$B \to K\pi\pi\gamma$ analysis in the Belle II Experiment

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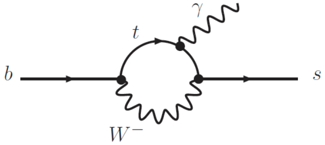
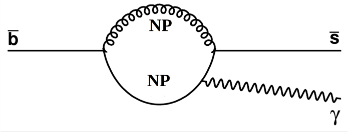
Outline

1. Motivation for the $B \to K\pi\pi\gamma$ studies;
2. Theoretical framework;
3. Establishing analysis procedure with $B^0 \to K^{*0}\gamma$;
4. Towards $B \to K\pi\pi\gamma$ analysis;
5. Conclusions;

$B \to K\pi\pi\gamma$

Rare $b \to s\gamma$ FCNC transitions are expected to be sensitive to NP effects.





γ emitted from $b \to s\gamma$ transition is predominantly left-handed up to small corrections of the order m_s/m_b due to the left-handedness of W boson coupling.

Measured inclusive $b \to s\gamma$ rate agrees with the SM calculations. Few SM extensions are also compatible with the current measurements, but predict that the photon acquires a significant right-handed component, due to the exchange of heavy fermion in the electroweak penguin loop. *Atwood, Gronau and Soni PRL79,189 (1997)*

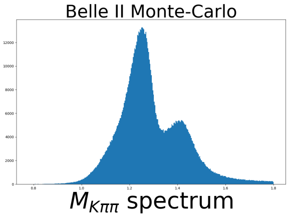
LHCb has observed non-zero up-down asymmetry in the $B^+ \to K^+\pi^+\pi^-\gamma$ PRL 112,161801 (2014). But it is not enough to provide any quantitative measurement of the photon polarization.

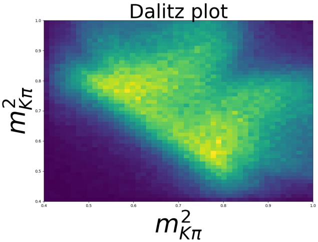
Theoretical framework

Decay rate of interfering kaonic resonances can be written as (*implemented in collaboration with E. Kou in Gampola package (being incorporated in EVTGEN)*):

$$\frac{d\Gamma}{d\cos\theta d\varphi ds ds_{K\pi} ds_{\pi\pi}} = (1-\lambda)\left|(\vec{\varepsilon}_R \cdot (\vec{J}_R + \vec{L}_R + \vec{K}_R))\right|^2 + (1+\lambda)\left|(\vec{\varepsilon}_L \cdot (\vec{J}_L + \vec{L}_L + \vec{K}_L))\right|^2$$

$\vec{J}, \vec{L}, \vec{K}$ are helicity amplitudes of $K_{res} \to K\pi\pi$, λ — photon polarization;

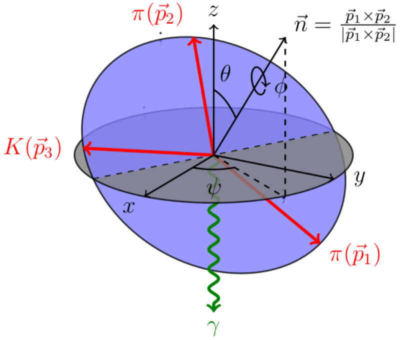




In order to determine photon polarisation, we need to obtain the hadronic parameters included in helicity amplitudes through angular and Dalitz analysis.

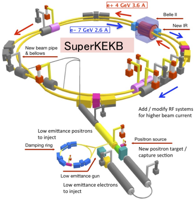
Simultaneous extraction of photon polarization and other hadronic parameters

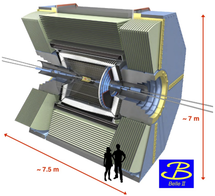
Photon polarization can be extracted together with other hadronic parameters by fitting 5-dimensional data $(m^2_{K\pi\pi}, m^2_{K\pi}, m^2_{\pi\pi}, \cos\theta, \phi)$ in the frame of above mentioned theoretical framework.



Fitting tools included in Gampola package (B.K.)

Belle II Experiment and first data





SuperKEKB accelerator:

- Asymmetric beam energy $\rightarrow$ boosted $B\bar{B}$ pairs production;
- Target luminosity $8 \cdot 10^{35}$ $[cm^{-2}s^{-1}]$;
- Recently reached peak luminosity $> 1 \cdot 10^{34}$ $[cm^{-2}s^{-1}]$;

Belle II Detector:

- 4π acceptance;
- High background resilience;

First $B \rightarrow K\pi\gamma$ analysis results for $2.6\ fb^{-1}$ (Belle II status and Prospect, Zdenek Dolezal's talk:)

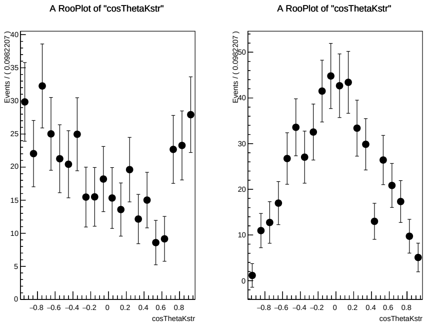
Channel	Significance
$B^0 \rightarrow K^+\pi^-\gamma$	4.4
$B^+ \rightarrow K^+\pi^0\gamma$	3.7
$B^+ \rightarrow K_S\pi^+\gamma$	2.1

High selection efficiencies for states with neutral

Establishing analysis procedure with $B^0 \to K^{*0}\gamma$

The procedure includes:

- Applying rectangular cuts;
- Continuum suppression using event topology and MVA algorithms;
- Extraction signal and background yields using extended likelihood fit followed by ${}_sPlot$;



Belle II Monte-Carlo: $\cos\angle(\overrightarrow{p}_{\pi}\overrightarrow{p}_{K^*})$

Towards $B^+ \to K^+\pi^+\pi^-\gamma$ analysis

In general the procedure is the same as in $B \to K^*\gamma$ analysis however more complex analysis is required:

- Lower selection efficiency $\to$ more integrated luminosity is needed to obtain sufficient amount of events;
- Higher multiplicity $\to$ higher level of self-cross feed events;
- Rich resonance structure $\to$ complex signal monte-carlo is needed;
- Non-unit efficiency map over phase space;

With luminosity $\approx 200\ fb^{-1}$ by the summer of 2020 it is expected with current preliminary analysis procedure to obtain

90 signal ($B^+ \to K^+\pi^+\pi^-\gamma$) and 140 background events in the signal window.

However the final aim of this analysis is to include all types of $K\pi\pi$ modes.

Conclusion

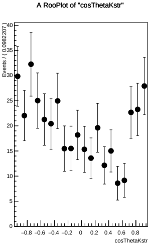
- Rare $b \to s\gamma$ transitions are expected to be sensitive to NP effects;
- $K\pi\pi$ phase space is populated by various interfering resonances decaying to interferring sub-resonances;
- Photon polarization can be measured by performing angular analysis of 5-dimensional data using developed model-dependent approach;
- Using $B \to K^*\gamma$ as control and training mode allows to establish reliable events preselection and approach which can be used for $B \to K\pi\pi\gamma$ analysis;
- Preliminary yields estimations of $B \to K\pi\pi\gamma$ were obtained;
- With a few ab^{-1} it will be possible to perform angular analysis and extract the photon polarization parameter and start constraining NP models.
- With 10 ab^{-1}, this should open a promising new window to New Physics search.

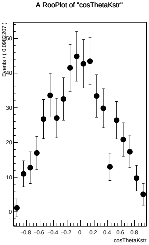
Backup slides

${}_s\mathit{Plot}$ validation of $B^0 \to K^{*0}\gamma$

Belle II Monte-Carlo

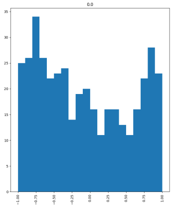
Background Signal

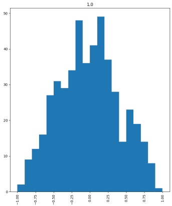




Reconstructed

Background Signal





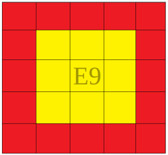
Truth

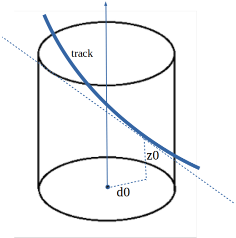
Monte-Carlo and real data

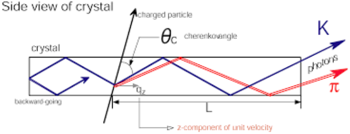
Initial data consists of:

- Real data (5.21 fb^{-1}) for discriminating features validation (cut off of the signal window);
- Training monte-carlo sample consisting of equal amount of:
  1. Signal $B^+ \to K^+\pi^-\pi^+\gamma$ events produced using developed generator (includes interference between kaonic resonances);
  2. Background part of generic monte-carlo.
- Validation sample: generic monte-carlo consisting of 100 fb^{-1}

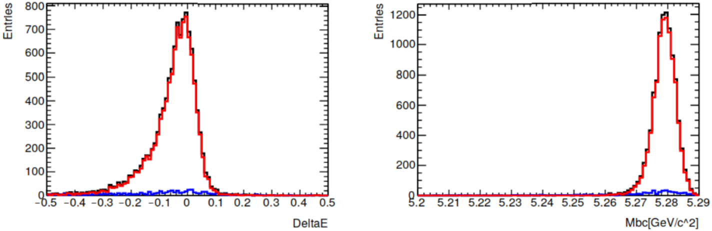
Preselection cuts





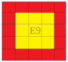
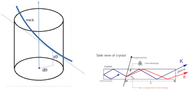
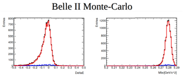


Belle II Monte-Carlo



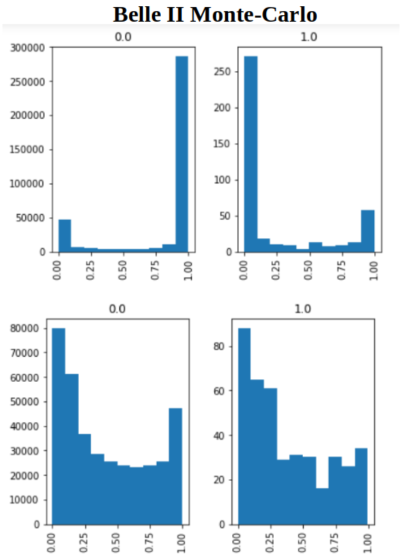
Preselection cuts

Table: Preselection cuts

γ: $clusterE9E25 > 0.95$; $1.8 < E_{\gamma CM} < 3.4\ GeV$; $clusterNHits \geq 8$; $clusterSecondMoment \leq 1.5$	
$dr < 0.5$; $\lvert dz\rvert < 2$; $PID > 0.6$; $thetaInCDCAcceptance$	
$5.29 > M_{bc} > 5.2\ GeV$ and $-0.5 < \Delta E < 0.5$	

- 412 of $B^+ \to K^+\pi^-\pi^+\gamma$ events;
- 375366 of background events (99.936 % of background reduction)

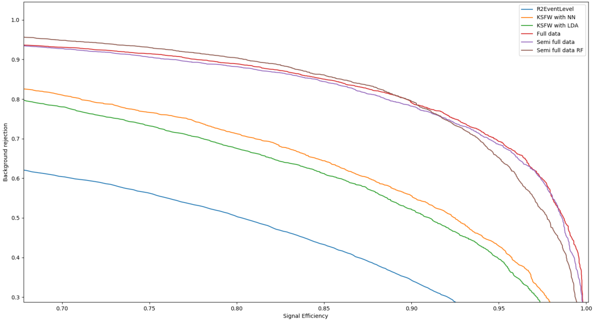
π^0/η probabilities



$P(\pi^0) < 0.5$;
$P(\eta) < 0.5$
which allows to keep 211 signal events (51.4 %) and subtract 344242 background events (91.7 %)

ROC curve

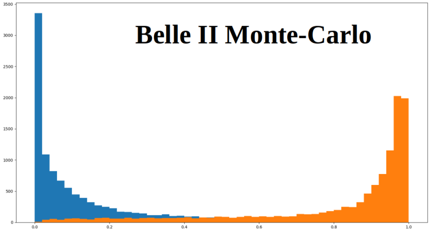
Comparing potentially discriminating variables in case of generic MC and off-resonance real data in order to extract stable features.
R2EventLevel $<$ KSFW (LDA) $<$ KSFW (NN) $<$ Semi Full $\leq$ BDT $\leq$ Full.



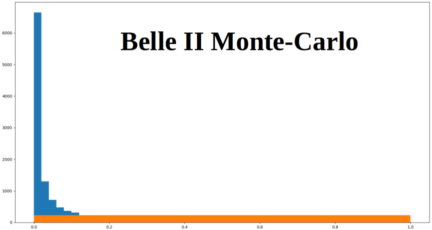
Accuracy: 84.71 %, Precision: 85.66 %, Recall: 84.5 % at $NN_{out} = 0.5$

Background suppression

$\mu(y) = \int_0^y y'dy' / \int_0^1 y'dy'$, where y' — coming form distribution, which need to be flatted.



NN output

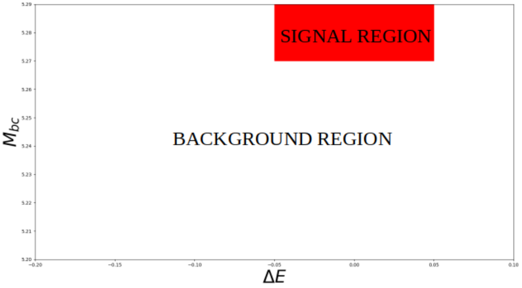


μ-transform of output

- Cutting on $\mu NN > 0.4$ allows to keep 60 % of signal events (127 events) while suppressing 91.6 % of background events (28704 events);
- $|\Delta E| < 0.1\ GeV$ and selecting only events with one candidate allows to keep 36.1 % of signal and suppress 89 % of background.

Efficiencies summary table

	π^0, η probs.	NN cut	BCS	total	N_{evt}
S	51.4 %	60 %	36.1 %	11.4 %	46
B	8.3 %	8.4 %	11 %	$7.7 \cdot 10^{-4}$ %	72



Scaling down the statistics by available integrated luminosity one obtains 6 signal events among which $N_{sig}^{truth} = 3$ and $N_{bgr}^{truth} = 3$.