QED Background: Comparison of Data and Monte Carlo

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- Expected Background at Belle II
- QED expectations based on different MC generators
- Performed QED experiments at KEK
- Comparison between data and MC
- Summary and Conclusion
Expected Background at Belle II

Machine background

- Beam – gas scattering (bremstrahlung and Coulomb scattering)
- Touschek effect (intra-bunch scattering)
- Synchrotron Radiation

expected increase by a factor 20

Luminosity–related background

- Radiative Bhabha scattering

$\gamma \gamma$ reactions

$\sigma \sim O(10^7 \text{nb})$

$\sigma \sim 50 \text{nb}$

increase by a factor of 40 (due to luminosity)

this is main reason
2 photon (QED) processes

- to predict the situation for Belle II we need MC
- we have a set of three “standard” MCs

- Berends – Daverfeldt – Kleiss (BDK)
- S.Jadach et al. (KW)
- J.Fujimoto et al. (Grace)

- BUT: there is also a prediction from SUPERB which deviates strongly

The answers from these three MCs are consistent amongst themselves.

<table>
<thead>
<tr>
<th>MC generator</th>
<th>SuperB (BDK)</th>
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<tbody>
<tr>
<td>Tracks</td>
<td>13800</td>
<td>~ 710</td>
<td>~ 800</td>
</tr>
<tr>
<td>Occupancy</td>
<td>1.3%</td>
<td>0.07%</td>
<td>0.1%</td>
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a factor of 15 difference

Question: Who is right?
QED spectrum normalized to one event

Minimum momentum needed to reach the tracking detectors

PXD : $e^-$ with energy $> 5.8 \text{MeV}$
SVD : $> 40 \text{MeV}$
CDC : $> 100 \text{MeV}$

Expected number of tracks from the consistent MCs is ~ 800

high rate at very low momentum
($\sim 5 - 20 \text{MeV}$)
What do we expect?

**SuperKEKB** Simulation: \(~ 800\) tracks per PXD frame
\(~ 13,000\) tracks, SuperB Simulation

- \(L \sim 1000\) /nbs
- Integration time = \(20\) \(\mu s\) (PXD)

Scale to **KEKB**:

- \(L \sim 10\) /nbs (\(10^{32}\) cm\(^{-2}\) s\(^{-1}\))
- Integration time = \(2\) \(\mu s\) (SVD)

**Belle**

- \(0.8\) tracks/SVD frame

**SuperB MC**: 13 tracks/frame on average

(\ radius correction included)
QED Background Runs

*Real data* to solve the MC puzzle

- A few MeV cannot be triggered at Belle

Random Triggers (unbiased background)

**IDEA:**
- vary luminosity
- look at change in # hits in SVD
- extrapolate to $L = 0$ to estimate non–QED machine background

Background events generated by 3 sources:

- B – physics (few)
- Machine background
- QED

depends only on luminosity and not on the particular beam setting
Performed QED experiments

Random Trigger Runs and Data Sample:

Exp. A (separate the beams vertically)
Run (415 – 420) each run 500 k triggers

Exp. B (increase vertical beam size in HER)
Run (401 – 411) each run 500 k trigger

Exp. C (change beam currents by stopping injection)
Run (421 – 427) each run 10 min

Random trigger rate: 400Hz
Bhabha trigger rate: 50Hz moderate start luminosity ( ~ 10/nbs)

Each experiment started with a run ~ 10 /nbs ( “default“)
500 k triggers at 400Hz = 30 min (including beam setup)
vary luminosity steps of 2 /nbs
10, 8, 6, 4 /nbs
Luminosity Change

**Run 401**
$L = 9.7 / \text{nbs}$

**Run 408**
$L = 6.3 / \text{nbs}$

SVD hit multiplicity in the 1st SVD layer

$R = \langle N_{\text{hits}} \rangle = 113$

Hit Rate decreases

$R = \langle N_{\text{hits}} \rangle = 103$
Luminosity Of Observed Background Hits

New analysis: use the CDC hits

old analysis: correct by the CDC current
Look Into SVD Hits More Closely

this was the original coarse binning

Δhits
Observed Increase In Number Of Hits For All Measurements

- All Layers and All Experiments included

Surprise: two components !!!

<table>
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<th>QED_histogram - CDC hits corrected</th>
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<tbody>
<tr>
<td>Entries</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>RMS</td>
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<tr>
<td>Constant</td>
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<tr>
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<tr>
<td>Sigma</td>
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Where do the two components come from?
Origin Of The Big Peak

2nd - 4th SVD layer - all experiments included

\[ \langle N_{\text{hits}} \rangle = -2.9 \pm 2.1 \]

consistent in all experiments and all outer layers
Origin Of The Small Peak

1st SVD layer - all experiments included

High yield comes from the 1st SVD layer

\[ \langle N_{\text{hits}} \rangle = 13.3 \pm 2.6 \]

Can Layer 1 peak come from QED?
Use Full Detector Simulation

➢ to determine how many hits a track produces in each SVD layer

☐ SVD hit multiplicity – z strips (similar for φ strips)

Layer 1
\[ \langle N_{\text{hits}} \rangle = 11.31 \]

Layer 2
\[ \langle N_{\text{hits}} \rangle = 3.99 \]

Layer 3
\[ \langle N_{\text{hits}} \rangle = 1.84 \]

Layer 4
\[ \langle N_{\text{hits}} \rangle = 1.32 \]

Counts decrease as the radius increase

1st SVD layer
Expectation: 3 hits/cluster
Assume: 1 track makes 1 cluster
Simulation: 4.5 hits/cluster
more than 1 cluster per track

Simulation shows discrepancy from naive expectation
Summary Of The Performed Measurements

In layer 1 measured: \( <\Delta\text{hits} > = 13.3\pm 2.6 \)
In layer 2-4 measured: \( <\Delta\text{hits} > = -2.9\pm 2.1 \)

Observation can be explained when looking at the full detector simulation:

- predicts in layer 1 \( <\#\text{hits} > = 11.31 \) per QED event
- predicts in layer 2-4 \( <\#\text{hits} > = 2.38 \) per QED event

Conclusion:
the observation for layer 1 and layer 2 – 4 are consistent and in agreement with the full MC Simulation
Comparison Between Data And Monte Carlo

Naive Expectation
Assume: 1 track makes 1 cluster

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<td></td>
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<tr>
<td><strong>Hits</strong></td>
<td>24</td>
<td>1.1</td>
<td>1.5</td>
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**MC vs. Data**

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<td><strong>Hits (1st SVD layer)</strong></td>
<td>181</td>
<td>11.31</td>
<td>~ 100</td>
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<tr>
<td><strong>Hits (2nd – 4th SVD layer)</strong></td>
<td>38.1</td>
<td>2.38</td>
<td>~ 45</td>
</tr>
<tr>
<td><strong>Occupancy (1st SVD layer)</strong></td>
<td>5.5%</td>
<td>0.3%</td>
<td>0.4%</td>
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1 QED track makes more than 1 “curlers”

The expectation form SuperB is completely excluded

Still far away from the limit of 2 %
Summary and Conclusion

- Strong discrepancies in MC predictions for QED Background between Belle II and SuperB

- Use measurements with different beam tunings to extract QED background hits in SVD2

- Measurements show additional luminosity – depended background which is also seen in CDC

- Δhits for layer 1 of SVD2 very different from naive expectation (outer layers in agreement)

- Full MC simulation explains this observation and gives consistent picture of measurements

- Expected occupancy for layer 1 rises to 0.3%

- Comparison of measured Δhits with predictions of different MC generators again allows complete exclusion of SuperB prediction
**Experiment B – Run 408**

- SVD hit multiplicity – z strips (similar for $\varphi$ strips)

**Layer 1**

$< N_{\text{hits}} > = 103$

**Layer 2**

$< N_{\text{hits}} > = 46.5$

**Layer 3**

$< N_{\text{hits}} > = 43.3$

**Layer 4**

$< N_{\text{hits}} > = 37.7$

$L = 6.3/\text{nbs}$

Counts decrease as the radius increase.
CDC Hits Corrected SVD Hits

- 2nd – 4th SVD layer – Experiment A
CDC Hits Corrected SVD Hits

- 2\textsuperscript{nd} – 4\textsuperscript{th} SVD layer – Experiment B
CDC Hits Corrected SVD Hits

- 2nd – 4th SVD layer – Experiment C