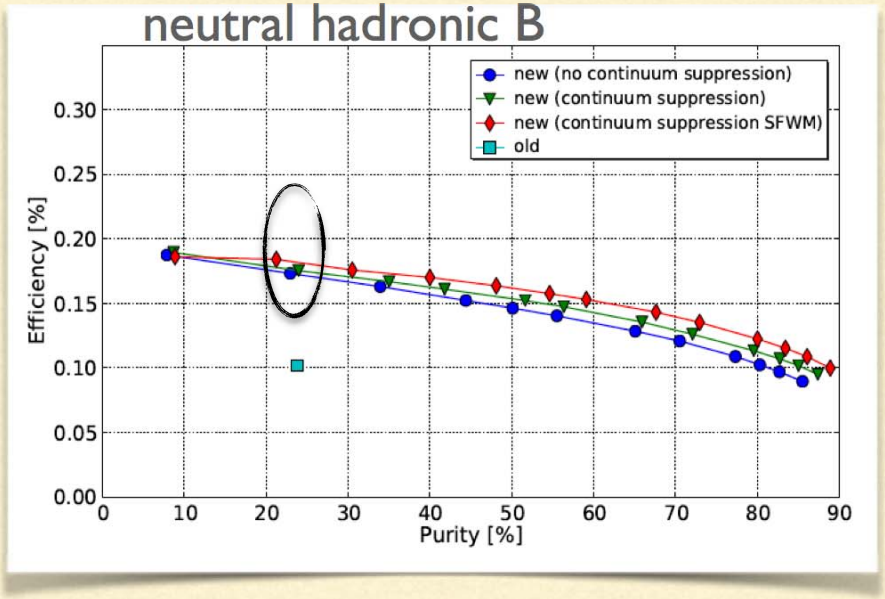
→ Ideal environment to search for decays with missing energy in the final state

- Full Event interpretation already discussed by Mario, I'll focus on performances studies on hadronic tag we've performed for the B2TIP report

Belle Full reconstruction

- Multivariated algorithm, used in latest Belle recoil analysis (including $B \to K^{(*)}\nu\nu$)
- ROC curves for Belle "Full reconstruction"





(https://arxiv.org/pdf/1102.3876.pdf)

- Belle full reconstruction compared to former Belle algorithm:
  - with continuum suppression, including event shape variables, (red rhombus) @ ~ 20-25% purity: 28% and 18% efficiency for charged and neutral B modes, respectively

Belle II FEI vs Belle Full reconstruction

Table 6: Tag-side efficiency defined as the number of correctly reconstructed tag-side B mesons divided by the total number of $\Upsilon(4S)$ events. The presented efficiencies depend on the used BASF2 release (7.2), MC campaign (MC 7) and FEI training configuration.

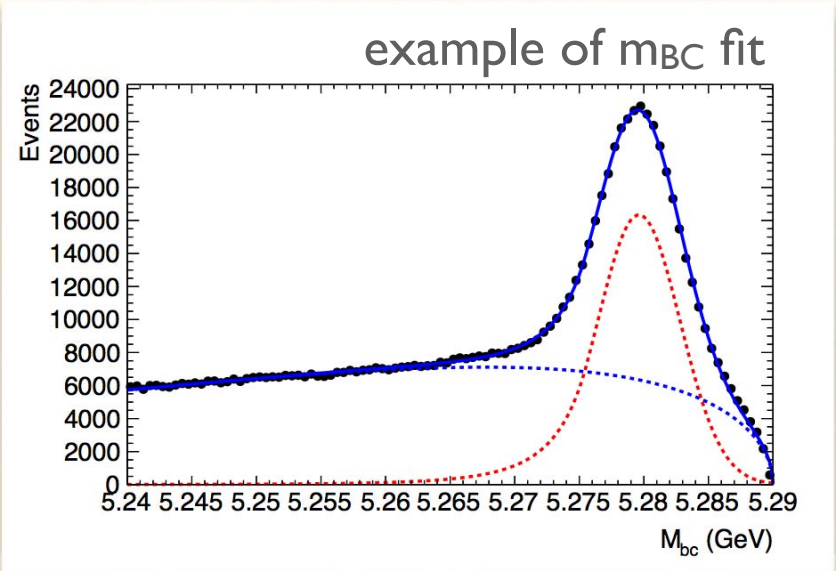
Tag	FR[1] @ Belle	FEI @ Belle MC	FEI @ Belle II MC
Hadronic B^+	0.28 %	0.49 %	0.61 %
Semileptonic B^+	0.67 %	1.42 %	1.45 %
Hadronic B^0	0.18 %	0.33%	0.34 %
Semileptonic B^0	0.63 %	1.33%	1.25 %

- B2TIP table from T. Keck studies: FEI @ Belle II double he efficiency on both SL and HAD reconstruction wrt Belle
- In the UL estimate with full Belle II statistics, we considered such an enhancement on reconstruction efficiency when extrapolating from Belle analyses

….. BUT IT CLEARLY DEPENDS ON PURITY

ROC curve for Belle II FEI: strategy

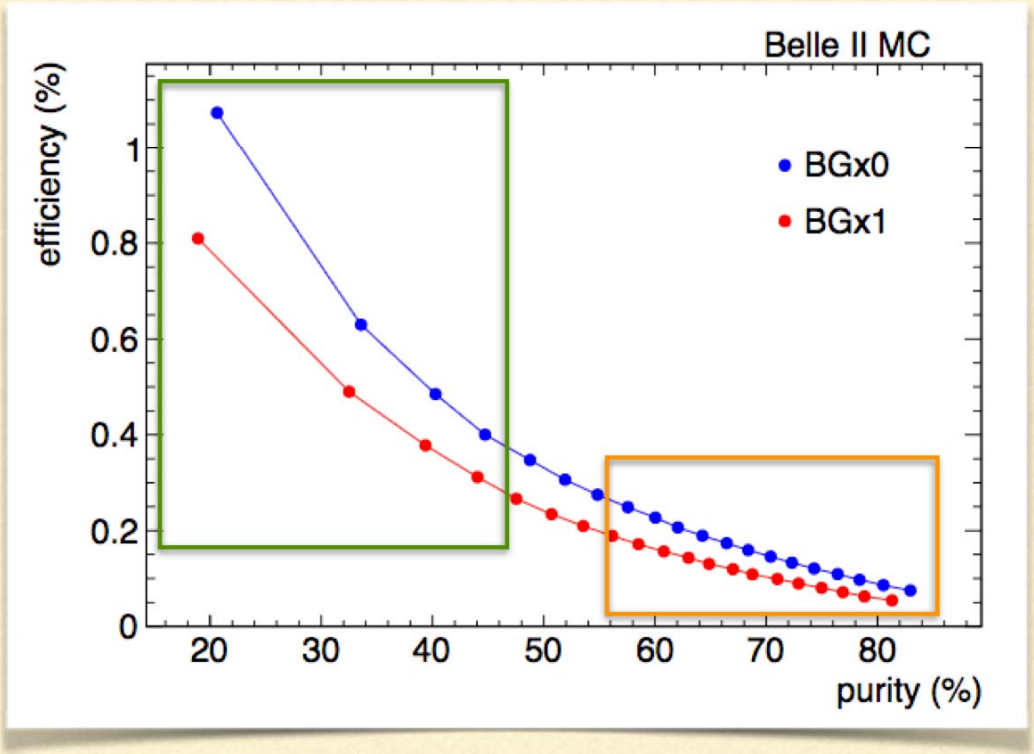
- MC7 used for this study
- Perform a scan of FEI output discriminant (SigProb) and evaluate efficiency/purity of B tag reconstruction as done by Belle fuller reconstruction (https://arxiv.org/pdf/1102.3876.pdf)
  - **Fit the m_{BC} distribution** with Argus function (N_{bkg}) + Crystal Ball (N_{sig}) for correctly reconstructed B candidates
  - **Efficiency** = N_{sig} (for m_{BC}> 5.27 GeV/c^2) / # generated BBbar
  - **Purity** = N_{sig} / (N_{sig}+N_{bkg}) in m_{BC}> 5.27 GeV/c^2
  - compute efficiency and purity, scanning the cut on the B-tag signal probability from 0.01 on, with step of 0.04



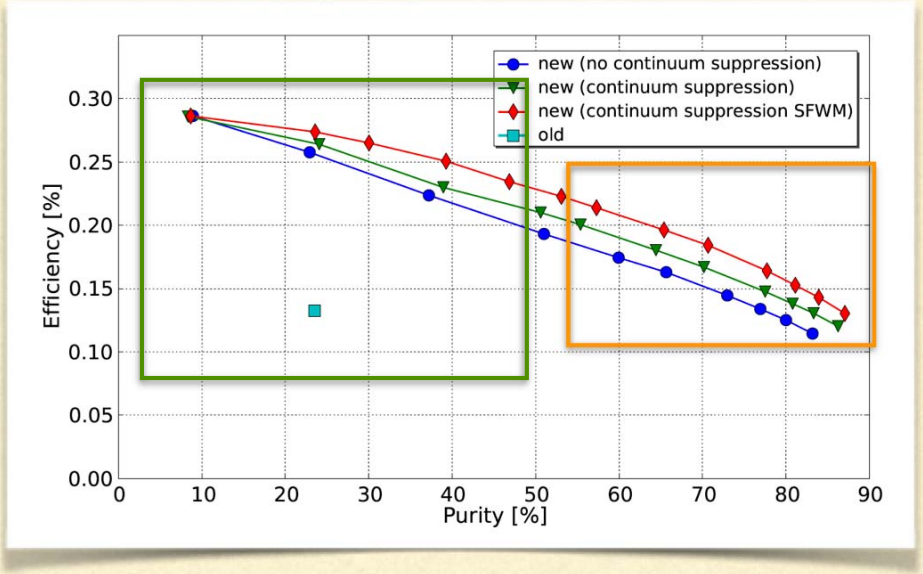
- ROC curves evaluated for charged

B-tag and neutral B-tag, separately

Charged B ROC curve (I)



Belle MC

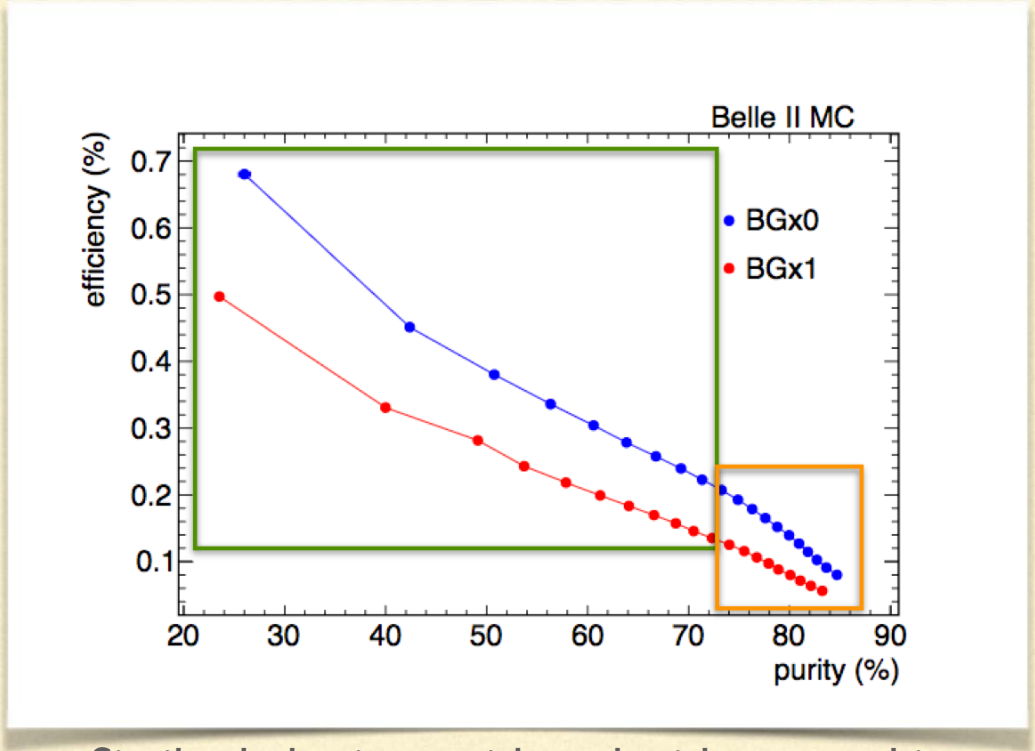


- Similar behaviour with and without machine BG
- Higher B-tag efficiency with BGx0

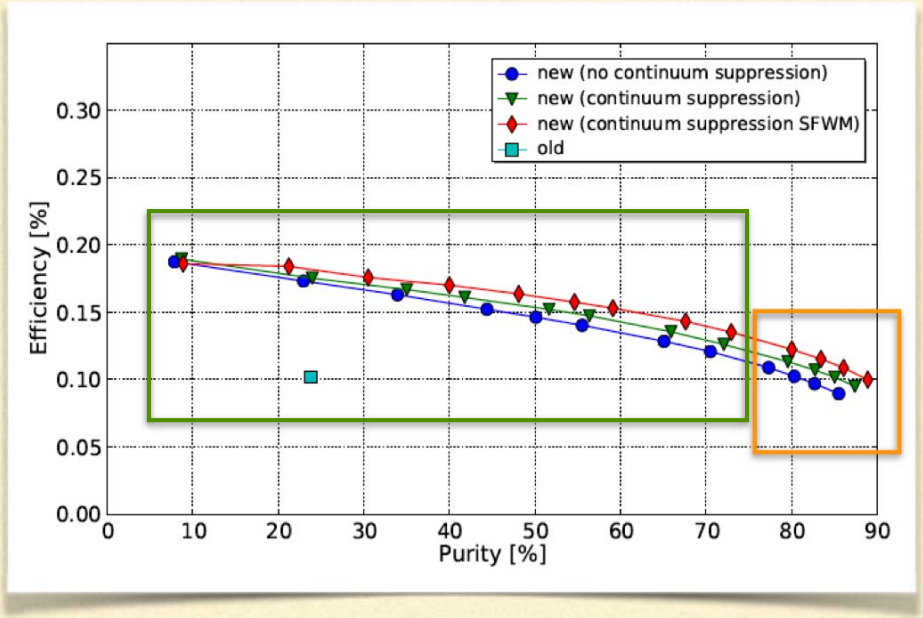
@ Belle II:

- Much higher efficiency below purities of ~50%
- Lower efficiency above purities of ~55%

Neutral B ROC curve (I)



Belle MC



- Similar behaviour with and without machine BG
- In general the efficiency is higher than for charged B reconstruction

@ Belle II:

- Much higher efficiency @ purities below ~75%

Belle - Belle II comparison

- Belle II FEI tagging efficiency much better than Belle FR up to purities of ~55 % for charged B and ~75% for neutral B

- For high purities, FEI tagging efficiency is a bit lower than Belle FR and this may be due to:

  1. Number of B/D decay modes used in Belle FR / Belle 2 FEI

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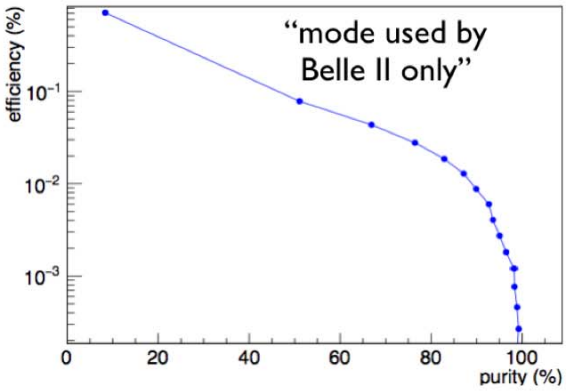
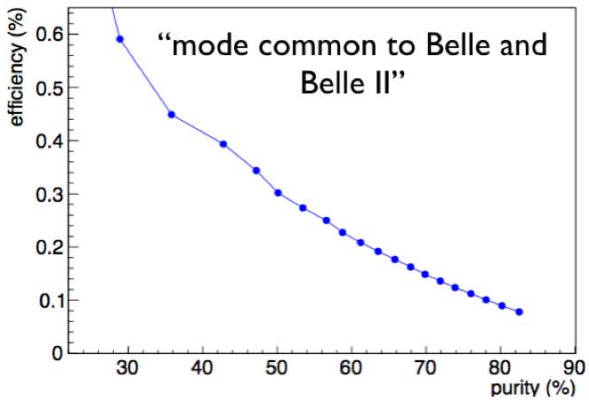
- ROC curve split by "mode common to Belle and Belle II" and "mode used by Belle II only"

Charged B reconstruction, BGx0





- BelleII-only modes seems to be dirtier than common modes

→ hard to evaluate the impact of the added modes on final purity/efficiency, a detailed mode by mode study would be needed on both BelleII and Belle side (not in the B2TiP timescale)

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- Different selections applied in the FEI and FR trainings have been compared
- Some differences are present (e.g. : π^0 invariant mass pre-cut)
- Invariant masses and other variables for which the initial selection shows differences between Belle and BelleII, are used in MVA discriminators

→ hard to evaluate the impact of the selection differences on final purity/efficiency

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→ mode-by-mode studies would be needed in order to fully understand Belle FR vs BelleII FEI comparison and to select best efficiency/purity working point

SENSITIVITY STUDIES

Samples & strategy for B2TIP results

- SIGNAL SAMPLES:~1M evts for BGx1 and BGx0 configs (private production with release-00-05-03), $K^{*+} \rightarrow K^{+}\pi^{0}$ only
- GENERIC MC SAMPLES: (MC5 production, release-00-05-03) corresponding to 1 ab^{-1} both for BGx0 and BGx1

- @ reco level:
  - Hadronic tag side reconstructed with FEI algorithm (B_{tag} signal probability > 0.5%)
  - Best Y candidate selected according to highest Btag signal probability and K* with smallest $|m_{K^*,reco}-m_{K^*,PDG}|$
  - dedicated clustering cleaning optimised on BGx1 sample on MC5 (no the one discussed by Mario in the previous session)

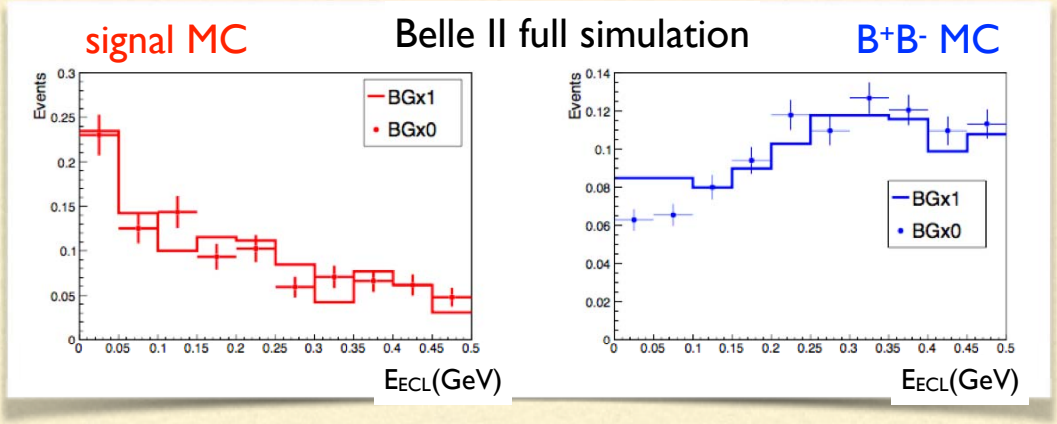
- Apply pre-selection cuts on m_{BC}, ΔE; optimise cuts on R2, m_{K^*} using S/sqrt(B) as figure of merit; apply cuts on $\cos^{*}\theta_{miss}$, $cp^{*}_{miss}+E^{*}_{miss}$
- Define a signal window on E_{ECL} and evaluate signal efficiency and expected number of background events
- Estimate UL with Bayesian approach and extrapolate at higher luminosities

Robustness against machine background

- Nominal machine bkg (BGx1) and machine bkg-free (BGx0) simulated samples analysed

- Negligible impact of machine background both in terms of variables shape and signal significance

1 ab^{-1} equivalent statistics		
	"BGx0"	"BGx1"
N_{bkg}	6415 ± 80	3678 ± 61
ε (10^{-4})	10.3 ± 0.3	5.38 ± 0.23
$N_{sig}/\sqrt{N_{bkg}}$	0.16	0.15
UL (10^{-4})	2.6	3.8



- Detector performances and reconstruction proves to be robust against machine background

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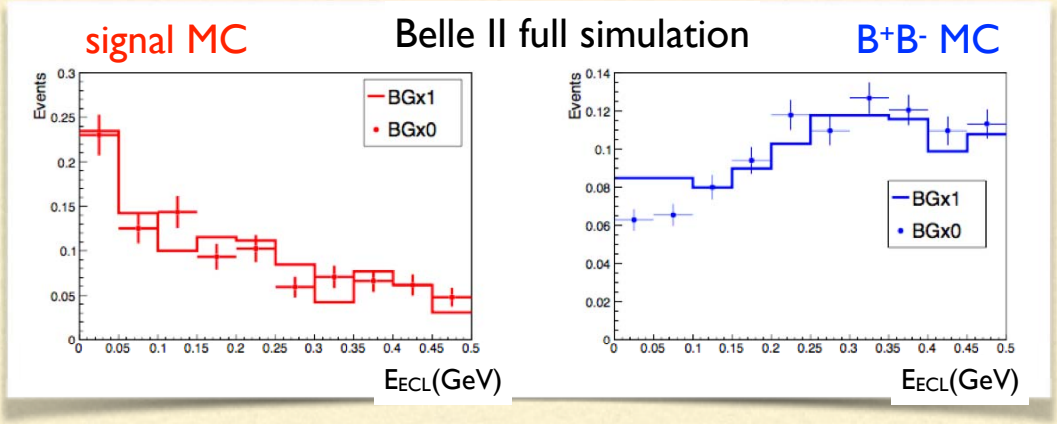


- Detector performances and reconstruction proves to be robust against machine background

… considering MC5 machine background. In new PHASE III simulation, machine background increased of a factor of 3, studies will be repeated with latest MC production, including new extra neutral and neutral pion selection discussed by Mario

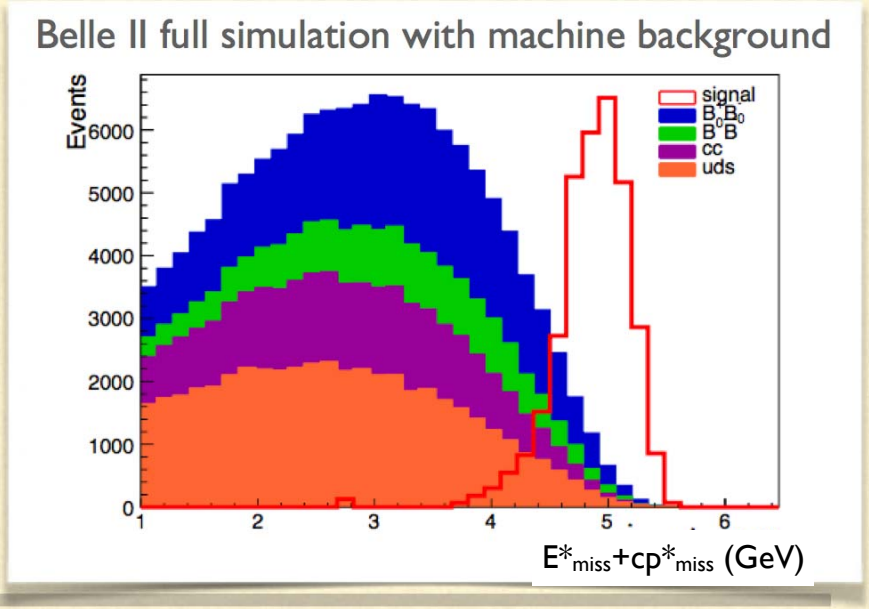
Perspectives with full Belle II statistics

- Extrapolation on full Belle II statistics on Belle HAD and SL analyses, assuming two times better B_{tag} reconstruction efficiency:
  - observation with about 18 ab^{-1}
  - precision on the branching fraction at 50 ab^{-1}:

	stat only	total
$B^+ \to K^+ \nu\nu$	9,5%	10,7%
$B^+ \to K^{*+} \nu\nu$	7,9%	9,3%
$B^+ \to K^{*0} \nu\nu$	8,2%	9,6%

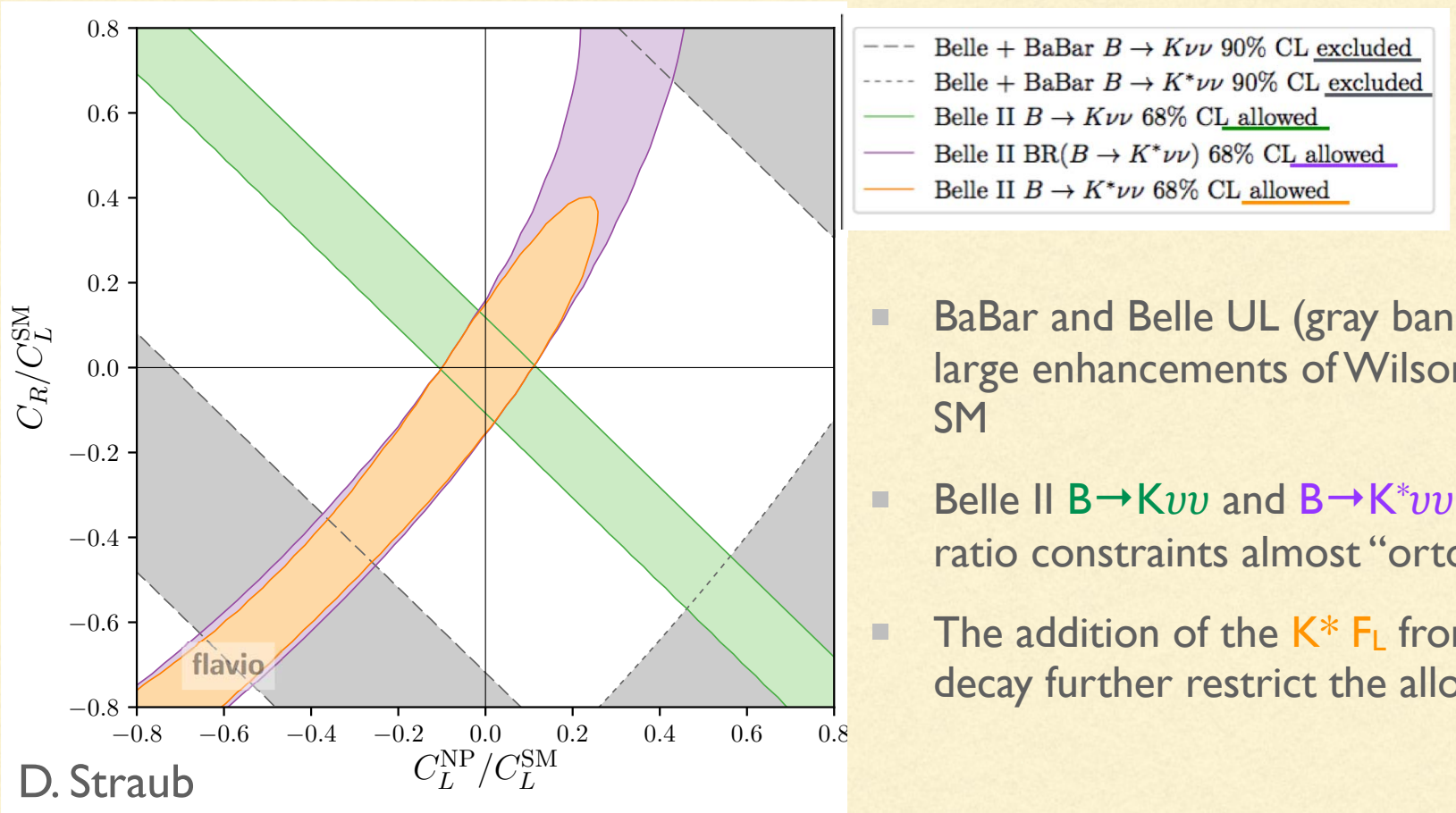
- Fraction of longitudinally polarized K* may be measured, ~20% precision with full statistics

- Predicted precision can be exceeded by improving analysis strategy



Constraints on NP models

- Constraints on (real and neutrino-flavour-independent) Wilson coefficients C_L^{NP} and C_R^{NP} normalised to SM C_L, assuming SM central values and sensitivities from previous page



- BaBar and Belle UL (gray bands) ruled out large enhancements of Wilson coeffs. wrt SM
- Belle II $B \to K\upsilon\upsilon$ and $B \to K^*\upsilon\upsilon$ branching ratio constraints almost "ortoghonal"
- The addition of the K^* F_L from $B \to K^*\upsilon\upsilon$ decay further restrict the allowed region

Conclusions

Summary of studies performed for B2TIP report

- FEI studies on MC7: from comparison with Belle Full reconstruction
  - much higher efficiency at low purity, similar or low efficiency at high purity
  - quantitative estimation of such effects requires mode-by-mode study, may help in optimising set of modes chosen for the different analysis in HAD and SL recoil

- Sensitivity study on MC5
  - Belle II full simulation studies proved the detector performances and the reconstruction algorithms to be robust against simulated machine background
  - If SM holds, observation of $K^{(*)}$ channels at ~ 18 fb^{-1}
  - Precision on branching fraction (F_L) with full Belle II sample at 10% (20%) level
  - Large portion of the currently allowed parameter space will be excluded with the full Belle II statistic.

- Next steps: update the analysis to most recent MC campaign and evaluate machine background impact, apply new cluster cleaning discussed by Mario, improve analysis strategy (continuum suppression, fit for yield extraction)

References

[knn1] BELLE2-MEMO-2016-007, Buras et al. JHEP 1502 (2015) 184

[knn2] Belle collaboration, arXiv:1702.03224; Belle collaboration, Phys.Rev. D87 (2013) no.11, 111103; BaBar collaboration, Phys.Rev. D87 (2013) no.11, 112005