Update on a fully-inclusive $B \to X_s\gamma$ measurement using the hadronic FEI

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Inclusive analysis meeting

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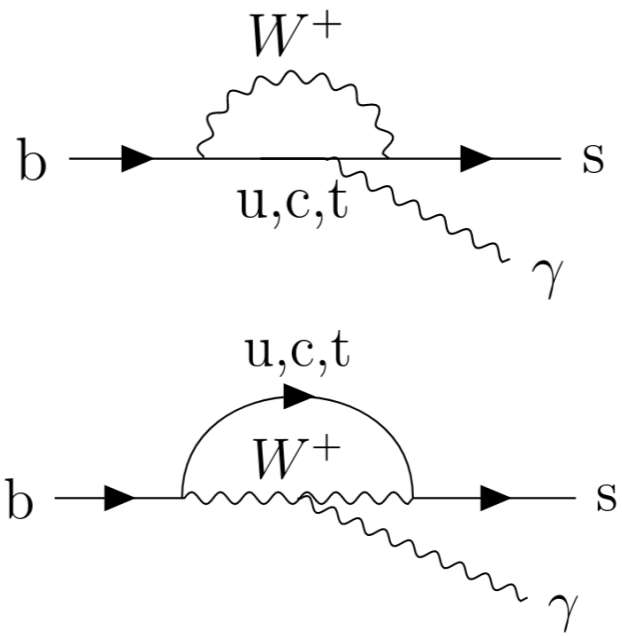
Brief introduction

- Group from DESY: Kerstin Tackmann, Simon Wehle, Markus Röhrken, Henrikas Svidras.
- A fully-inclusive $B \to X_s\gamma$ is planned using a hadronic tag.

Content Summary

- Considerations for signal selection.
- Backgrounds to reduce.

$B \to X_s\gamma$: motivation



- $B \to X_s\gamma$ is sensitive to SM extensions (2HDM, SUSY etc.)
- Allows to determine m_b^2 and μ_π^2 important for $|V_{ub}|$ extraction from $b \to u l \bar{\nu}$.
- An inclusive measurement minimises/changes some of the theoretical uncertainties arising in exclusive analyses.
- Hadronic tag: higher purity, E_γ measured in B rest frame.

FEI and gamma preselection

- Changed the reconstruction approach - shifted to FEI skims.

→ combined B^+, B^0 skim currently unavailable.

- Assessing selection variables for the analysis.

- Cleaned tracks (`pi+:eventShapeForSkims`): $d_0 < 0.5\,\text{cm}$, $|z_0| < 2\,\text{cm}$, and $p_T > 0.1\,\text{GeV}$
- Cleaned ECL clusters (`gamma:eventShapeForSkims`): $0.296706 < \theta < 2.61799$, and $E > 0.1\,\text{GeV}$

Event pre-cuts:

- $R_2 < 0.4$ (`foxWolframR2` from `modularAnalysis.buildEventShape` , calculated using all cleaned tracks and clusters)
- $n_{\text{tracks}} \geq 4$
- $n_{\text{cleaned tracks}} \geq 3$
- $n_{\text{cleaned ECL clusters}} \geq 3$
- Visible energy of event (CMS frame) $> 4\,\text{GeV}$
- $2\,\text{GeV} < E_{\text{cleaned tracks \& clusters in ECL}} < 7\,\text{GeV}$

Tag side B cuts:

- $M_{\text{bc}} > 5.24\,\text{GeV}$
- $|\Delta E| < 0.2\,\text{GeV}$
- signal probability > 0.001 (omitted for decay mode 25)

- Additional cuts on gamma:

→more than 1 γ with E>1.4 GeV in CDC acceptance.

Reconstruction and truth matching

Reconstruction of "$X_s\gamma$" utilises the new Belle 2 decay string grammar '...'

- $B^+ \rightarrow \gamma$ ... with no additional cuts.

$\rightarrow$ allows to use `matchMCTruth`.

- $\Upsilon(4S) \rightarrow B^+$:generic B^-:signal with 5.5 <= M <= 12.5

Still need to understand truth matching better:

$\rightarrow$ only `isSignalAcceptMissingGamma` works for B^+.

$\rightarrow$ possibly related question implies this is a known issue.

Currently a way to select $b \rightarrow s\gamma$:

$$\texttt{isBsgamma} = \begin{cases} \texttt{Btag\_isSignal} \\ \texttt{Bsig\_isSignalAcceptMissingGamma} \\ \texttt{gamma\_isSignal} \end{cases} \quad (1)$$

Photon selection

Selecting only `isBsgamma` candidates.
Look which FEI rank/ gamma rank they correspond to.

FEI rank\E$_\gamma$ rank	1	2	3	all E$_\gamma$ ranks
1	83.5%	0.6%	<0.1%	84.1%
2	10.3%	0.1%	<0.1%	10.4%
3	2.6%	<0.1%	<0.1%	2.6%
4	1.2%	<0.1%	<0.1%	1.2%
5	0.6%	<0.1%	<0.1%	0.6%
6	0.3%	<0.1%	<0.1%	0.3%
7	0.2%	<0.1%	<0.1%	0.2%
8	0.2%	<0.1%	<0.1%	0.2%
9	0.1%	<0.1%	<0.1%	0.1%
10+	0.2%	<0.1%	<0.1%	0.2%
all FEI ranks	99.3%	0.7%	<0.1%	248903

NOTE: On $B^+ \to X_s\gamma$ Signal MC13 (1 block: $50{\cdot}10^6$ evts).

Photon selection

Selecting only **NOT** `isBsgamma` candidates.
Look which FEI rank/ gamma rank they correspond to.

FEI rank\E$_\gamma$ rank	1	2	3	all E$_\gamma$ ranks
1	19.0%	0.2%	<0.1%	19.2%
2	15.2%	0.2%	<0.1%	15.4%
3	12.1%	0.2%	<0.1%	12.3%
4	10.0%	0.2%	<0.1%	10.2%
5	8.3%	0.1%	<0.1%	8.4%
6	7.0%	0.1%	<0.1%	7.1%
7	5.9%	0.1%	<0.1%	6.0%
8	4.9%	0.1%	<0.1%	5.0%
9	4.1%	0.1%	<0.1%	4.2%
10+	11.9%	0.2%	<0.1%	12.2%
all FEI ranks	98.4%	1.6%	<0.1%	22562194

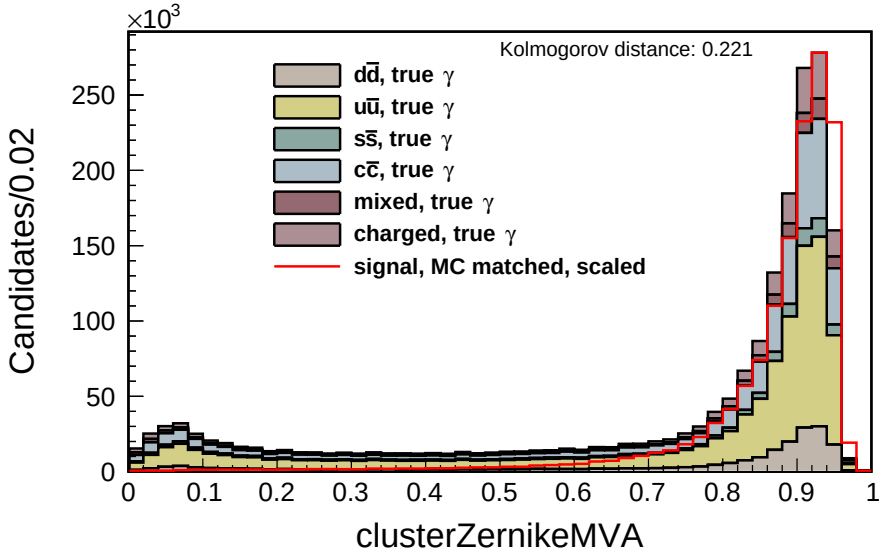
Photon selection

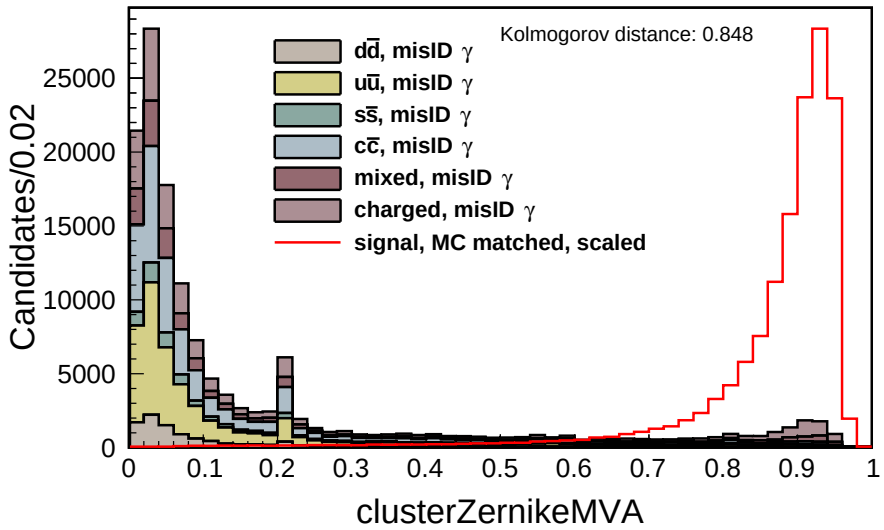
- Selecting FEI rank/ E_γ rank 1 seems a reasonable first rough cut:

$\rightarrow$ retains 84% of correct and 19% of incorrect combinations.

- Probably can be extended using other variables.

Some `basf2` vars provide separation for photon clusters as well, e.g.





- Other cluster variables might be considered as well.
- A cut at 0.5 retains:

$\rightarrow$ 98% of signal candidates

$\rightarrow$ 75% of background

Background composition

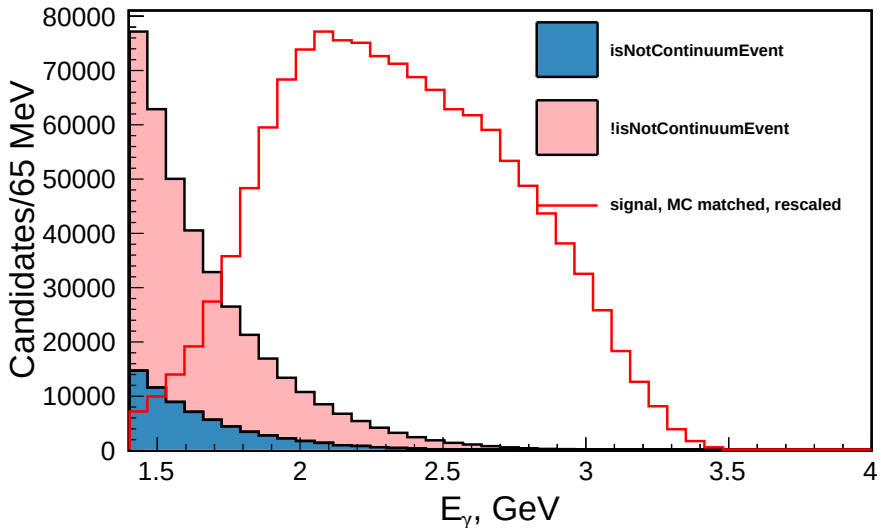
After selecting only events with these cuts:

```
Btag_feiSigRank == 1
gamma_gammaE_rank == 1
gamma_clusterZernikeMVA > 0.5
Btag_Mbc > 5.26
```

On generic MC:

- Retains about 19% of background.
- The background proportion is $\approx 83\%/17\%$ for cont./non-cont.
- γ from π^0 and η – about 90% of this background.

$\rightarrow$ Continuum and π^0/η background has to be reduced.

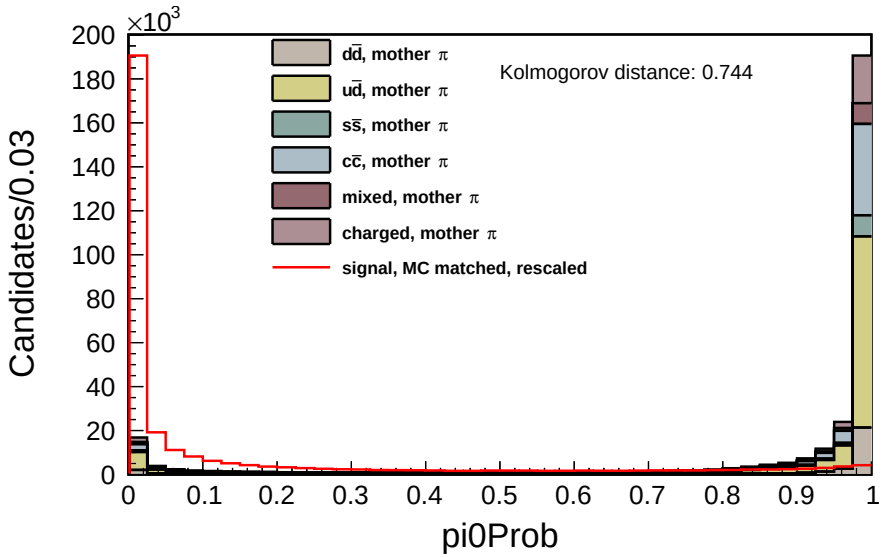


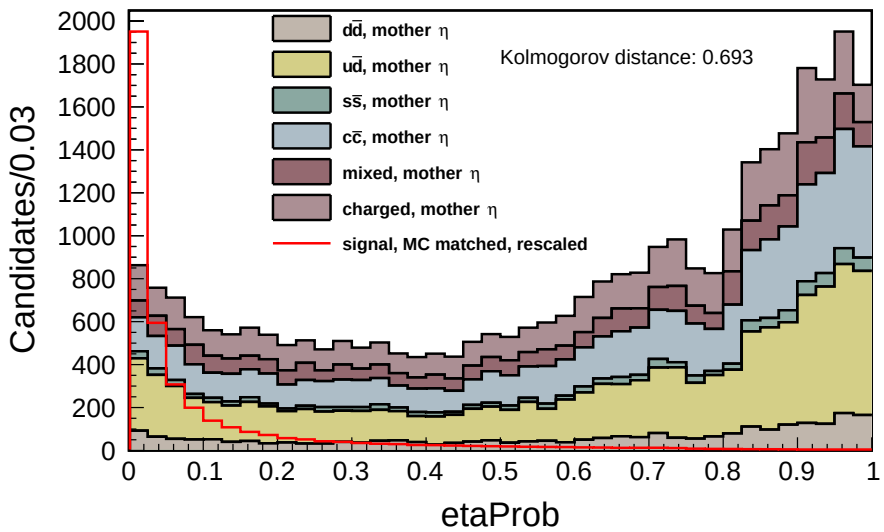
π^0 and η vetoing

Two strategies possible:

- Use current Belle 2 `writePi0EtaVeto` function.

→ make sure a bias for photon selection is not introduced.





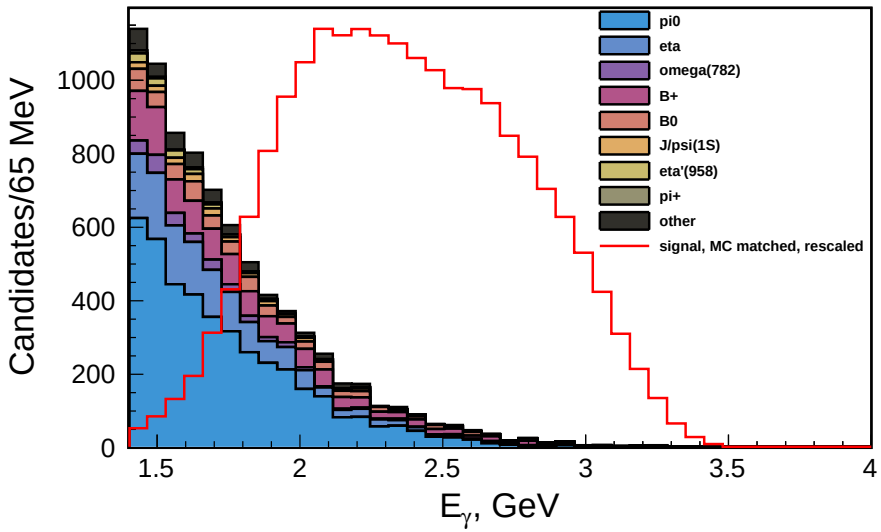
- Develop a dedicated selection for that.

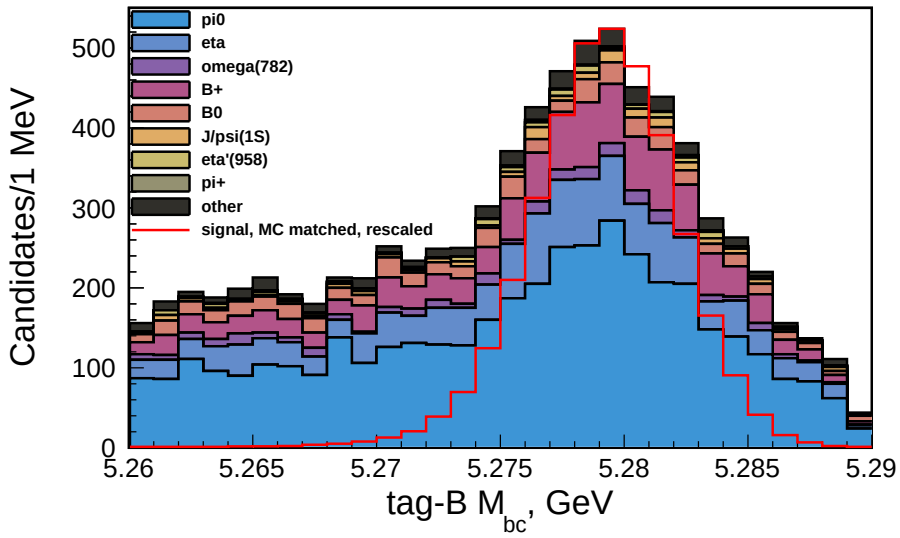
→ looking into and considering this as well.

π^0 and η vetoing

- Considerable $B\bar{B}$ background even with harsh `pi0Prob` and `etaProb`.

e.g. γ MC mother pdg distributions (only non-continuum background):

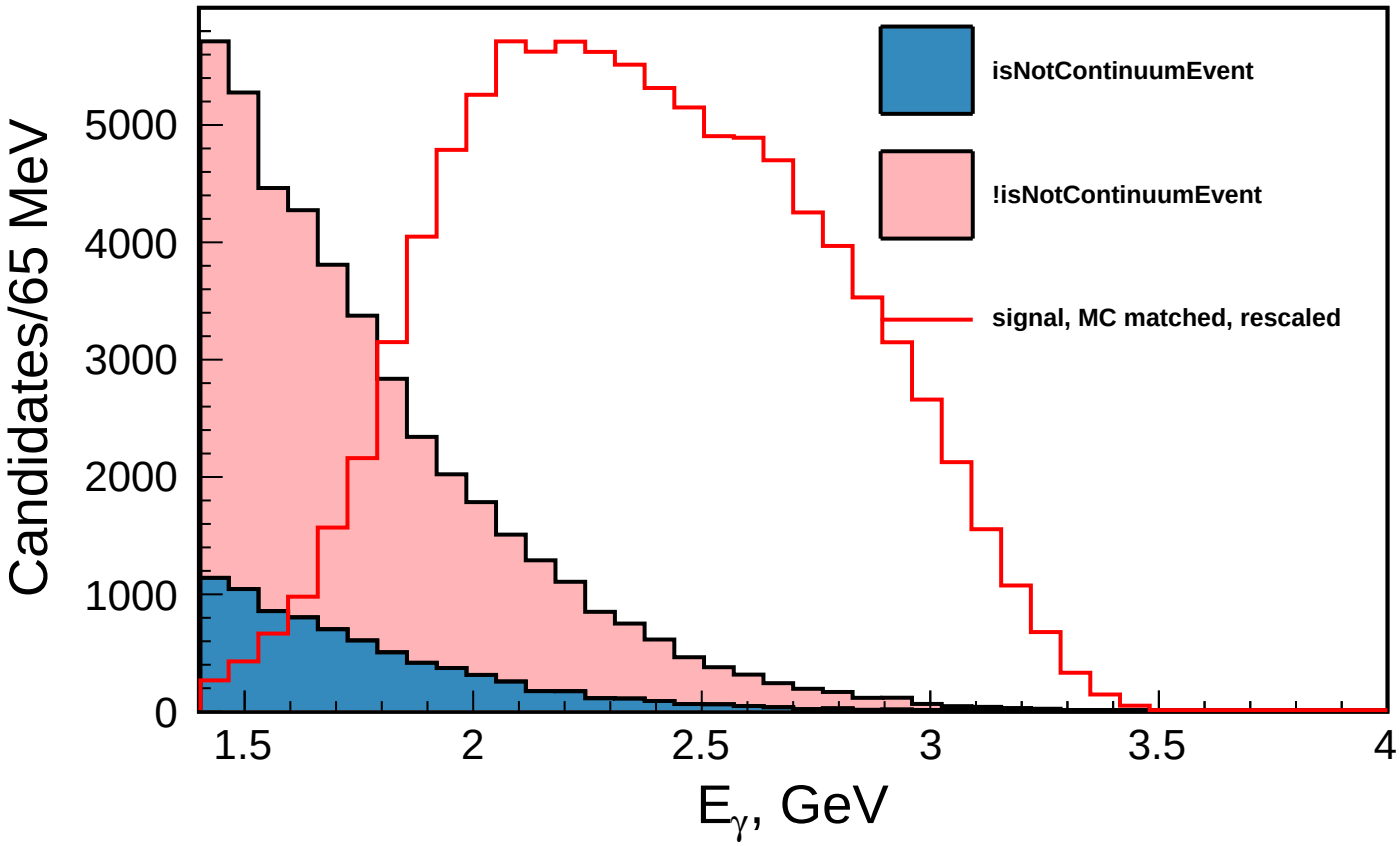




- further studies for optimal veto method to follow.

Continuum reduction

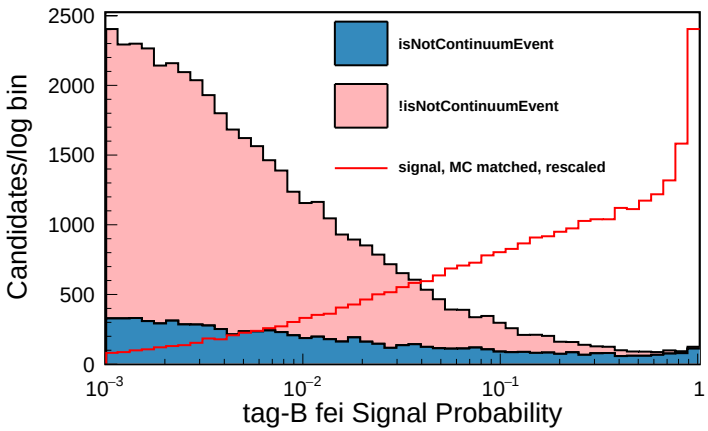
- Reducing continuum is also necessary.
- Even with harsh `piOProb` and `etaProb`, continuum is dominating.



- Event shape/FEI signal probability will be used to reduce this.
- Need to make sure to avoid biases with the FEI.

Continuum reduction

- Short term plans to combine feiSigProb and event shape.



$\Longrightarrow$

- cleoConeThrust.
- KSFW variables.
- etc.

- Will significantly reduce the number of continuum events.
- KSFW variables are uncorrelated with M_{bc} and ΔE.

$\rightarrow$ should ensure that B_{tag} selection is not biased.

Summary and plans

Background contributions need to be further reduced.

- Some simple selections can already be used for background studies, but will need to be further optimised in the future.
- Testing different ways for π^0, η vetos.
- Continuum background dominating, but should be significantly reduced.

Thanks for your attention!
Comments and insight very welcome.

Previous inclusive measurements (BaBar and Belle)

Year	Experiment	Measurement type	Data on res	Data off res
2007	BaBar	Hadronic	210 fb^{-1}	—
2009	Belle	No-tag/Semi-leptonic	605 fb^{-1}	68 fb^{-1}
2012	BaBar	Semi-leptonic	347 fb^{-1}	36 fb^{-1}
2012	BaBar	Sum-of-exclusive	429 fb^{-1}	45 fb^{-1}
2016	Belle	Semi-leptonic	711 fb^{-1}	90 fb^{-1}

$\rightarrow$ About 10% off-resonance data is required.

Expected signal yield

Current (conservative) estimation 50 $fb^{-1} \rightarrow 55 \cdot 10^6$ $B\bar{B}$ pairs.

Given hadronic FEI tag-side efficiency (just benchmark numbers):

- 0.2 % for hadronic neutral B.
- 0.4 % for hadronic charged B.

$\rightarrow \sim$ FEI 0.3 % : 165000 evts.

E_γ cut, GeV	$B_{(s+d)\gamma} \cdot 10^{-4}$*	Expected observable evts for 50fb^{-1}
1.7	3.20 ± 0.29	53 ± 5
1.8	3.15 ± 0.23	52 ± 4
1.9	3.07 ± 0.19	51 ± 3
2.0	2.92 ± 0.14	48 ± 2

$\rightarrow$ This is before any background treatment!

*Branching fractions from Belle semileptonic (2016)

Expected signal yield

- Assume signal efficiency & systematics as in BaBar hadronic (2007).

→ eff 30% (1.9 GeV) to 65% (2.6 GeV) approximately linear increase.

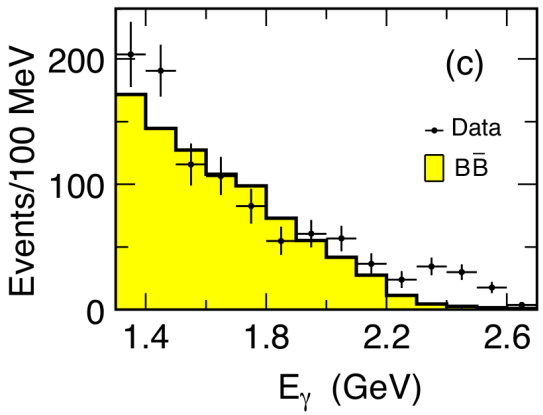
- Scale statistical error according to int. luminosity difference.

→ multiply by $\sqrt{\frac{210}{50}}$.

- Central value from BaBar semileptonic (2012).

So bin-by-bin one can expect:

E_γ, GeV	Expected events in bin	$\frac{N}{\sqrt{N+B}}$
1.9-2.0	2 ± 6	0.71
2.0-2.1	2 ± 6	0.71
2.1-2.2	3 ± 4	1.13
2.2-2.3	4 ± 4	1.41
2.3-2.4	5 ± 4	1.67
2.4-2.5	6 ± 3	2.00
2.5-2.6	7 ± 3	2.21
2.0-2.6	27 ± 10	4.44



→ approximately a fourth of events compared to this