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Study of R_2 distribution and B counting in Early Phase 3 Data

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Abstract

We have studied the event shape variable R_2 represented by the ratio of the second and zeroth Fox-Wolfram moment. The variable R_2 is a good indicator to understand if the collision data of the SuperKEKB are occurring at the $\Upsilon(4S)$ resonance. The study on the shape variable R_2 is used to derive the total number of produced $B\overline{B}$ pairs.

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1. INTRODUCTION

SuperKEKB is running, in the early Phase 3 at the $\Upsilon(4S)$ resonance. We indicate with continuum all the non $B\overline{B}$ events produced in the detector. Continuum contains many type of events, in particular for each type of quark (apart from t) $e^+e^- \to qq$ the cross section is of the order of 1 nb. On the other hand the cross section for events $e^+e^- \to \Upsilon(4S) \to B\overline{B}$ is 1 nb, continuum will then represent the dominant background. The ratio R_2 of Fox-Wolfram 2^{nd} to 0^{th} moments is the variable which provides the best separation between $B\overline{B}$ signal and continuum. Jet like continuum events tend to have higher values of R_2 than the more spherical $B\overline{B}$ events. Other variables like thrust and sphericity angles are also used for the same purpose.

2. R_2 DEFINITION

The Fox-Wolfram moments H_l, l = 0, 1, 2, ... are defined by

$$H_l = \sum_{i,j} \frac{|P_i||P_j|}{E_j^{vis}} P_l(cos\theta_{ij}) \tag{1}$$

where θ_{ij} is the opening angle between hadron i and j, E_{vis} is the total visible energy of the event, Pl are the Legendre polynomials and $|P_i|$ and $|P_j|$ are the momenta of the charged tracks or photons. R_2 is defined as the ratio of the second and zeroth moment, H_2/H_0 and it appears to be close to zero for $B\overline{B}$ events and 1 for others. It can be used to identify whether the collisions happen at the $\Upsilon(4S)$ resonance or not.

3. SAMPLES AND SELECTION

3.1. Data and MC sample

Results presented for this analysis are obtained with On-peak data corresponding to the following run numbers:

- bucket 4: runs 1135-1155, 1375-1587 (integrated luminosity: 69 pb^{-1})

- bucket 6: runs 3128-3847 (integrated luminosity: 344 pb^{-1})

for a total luminosity of 413 pb^{-1} (rounded to 410 pb^{-1}). Data have been reprocessed and calibrated, the used global tags are data_reprocessing_prompt_bucket4b and data_reprocessing_prompt_bucket6b for the two buckets.

The on-peak sample have been compare to MC12 simulated samples:

- generic $B\overline{B}$, udsc and $\tau^+\tau^-$ (samples used corresponds to $\simeq 10fb^{-1}$ each)
- eeee, $\mu\mu$ and ee, ee$\mu\mu$, $\gamma\gamma$, $\pi\pi + ISR$ (210M, 55M, 50M, 100M, 100M, 200M events respectively)

In the data-MC comparison plots, MC samples are normalised to the luminosity of data. For low multiplicity samples used the cross sections reported in [1].

For part of the study, in order to better describe the continuum component, we used off-peak data instead of continuum MC. Off-peak data corresponds to runs 1705-1835 and unofficial processing.

As for data, events passing the *hlt_hadron* skim have been used. The same skim selection have been applied to simulated data, according to the instruction in [2].

3.2. Event selection

The following selection criteria are used to select the R_2 sample:

1. Good tracks: $p_T > 100$ MeV, $|d_0| < 0.5$ cm, $|z_0| < 4$ cm, nSVDHits ≥ 6
2. Good clusters: E_{lab} >100 MeV and cluster in the CDC acceptance (0.296706 deg $< \theta < 2.61799$ deg)
3. Number of good tracks ≥ 3
4. Number of good clusters > 1
5. $E_{vis} \geq 0.2\sqrt{s}$ (sum of good track momenta and good photon energy)
6. Momentum balance $|p_z| < 0.5\sqrt{s}$ (sum of z component of momenta of good tracks and good photons)
7. $0.1\sqrt{s} \leq E_{sum} < 0.8\sqrt{s}$ (total energy in ECL)

In Tab. I, the efficiencies on the MC12 samples are reported.

A collection of the tracks, clusters and event variables are shown in Figs. 1 and 2. The agreement between data and simulation is poor in the low energy regions, in particular for events with low tracks and clusters multiplicity. This data excess could be attributed to the beam-gas machine background contribution, which is highly underestimated in the current MC12 campaign. In order to estimate this effect, we use off-resonance data instead of continuum MC. A list of variables comparing on-peak data, $B\overline{B}$ MC12 and off-resonance data are shown in Fig. 3.

TABLE I: Selection efficiency on MC12 samples.

sample	efficiency (%)
B^+B^-	98.96 ± 0.02
$B^0\bar{B}^0$	98.66± 0.02
$c\bar{c}$	93.56 ± 0.03
$u\bar{u}$	73.94 ± 0.05
$d\bar{d}$	72.74 ± 0.11
$s\bar{s}$	77.89 ± 0.10
$\tau^+\tau^-$	17.82 ± 0.06
ee	$(4.57 \pm 0.06) \times 10^{-3}$
$\mu\mu$	$(3.0 \pm 0.3) \times 10^{-2}$
$eeee$	$(7.0 \pm 0.2) \times 10^{-3}$
$ee\mu\mu$	$(9.5 \pm 0.4) \times 10^{-3}$
$\gamma\gamma$	$(4.3 \pm 1.4) \times 10^{-4}$
$\pi\pi + ISR$	0.105 ± 0.013

4. R_2 FIT AND B COUNTING

R_2 distribution for the Phase 3 data up to a collected luminosity of 410 pb^{-1} is shown in Fig. 4. On peak data are compared to MC12 samples.

As can be seen, a discrepancy between on-peak data and simulated samples near the peak region is visible. This is probably related to the poor simulation of the machine background discussed before. For this reason we decided to use off-resonance sample to account for the continuum component. At the moment, the collected luminosity for the off-resonance sample is not known with good accuracy. In order to determine the off-resonance normalization, we perform a template fit to R_2 with two components: $B\overline{B}$ taken from MC12 and continuum from off-resonance data. The result of the fit is reported in Fig. 5.

The fitted yields for the two event categories are:

- $B\overline{B}$: 378630 ± 1020
- continuum: 1452280 ± 1450

Using the $B\overline{B}$ efficiency reported in Tab. I and the fit result, we estimate a number of $B\overline{B}$ pairs as $N_{BB}^{fit}/\epsilon_{BB} = 383170 \pm 1020$ (the uncertainty is statistical only). The number of measured $B\overline{B}$ pairs is 15% lower than the expected $B\overline{B}$ pairs in $410\,\mathrm{pb}^{-1}$.

Using the continuum normalization from the fit, we obtain the plot in Fig. 6.

The R_2 distribution clearly indicates the presence of $B\overline{B}$ component confirming that the collisions are well positioned at the $\Upsilon(4S)$ resonance.

[1] *Low multiplicity cross-section tables*,
`https://confluence.desy.de/display/BI/Physics+CrossSectionsTable`.

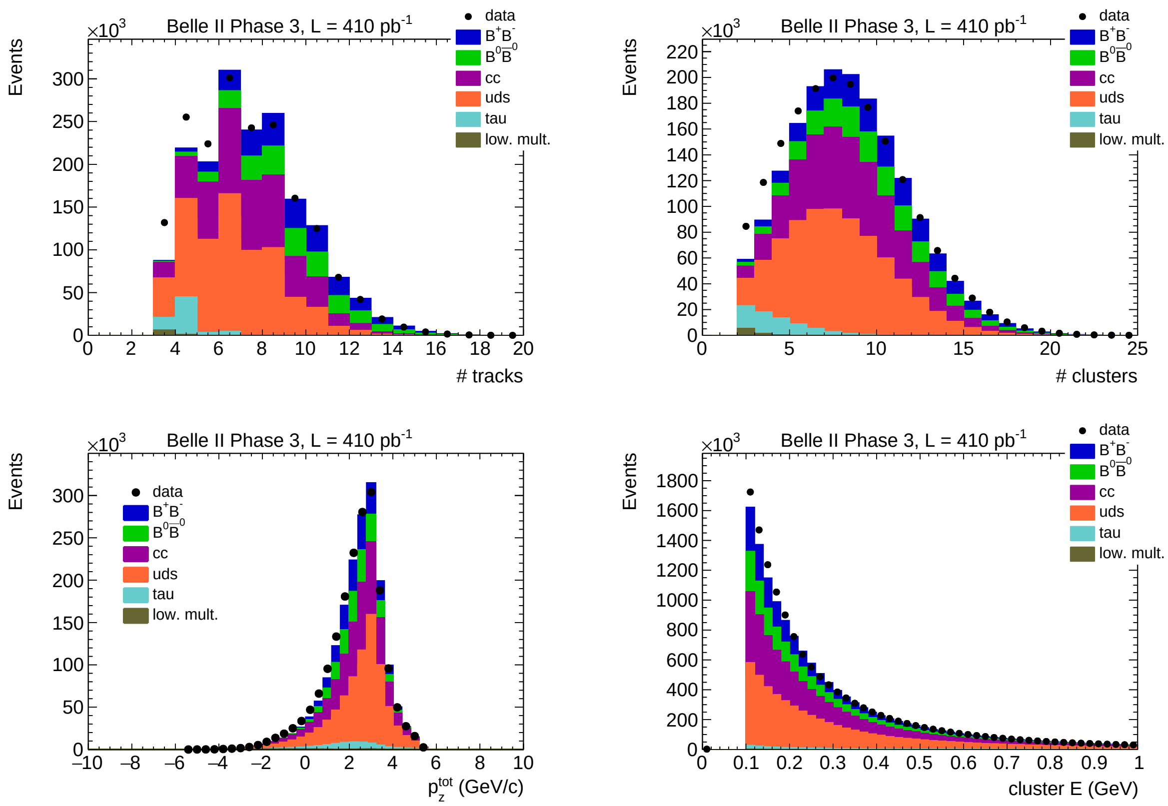

FIG. 1: Number of tracks (a), number of clusters (b), tracks longitudinal momentum (c) and cluster energy (d). Generic MC12 samples are compared to bucket 6 and bucket 4 calibrated data.

[2] *Software trigger module*, `https://confluence.desy.de/display/BI/The+HLT+Software+Trigger+and+Software+Trigger+Module`.

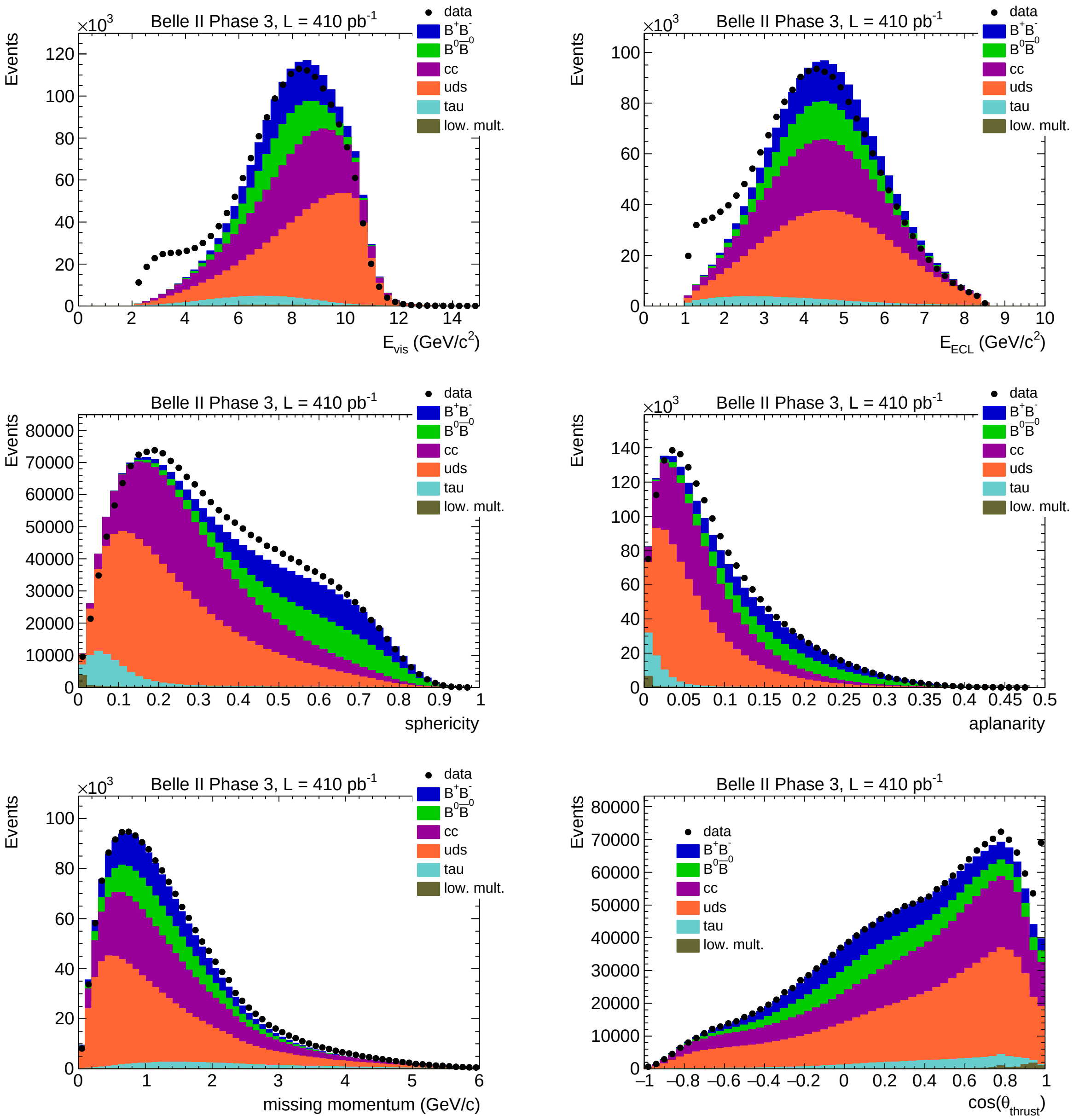

FIG. 2: Visible energy (a), total energy measured in the ECL (b), sphericity (c), aplanarity (d), missing momentum (e), and cosine of the polar angle of the thrust axis of the event (f). Generic MC12 samples are compared to bucket 6 and bucket 4 calibrated data.

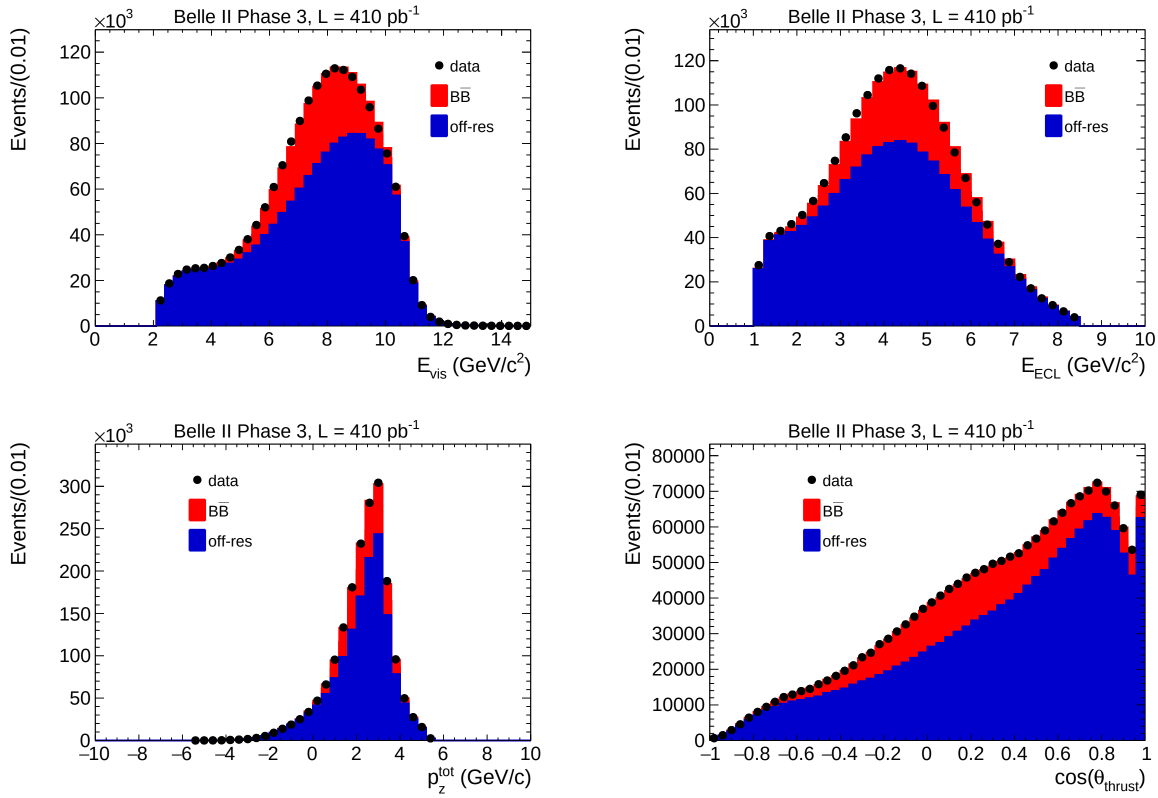

FIG. 3: Visible energy (a), total energy measured in the ECL (b), tracks longitudinal momentum (c), and cosine of the polar angle of the thrust axis of the event (d). The contributions are normalized to the R_2 fit results detailed in the Sec. 4. Generic MC12 samples and off-resonance data are compared to on-peak data.

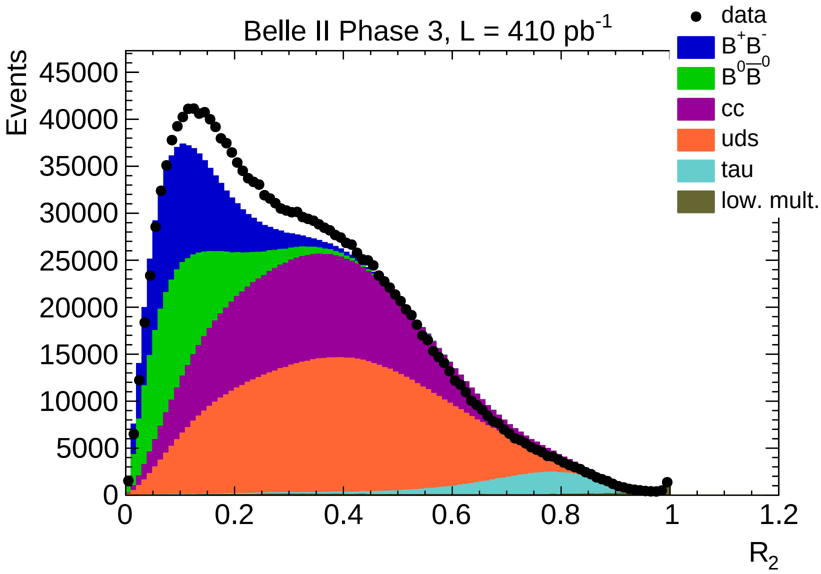

FIG. 4: R_2 distribution after the selection cuts detailed in Sec. 3 3.2. Generic MC12 samples are compared to bucket 6 and bucket 4 calibrated data.

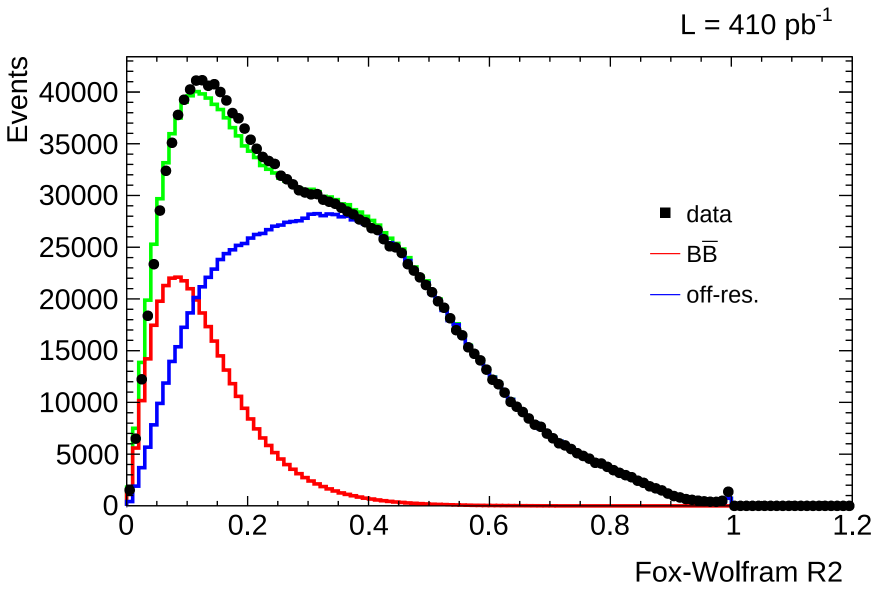

FIG. 5: Result of the template fit to R_2 distribution.

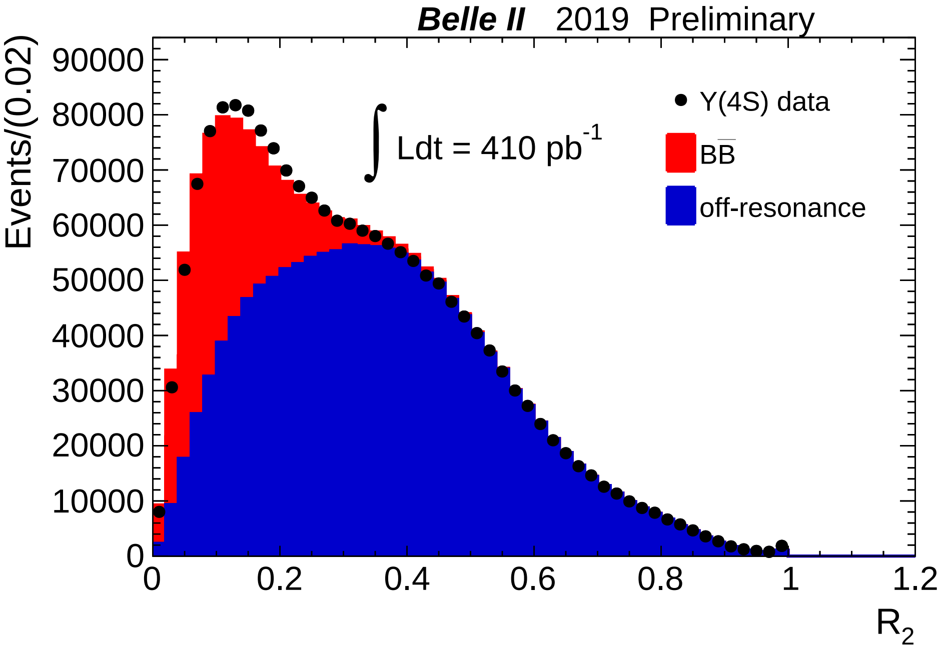

FIG. 6: R_2 distribution after the normalization to the fit results. Generic MC12 samples and off-resonance data are compared to on-peak data.