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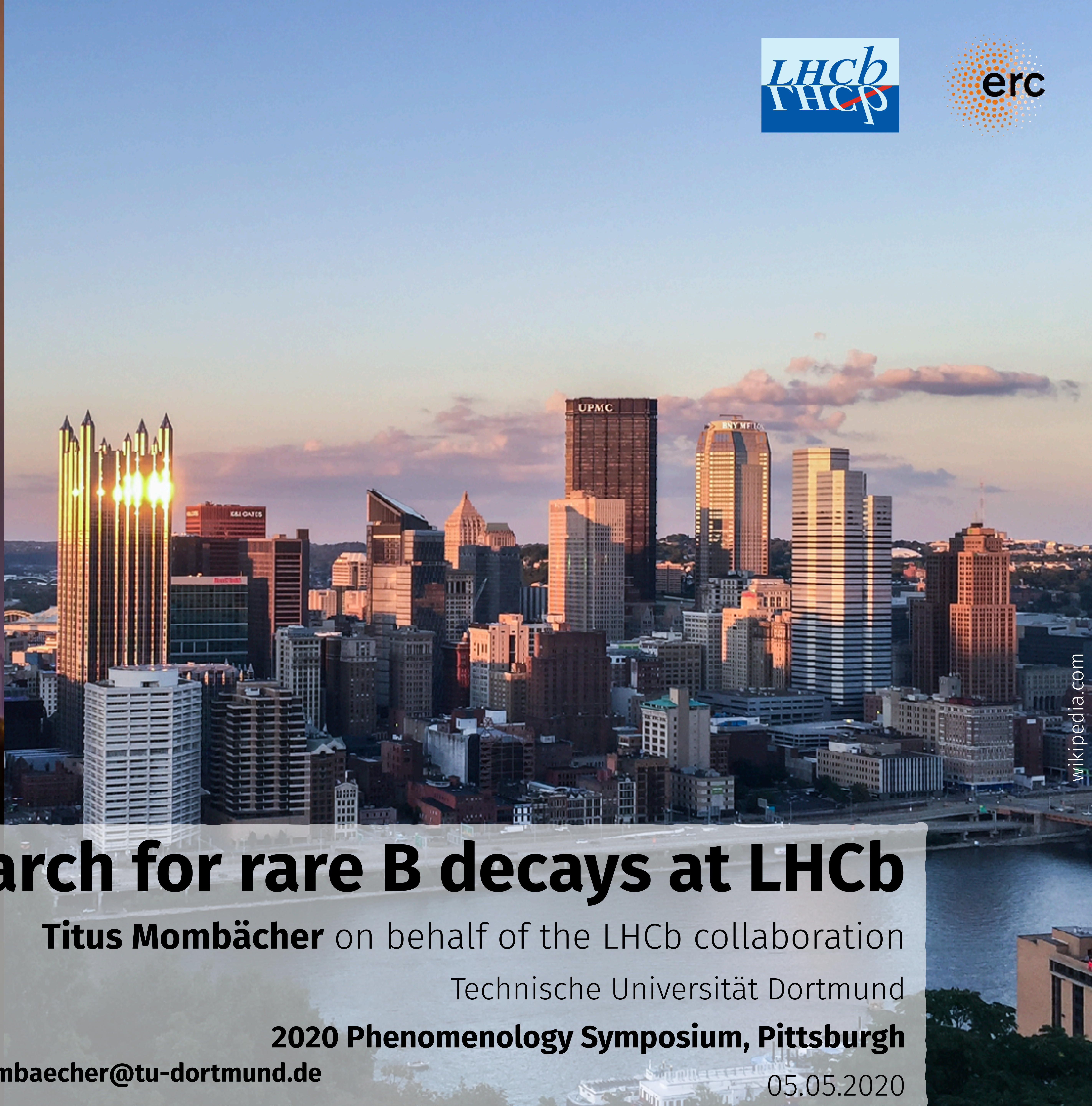

Search for rare B decays at LHCb

Titus Mombächer on behalf of the LHCb collaboration
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2020 Phenomenology Symposium, Pittsburgh

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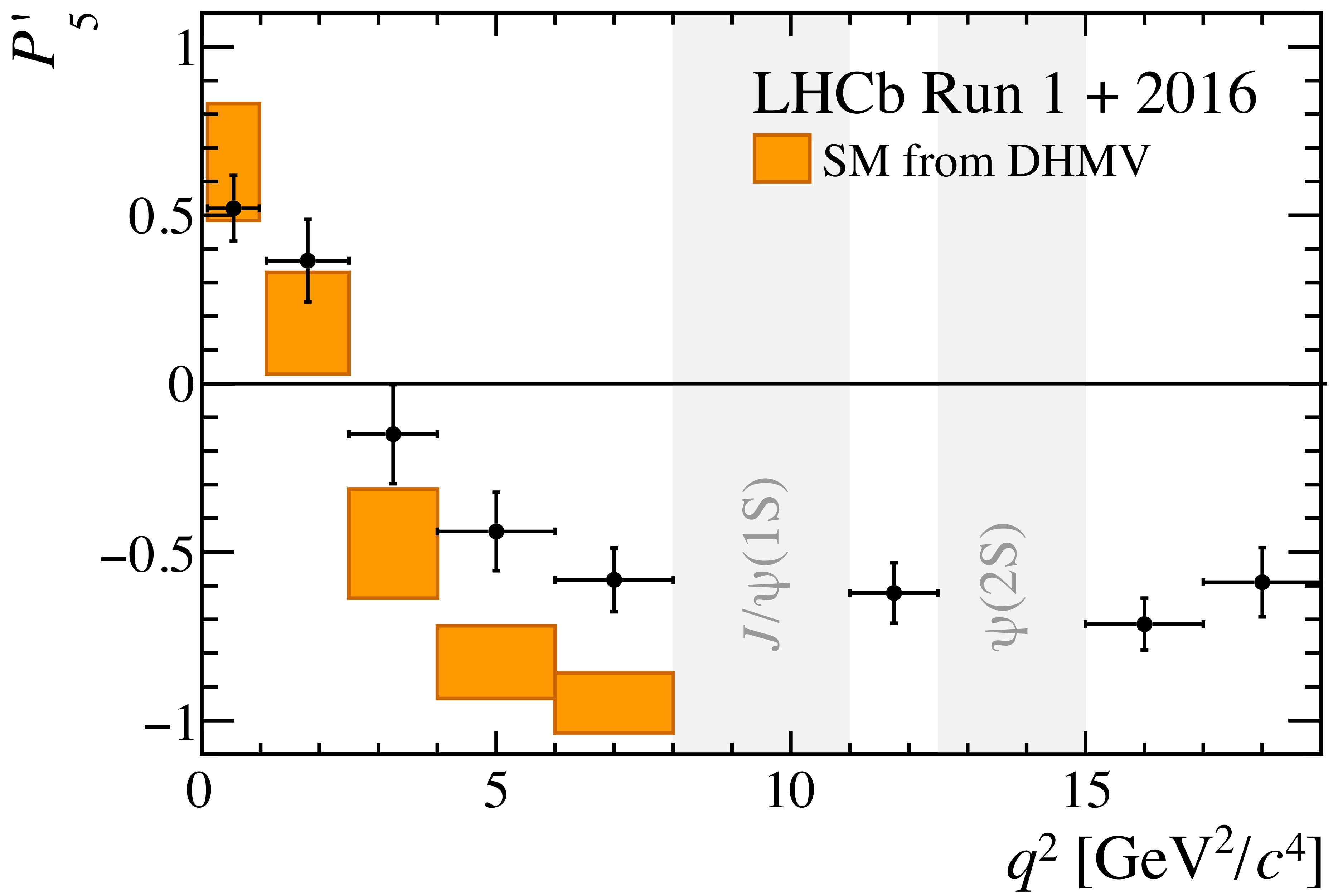
05.05.2020

Studies of $b \to s\ell\ell$ processes

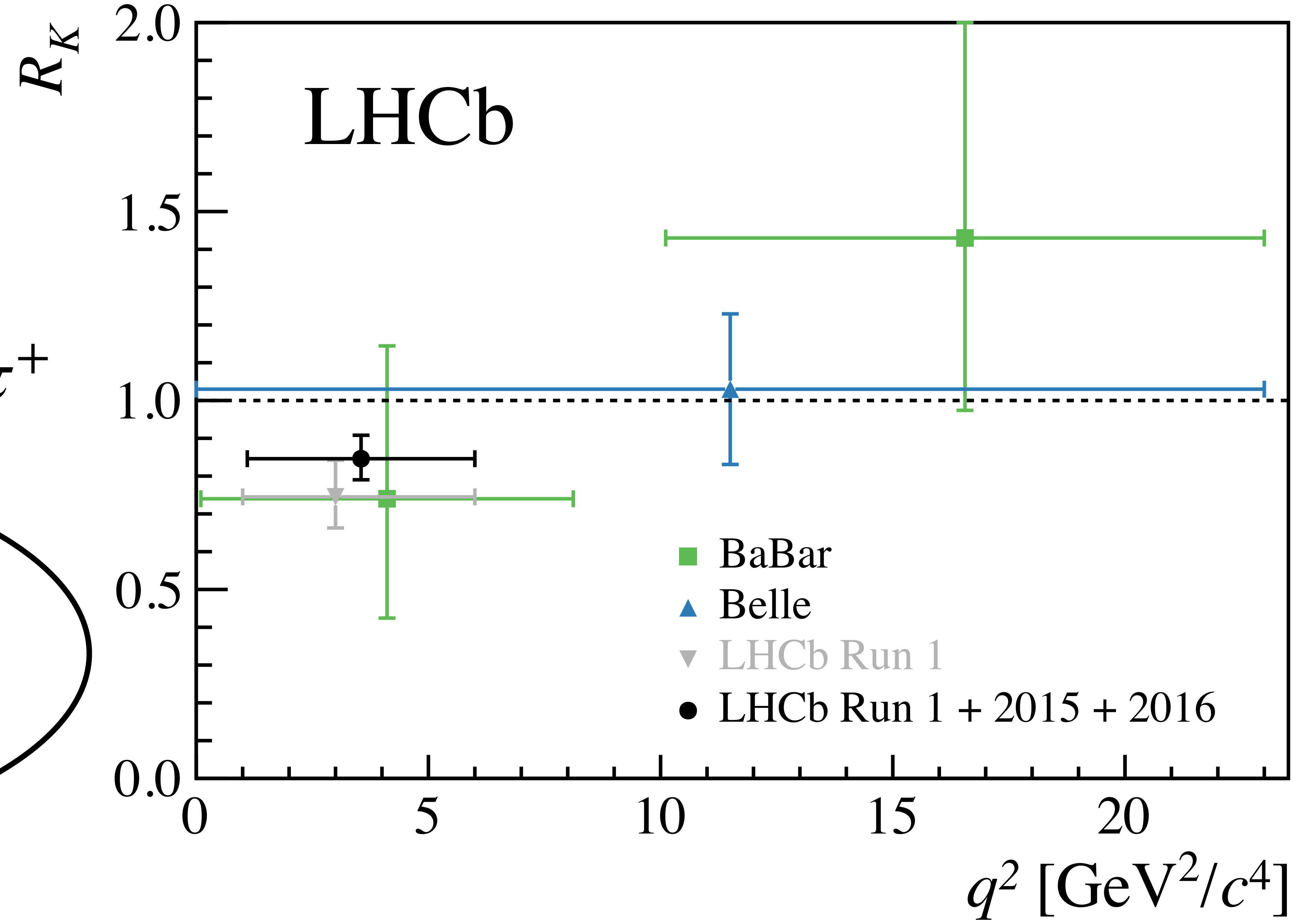
- Flavour Changing Neutral Currents
  - Strong suppression in the Standard Model (SM)
    $\to$ New Physics (NP) at loop/tree level might become visible
  - Complementary to direct NP searches $\to$ exploring higher energy scales
- Find deviations from the SM in
  - (Differential) $b \to s\mu^+\mu^-$ branching fractions
  - $b \to s\mu^+\mu^-$ angular distributions
  - Lepton Flavour Universality ratios

See also talk by Katharina Müller

- **Discuss 2 new results today: searches for $B^0_{(s)} \to e^+e^-, B^+ \to K^+\mu^-\tau^+$**



[arXiv:2003.04831]



[PRL 122 (2019) 191801]

Do leptons not interact universally?

pixabay.com

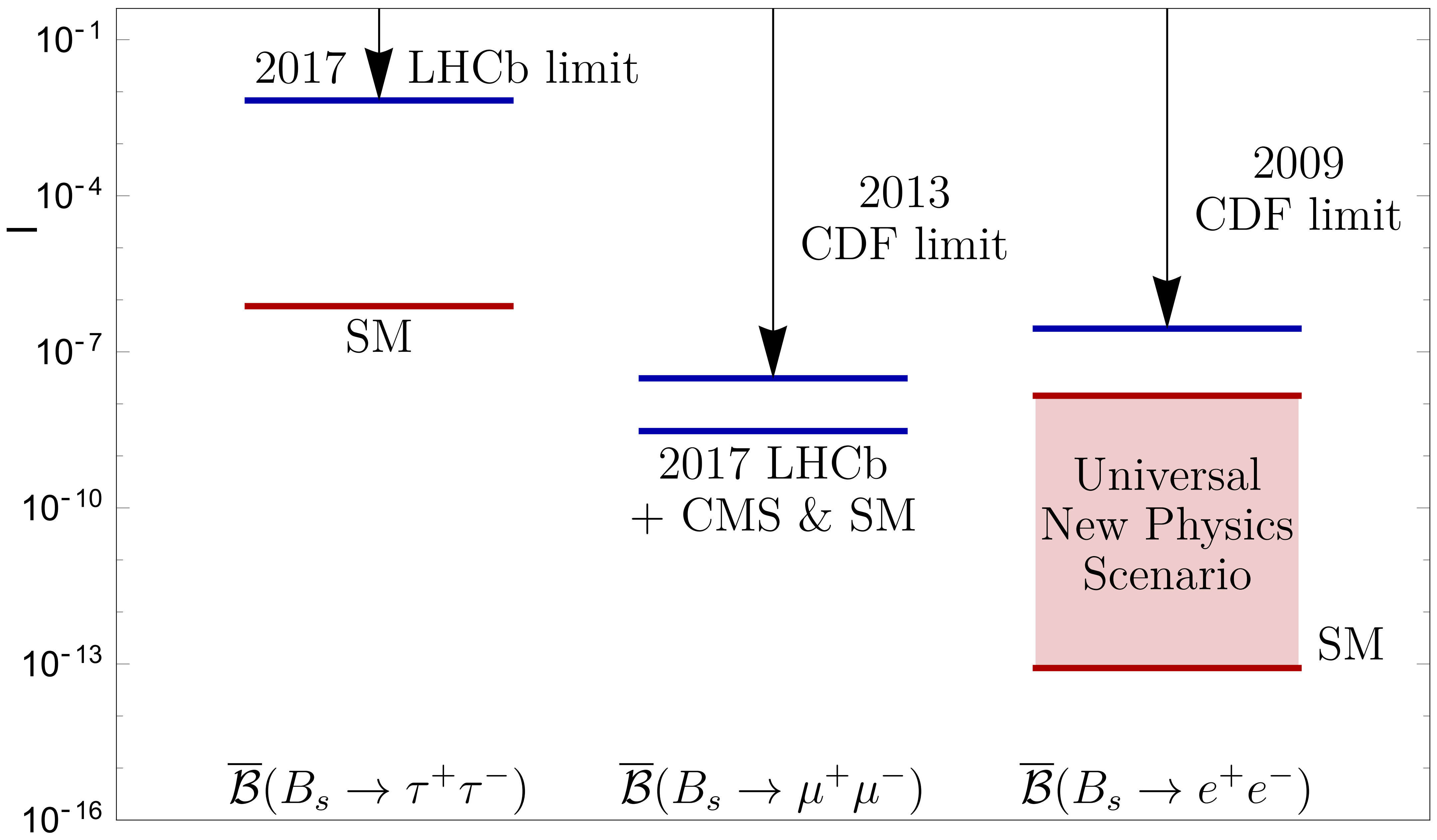
Search for $B^0_{(s)} \to e^+e^-$

- Very rare decays with clean prediction
  $\mathcal{O}(10^{-4})$ below $\mathcal{B}(B^0_{(s)} \to \mu^+\mu^-)$: **[Bobeth et al. JHEP 10 (2019) 232]**
  - $\mathcal{B}(B^0_s \to e^+e^-) = (8.60 \pm 0.36) \times 10^{-14}$
  - $\mathcal{B}(B^0 \to e^+e^-) = (2.41 \pm 0.13) \times 10^{-15}$

  → sensitive to NP processes not accessible in $B^0_{(s)} \to \mu^+\mu^-$
- Experimental bounds from CDF: **[PRL 102 (2009) 201801]**
  - $\mathcal{B}(B^0_s \to e^+e^-) < 2.8 \times 10^{-7}$ at 90% CL
  - $\mathcal{B}(B^0 \to e^+e^-) < 8.3 \times 10^{-8}$ at 90% CL

  → close to potential (pseudo) scalar NP scenarios explaining $b \to s\ell\ell$ deviations

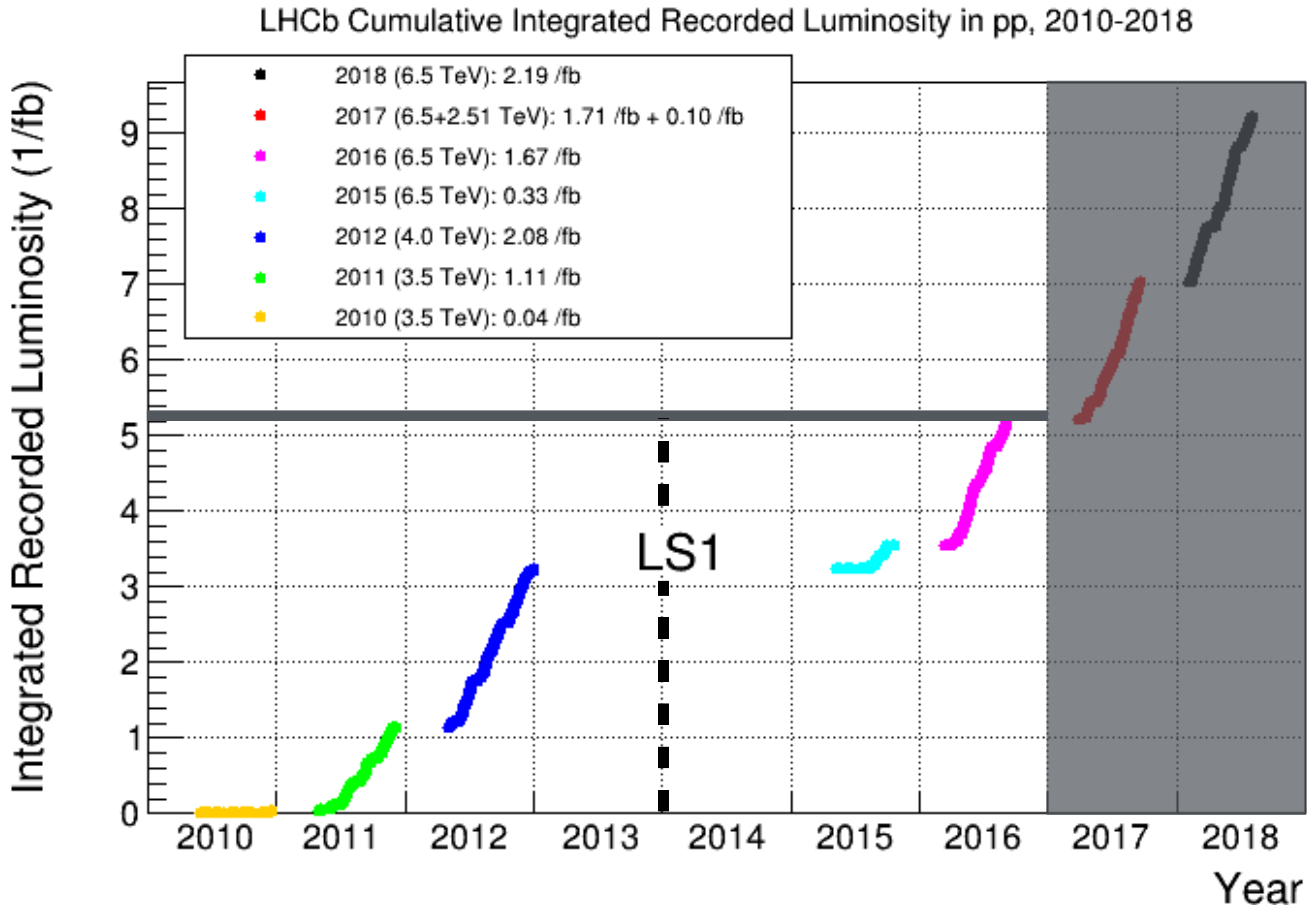
[Fleischer et al., JHEP 05 (2017) 156]



arXiv 2003.03999

Search strategy

- LHCb data taken in 2011/12 (Run 1) and 2015/16 (Run 2) → Luminosity $\mathscr{L} \approx 5\,\text{fb}^{-1}$
- Split analysis by Run 1/2
  - Different center-of-mass energies (7/8 vs. 13 TeV)
  - Different data taking conditions
- Measurement relative to $\mathscr{B}\left(B^+ \to (J/\psi \to e^+e^-)K^+\right)$:
  - Cancelling large uncertainties of $\sigma(b\bar{b})$
  - Cancelling potential systematic effects in electron reconstruction and selection

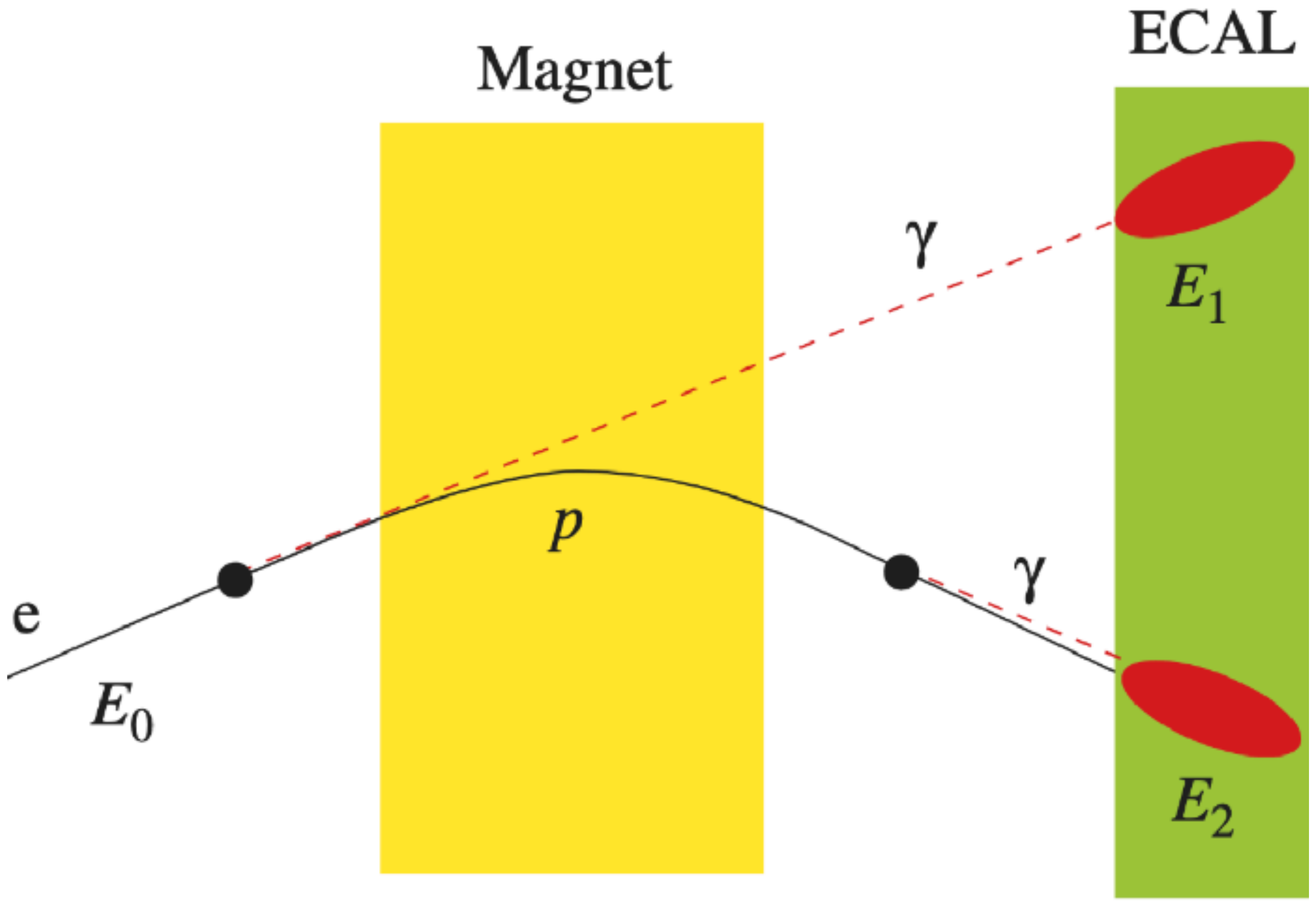


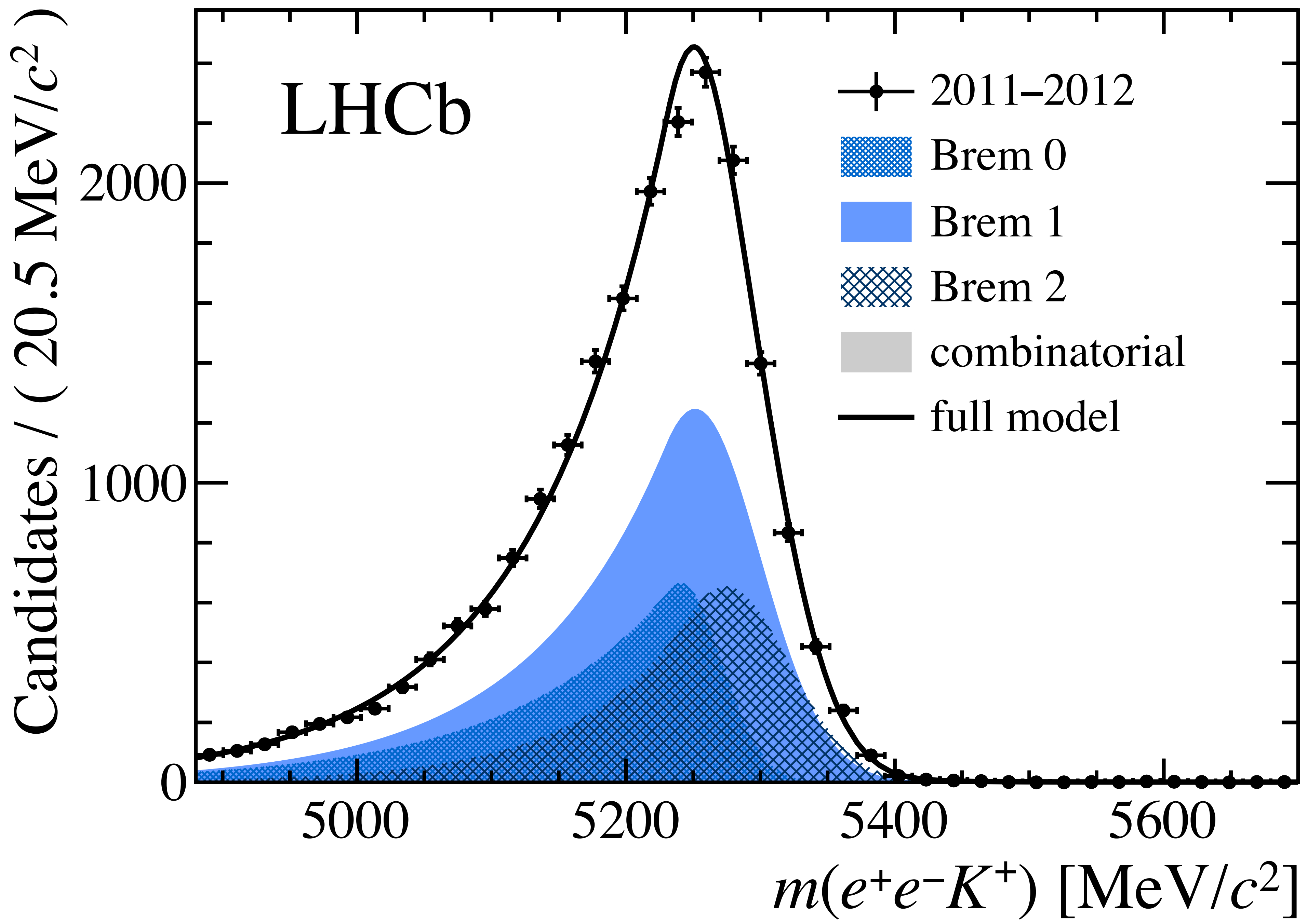
arXiv 2003.03999

Bremsstrahlung correction

- Electrons emit bremsstrahlung in the detector
  - Strong impact on track reconstruction and mass resolution
  - Photon momentum can often be reconstructed in the calorimeter
  - Associated to electron track upstream of the magnet
- Split analysis by bremsstrahlung correction
  - Brem 0/1/2: None, one or both electrons corrected
  - Increase sensitivity by splitting

    → Particle misidentification probability very small for electrons with correction





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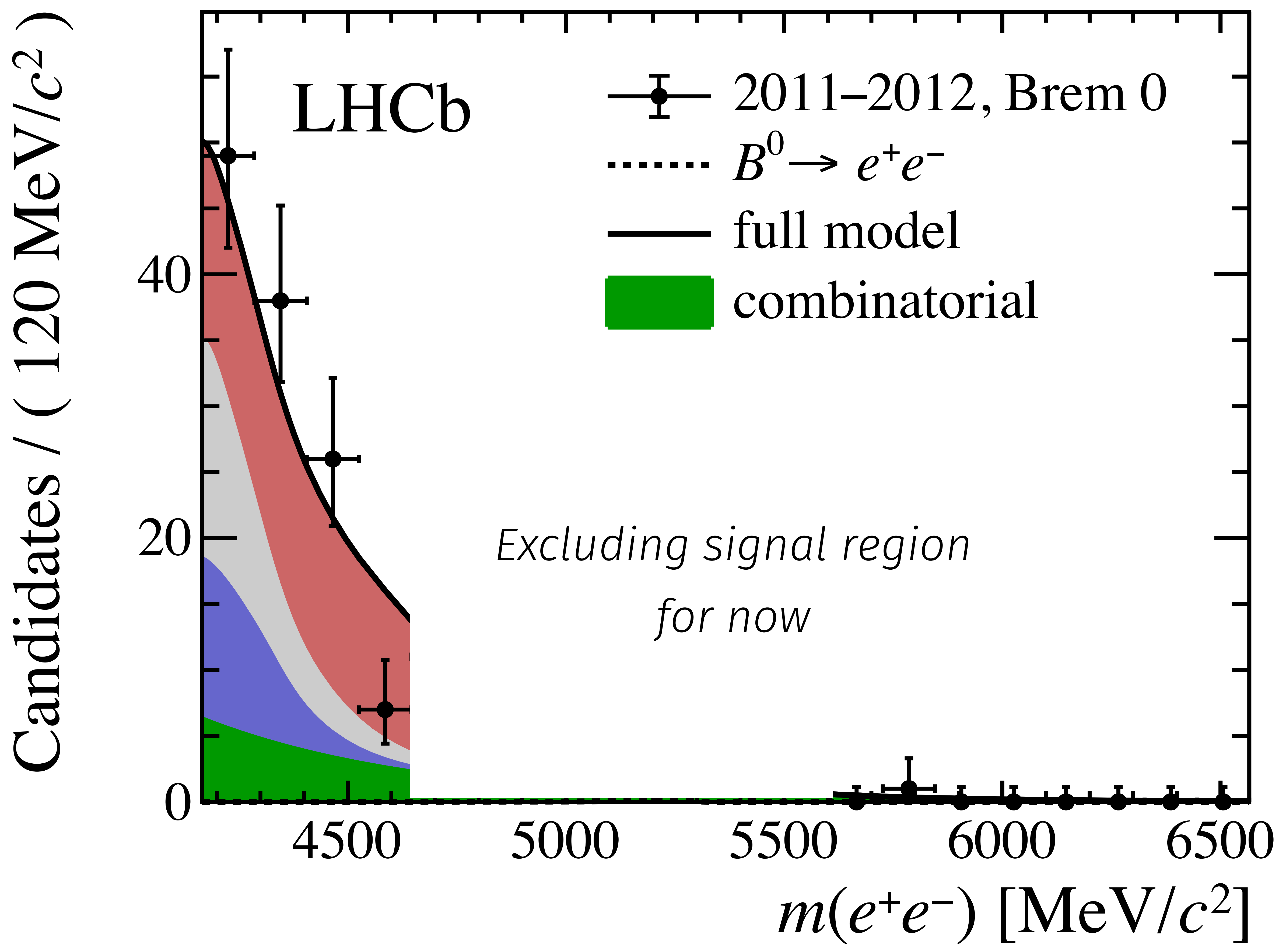
Background processes

Random track combinations removed with Boosted Decision Tree (BDT)
misID suppressed with particle identification criteria

- **Random track combinations** contribute little after BDT



arXiv 2003.03999

Background processes

Random track combinations removed with Boosted Decision Tree (BDT)
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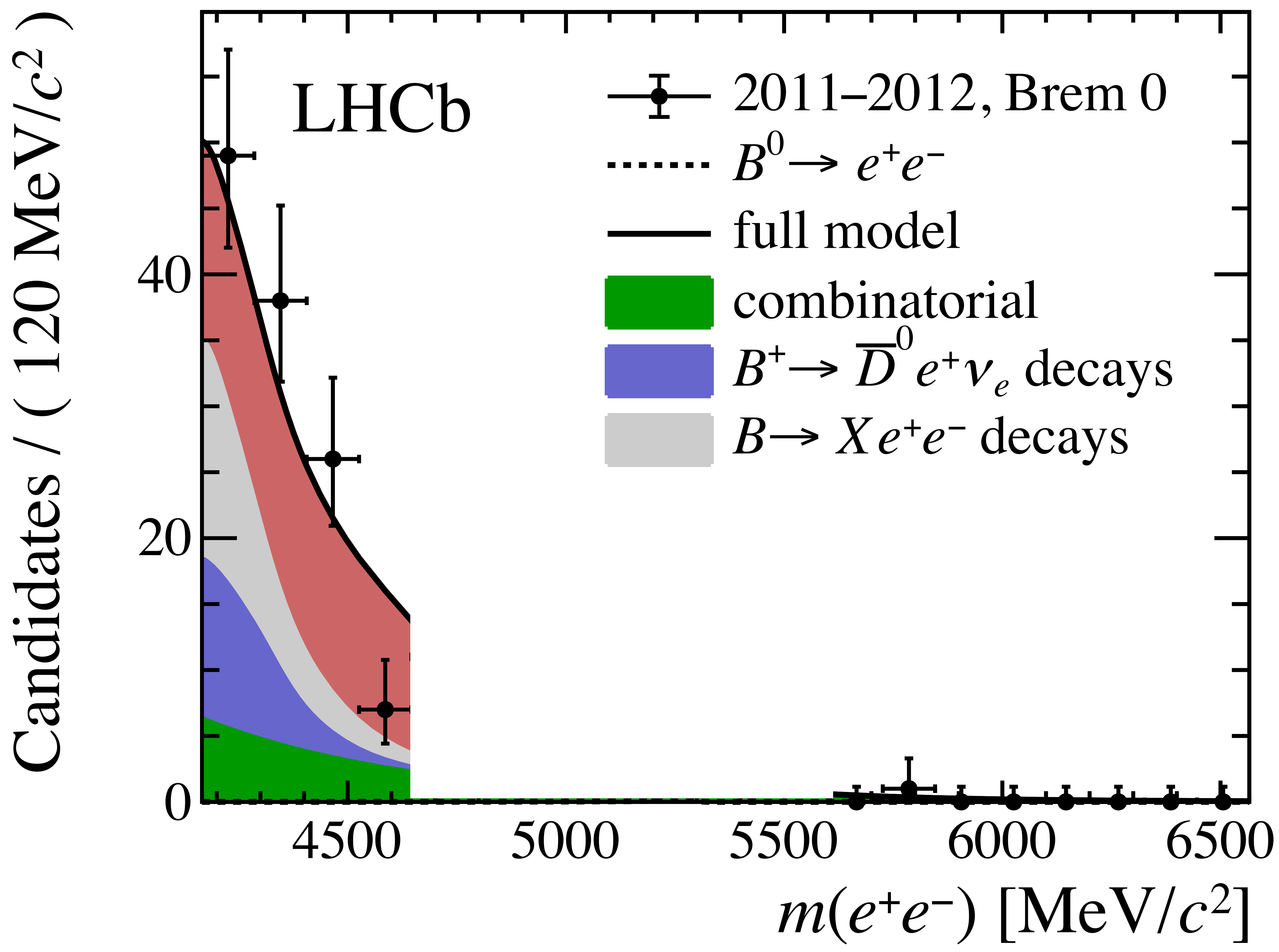
- **Random track combinations** contribute little after BDT
- **Partly reconstructed** backgrounds
  - $B \to X e^+ e^-$, $B^+ \to (\overline{D}^0 \to X^+ e^- \bar{\nu}_e) e^+ \nu_e$ ($X^{(+)}$ hadrons), $B_c^+ \to (J/\psi \to e^+ e^-) e^+ \nu_e$
  - Minor contributions in the signal region



arXiv 2003.03999

Background processes

Random track combinations removed with Boosted Decision Tree (BDT)
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- **Partly** **reconstructed** backgrounds
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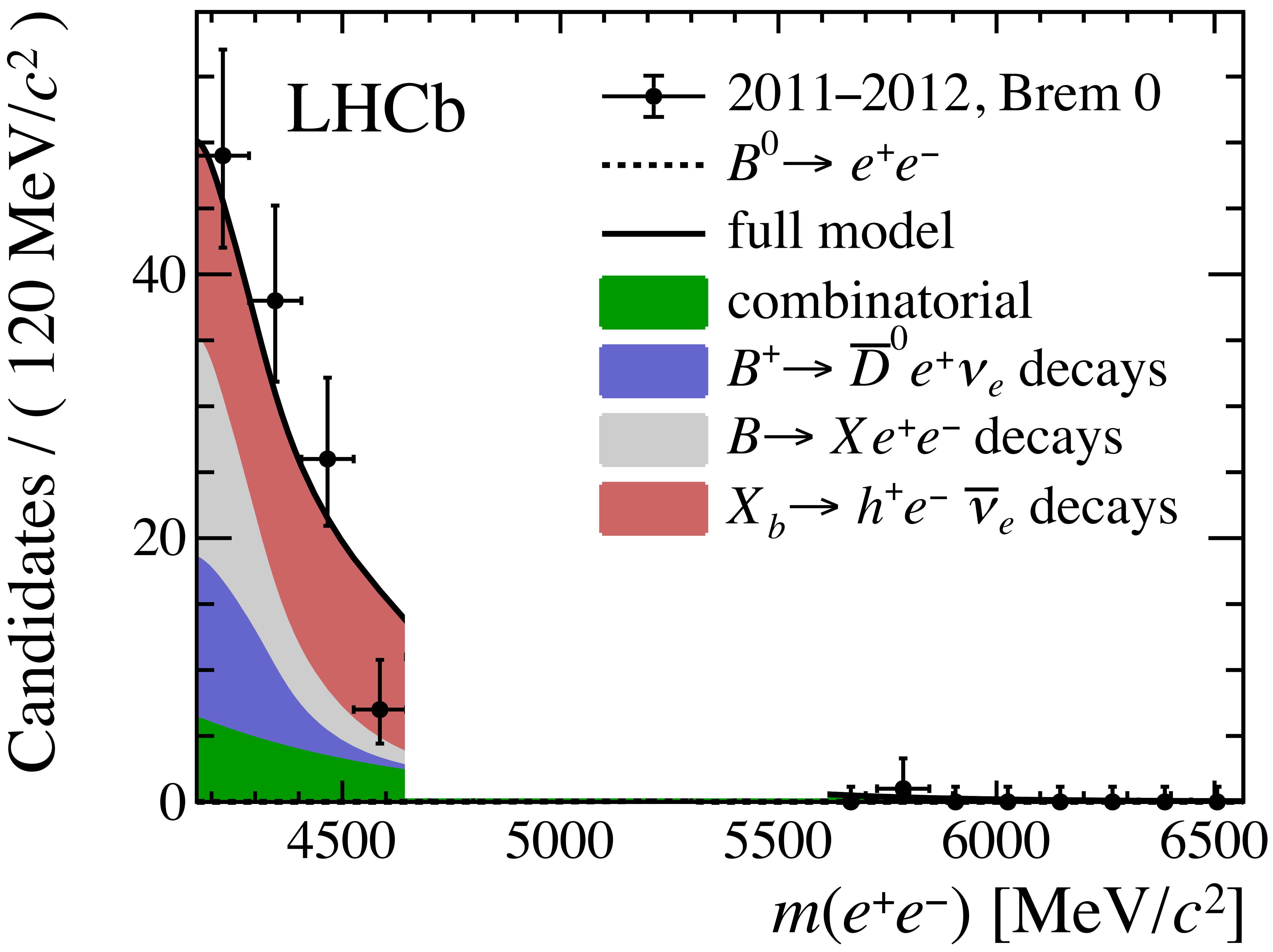
  - Minor contributions in the signal region
- Partly reconstructed backgrounds **with misidentification**
  - $B^0 \to \pi^+ e^- \bar{\nu}_e$, $B_s^0 \to K^+ e^- \bar{\nu}_e$, $\Lambda_b \to p e^- \bar{\nu}_e$
  - Suppressed by particle identification criteria
  - Peak in lower mass sideband



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Background processes

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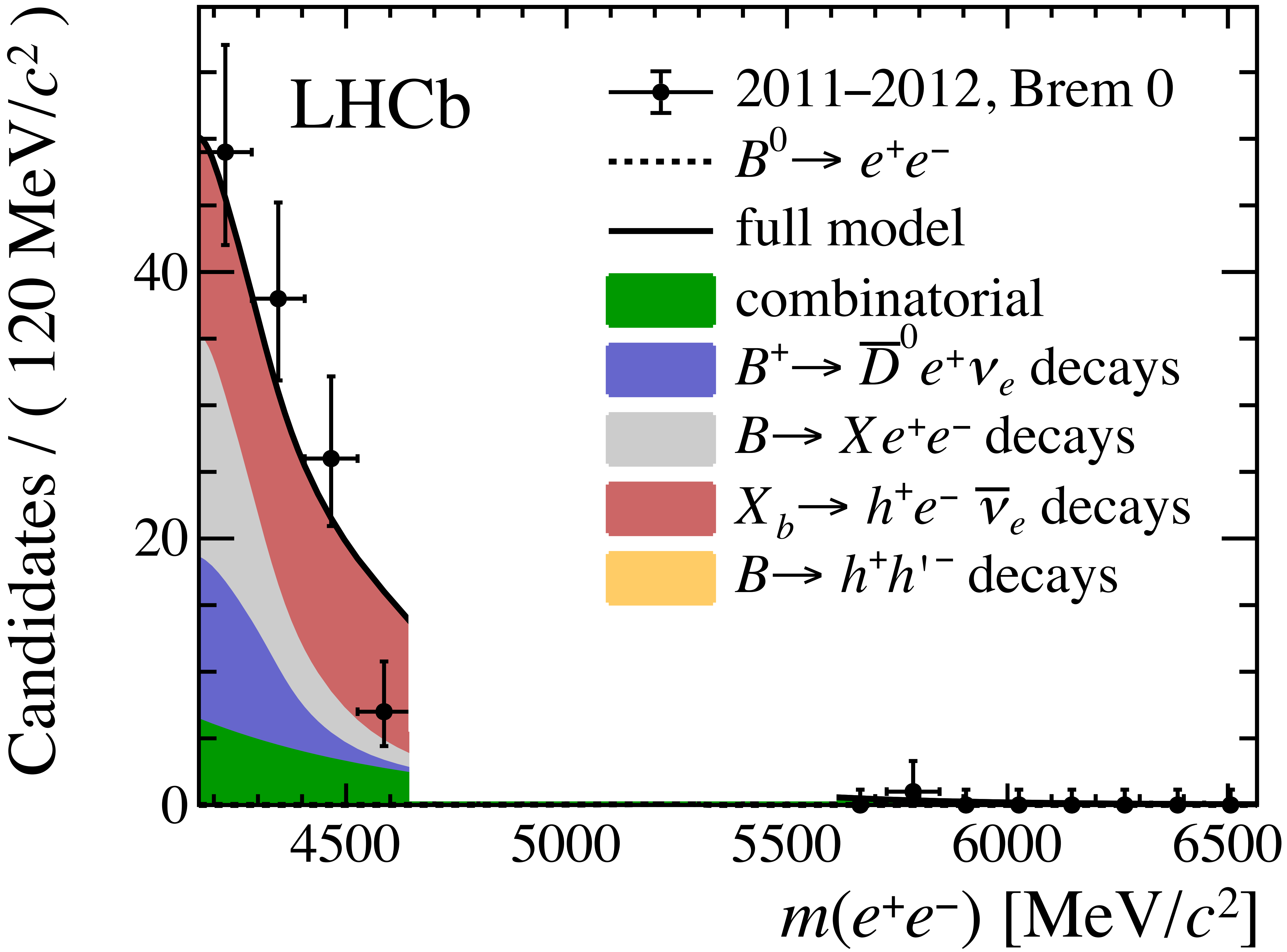
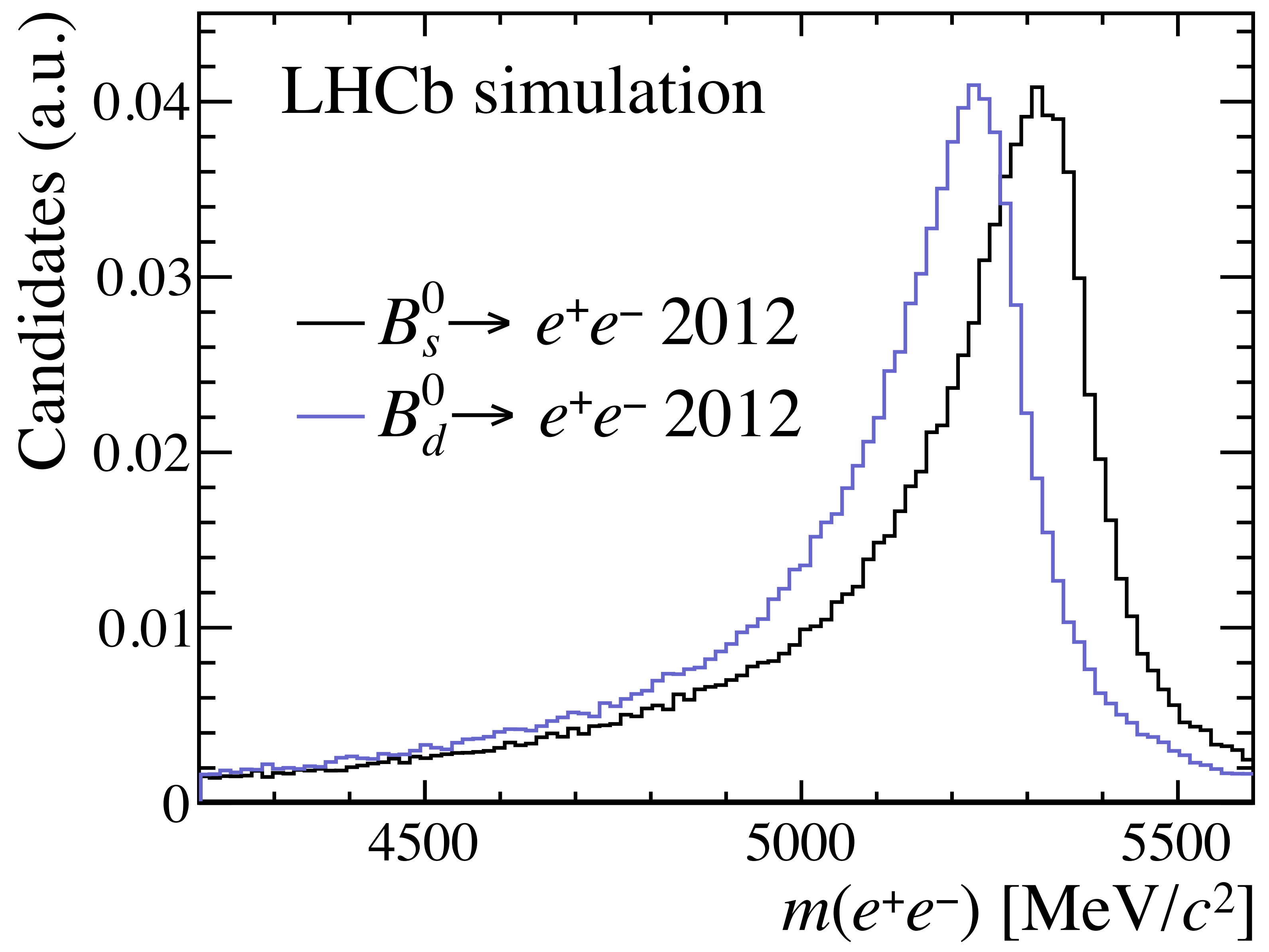
- **Random track combinations** contribute little after BDT
- **Partly reconstructed** backgrounds
  - $B \to X e^+e^-$, $B^+ \to (\overline{D}^0 \to X^+e^-\bar{\nu}_e)e^+\nu_e$ ($X^{(+)}$ hadrons), $B_c^+ \to (J/\psi \to e^+e^-)e^+\nu_e$
  - Minor contributions in the signal region
- Partly reconstructed backgrounds **with misidentification**
  - $B^0 \to \pi^+e^-\bar{\nu}_e$, $B_s^0 \to K^+e^-\bar{\nu}_e$, $\Lambda_b \to pe^-\bar{\nu}_e$
  - Suppressed by particle identification criteria
  - Peak in lower mass sideband
- **Doubly misidentified** backgrounds
  - $B^0 \to K^+\pi^-$, $B^0 \to \pi^+\pi^-$, $B_s^0 \to K^+K^-$ peak in signal region
  - Strongly suppressed by particle identification criteria
  - No bremsstrahlung emission (appear only in Brem 0)

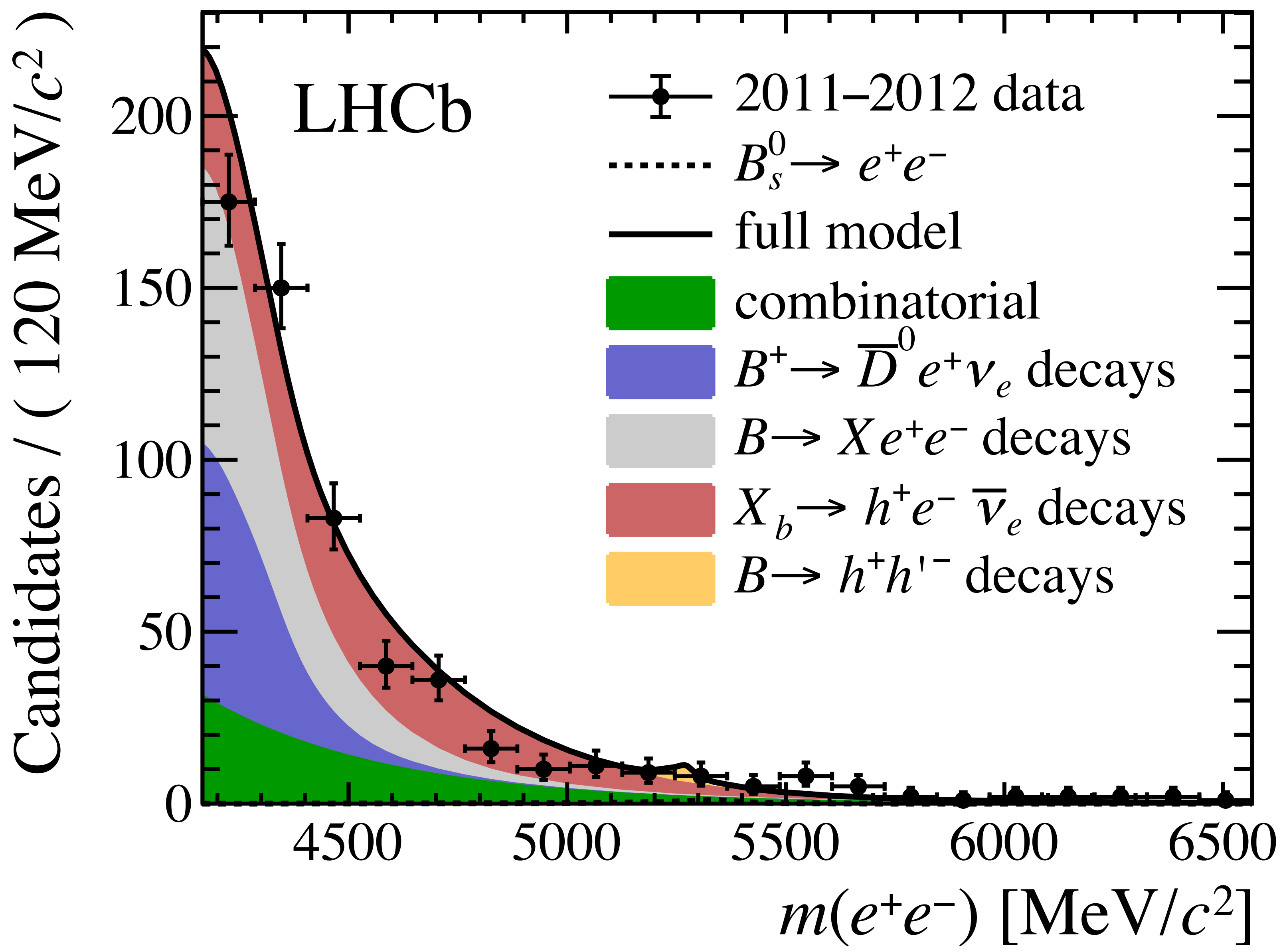


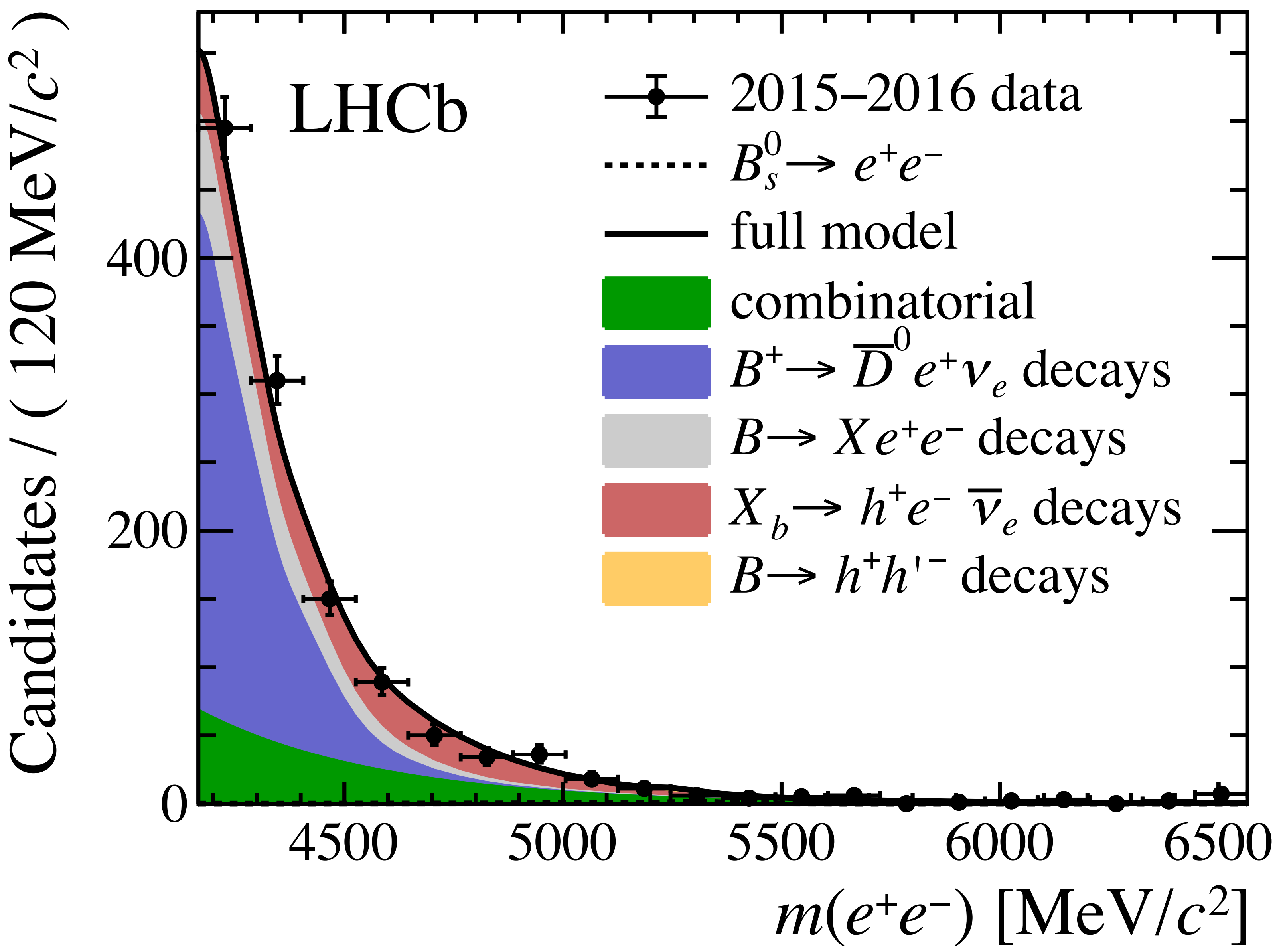
arXiv 2003.03999

Results

- Analysis statistically dominated
- Fit in 6 categories (brem. category and Run1/2)
- Due to low resolution cannot distinguish $B_s^0 \to e^+e^-$ from $B_d^0 \to e^+e^-$
- Fit for $B_s^0 \to e^+e^-$ while neglecting $B_d^0 \to e^+e^-$ and vice versa
- No signal excess found



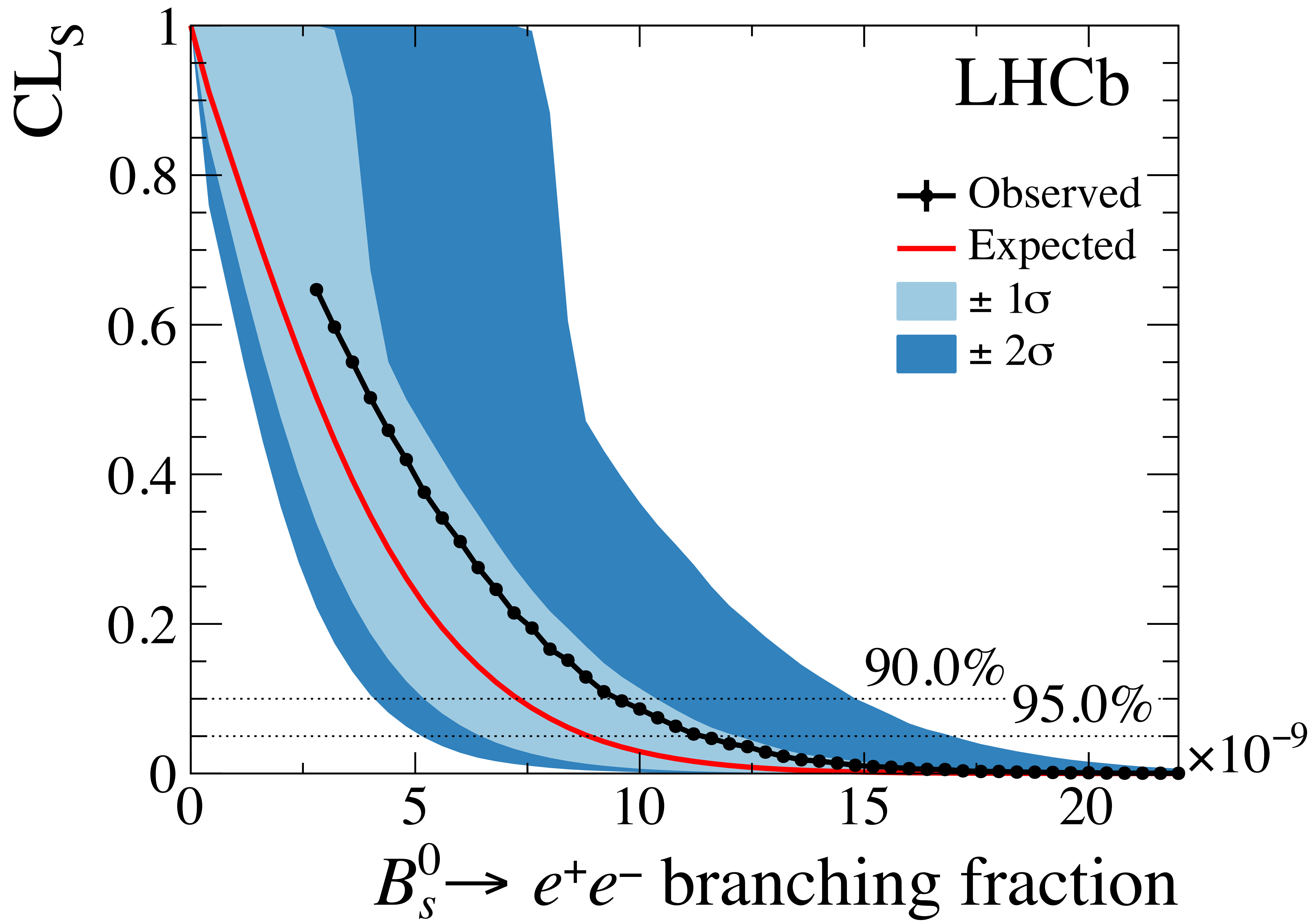




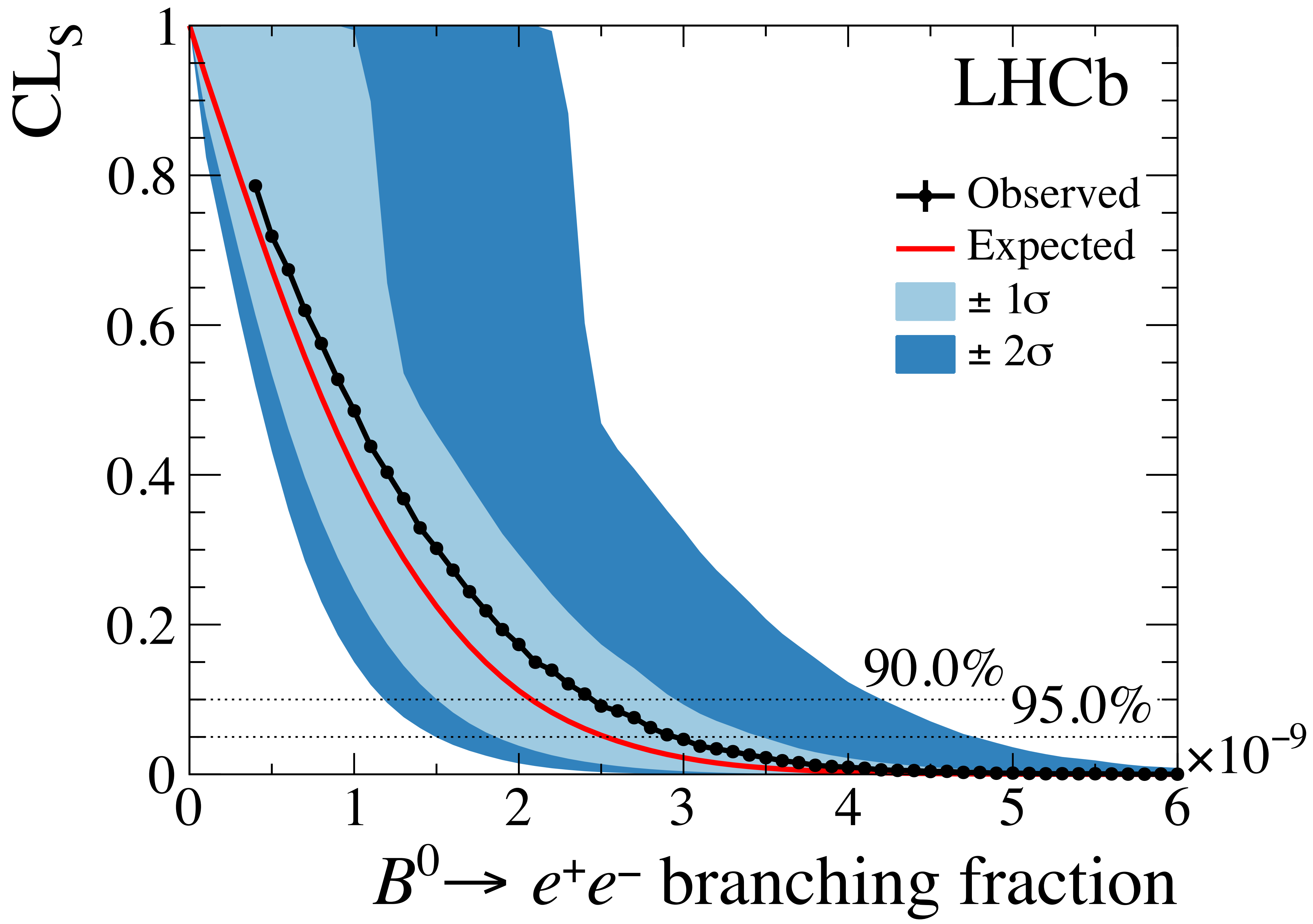
Upper limits

Fit $B_s^0 \to e^+e^-$ and $B^0 \to e^+e^-$ separately

$\mathcal{B}(B_s^0 \to e^+e^-) < 9.4 \times 10^{-9}$ at 90% CL



$\mathcal{B}(B^0 \to e^+e^-) < 2.5 \times 10^{-9}$ at 90% CL



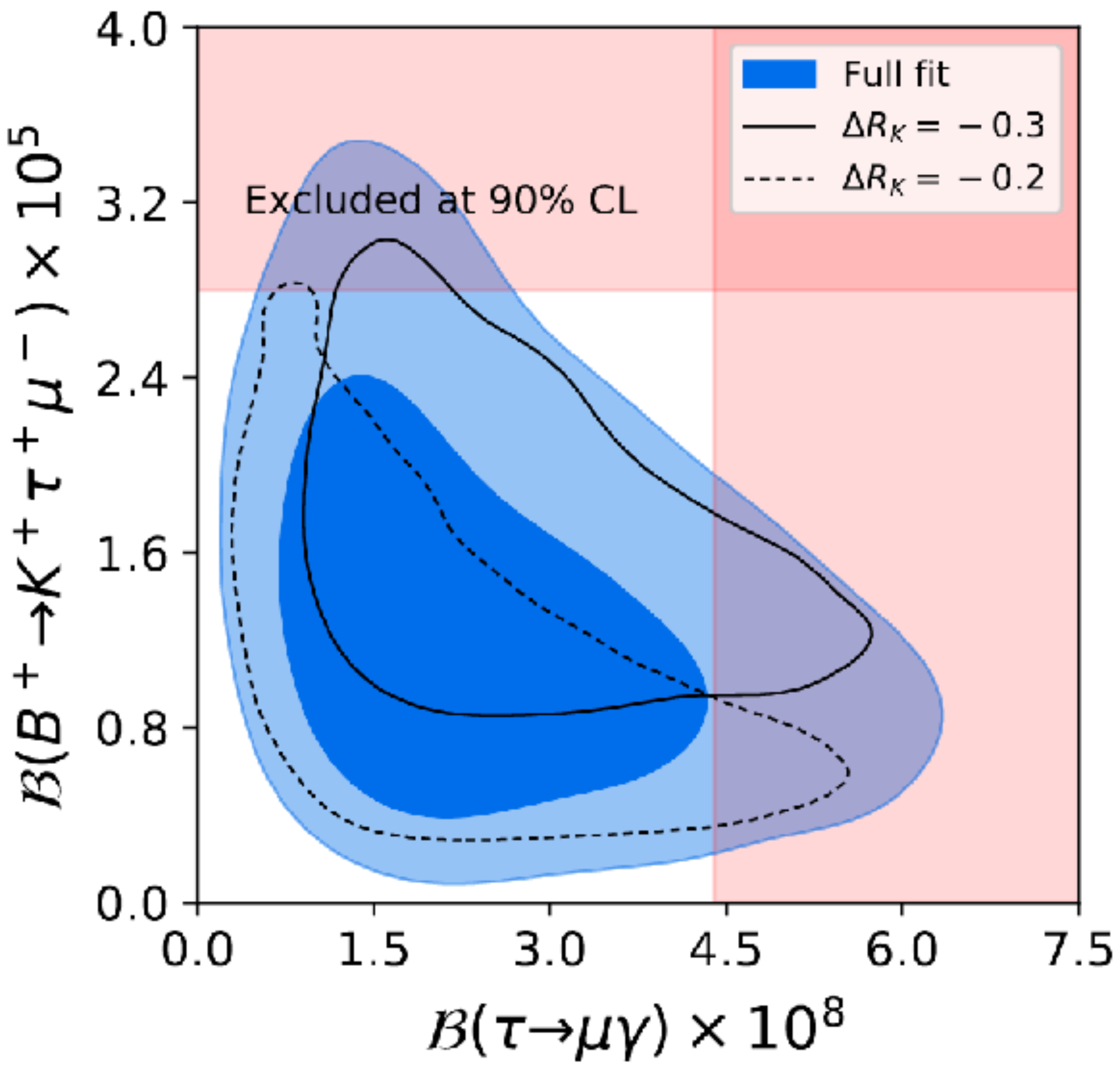
30x more sensitive than CDF limits!

arXiv 2003.04352

Search for $B^+ \to K^+\mu^-\tau^+$

- Hints for Lepton Flavour Universality breaking in $b \to s\ell\ell$ (R_K, $R_{K^{*0}}$) and $b \to c\ell\nu$ transitions (R_D, R_{D^*})
- If Lepton Flavour Universality broken, there will be Lepton Flavour violating decays!
  (Leptoquarks, Z', Extended Higgs, little Higgs, SUSY, ...)
- Current limit: $\mathscr{B}(B^+ \to K^+\mu^-\tau^+) < 2.8 \times 10^{-5}$ @90% CL

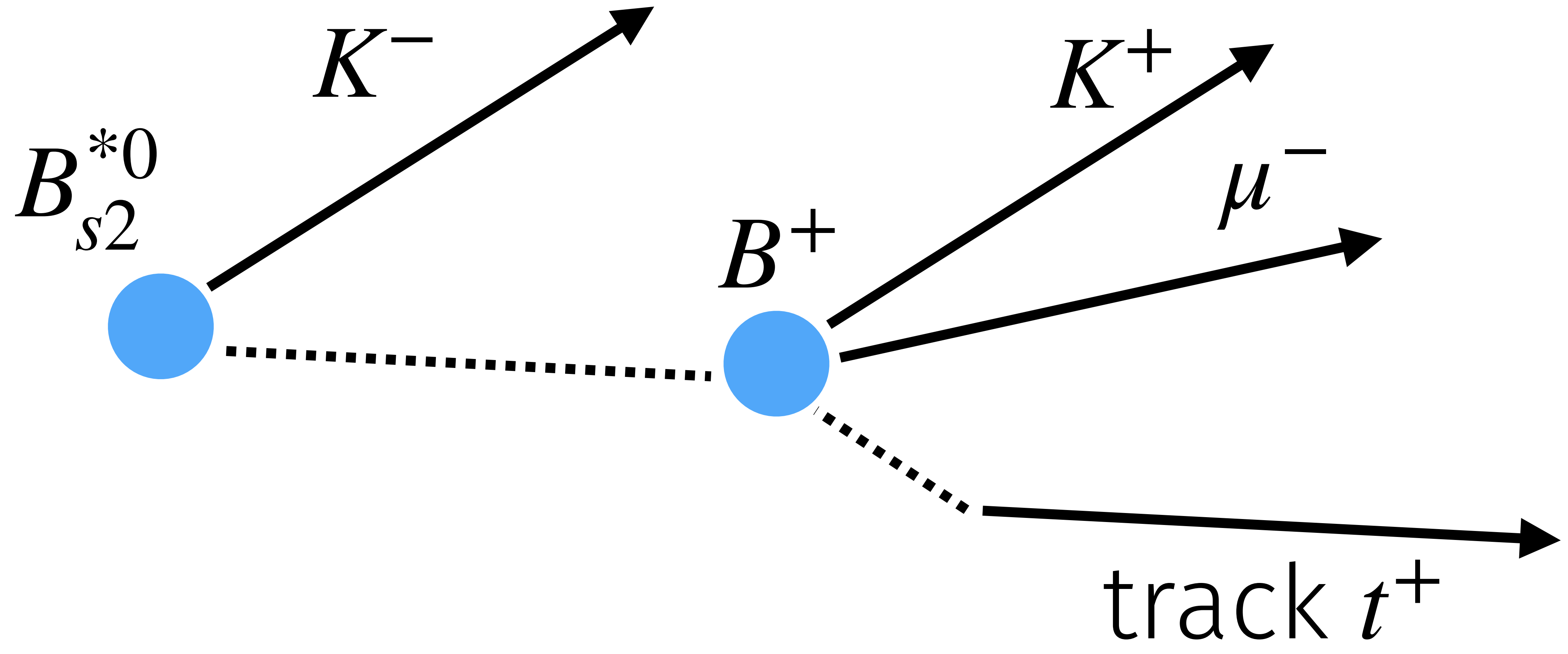
[BaBar: PRD 86, 012004]



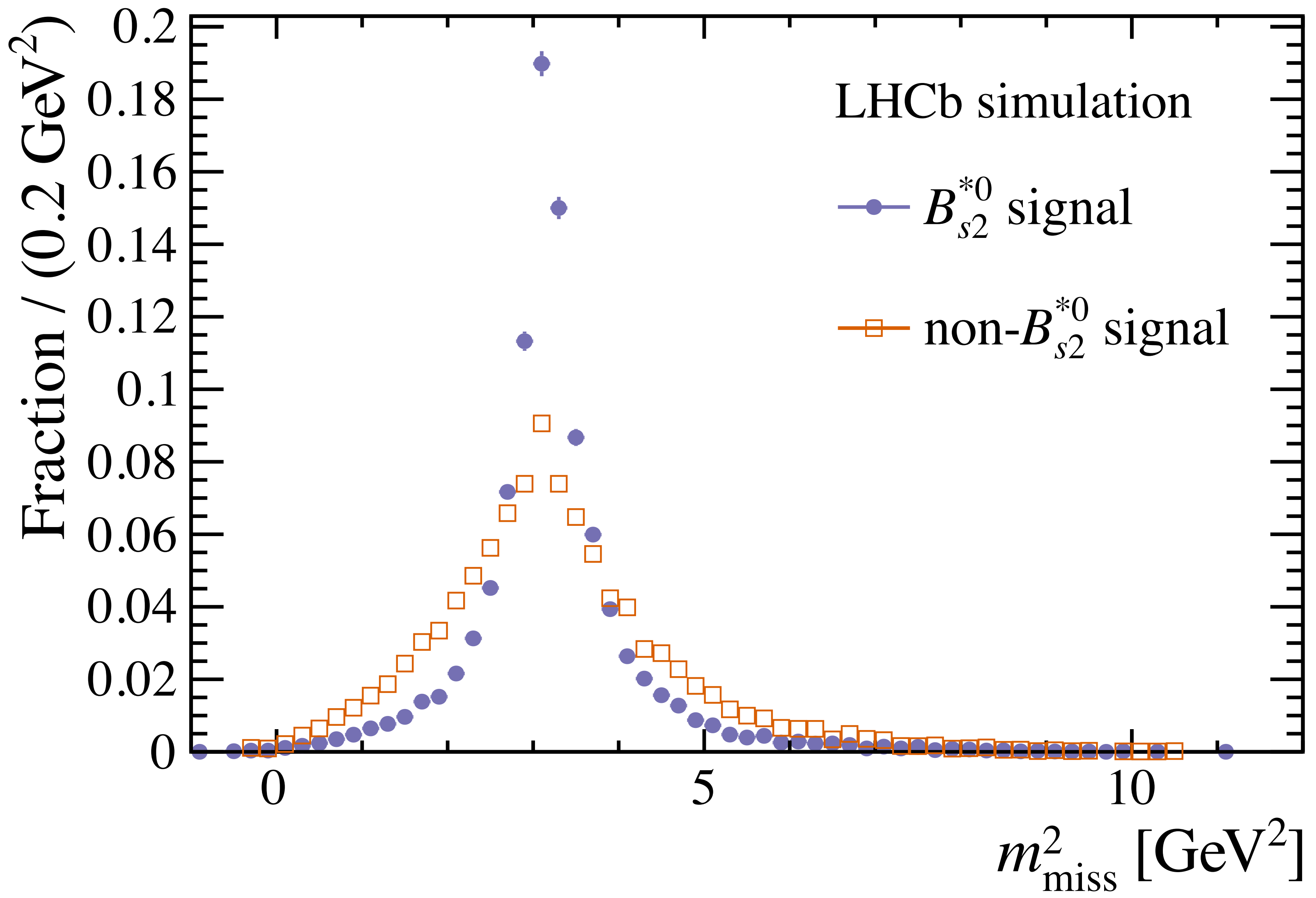
Example model: three-site Pati-Salam [Bordone et al.: PLB 779 (2018) 317; JHEP 1810 (2018) 148]

arXiv 2003.04352

Search for $B^+ \to K^+\mu^-\tau^+$ using B_{s2}^{*0} decays



- Problem: τ reconstruction difficult due to missing ν
- Idea: tag B^+ mesons with $B_{s2}^{*0} \to B^+K^-$ (rate ~1%)
  - Use B_{s2}^{*0}, K^- and B^+ constraints
  - Can compute $m_{miss}^2 \approx m_\tau^2$
  - Find ~4300 events in normalisation mode $B^+ \to J/\psi(\mu^+\mu^-)K^+$
- Inclusive τ reconstruction: one track $t + X$
  - Remove $B^+ \to K^+[c\bar{c}](\mu^+\mu^-)$ by $m(K^+\mu^-t^+)_{t=\mu} < 4.8$ GeV
- Use the full LHCb data set

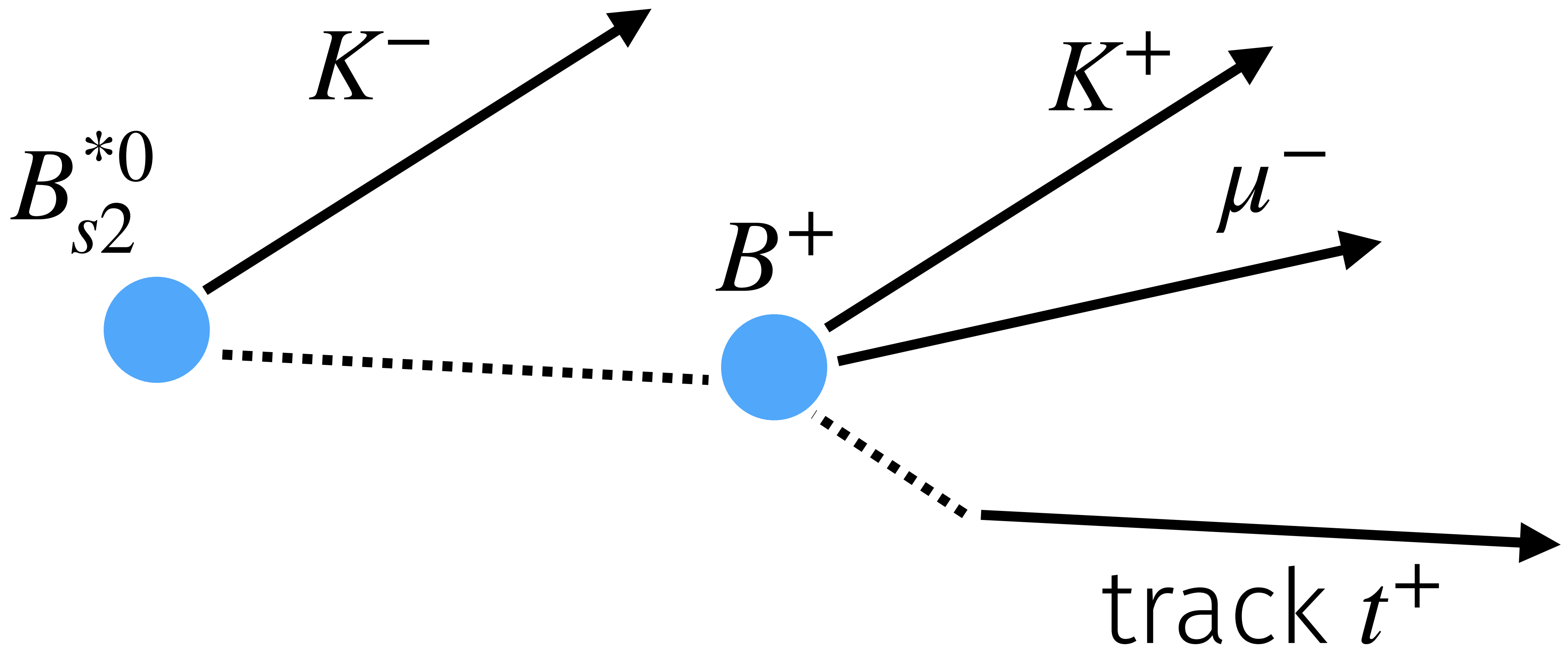


Disregard $B^+ \to K^+\mu^+\tau^-$ due to large backgrounds from $B^+ \to \overline{D}X\mu^+\nu_\mu$ decays

arXiv 2003.04352

Selection

- Multivariate selection (BDT) using
  - Decay topology
  - Two-body kinematics
  - τ flight distance
- Backgrounds dominantly semileptonic:
  - $B^+ \to \overline{D}^0(K^+\mu^-\bar{\nu}_\mu)X$
  - No peaking background with $m^2_{miss} \approx m^2_\tau$



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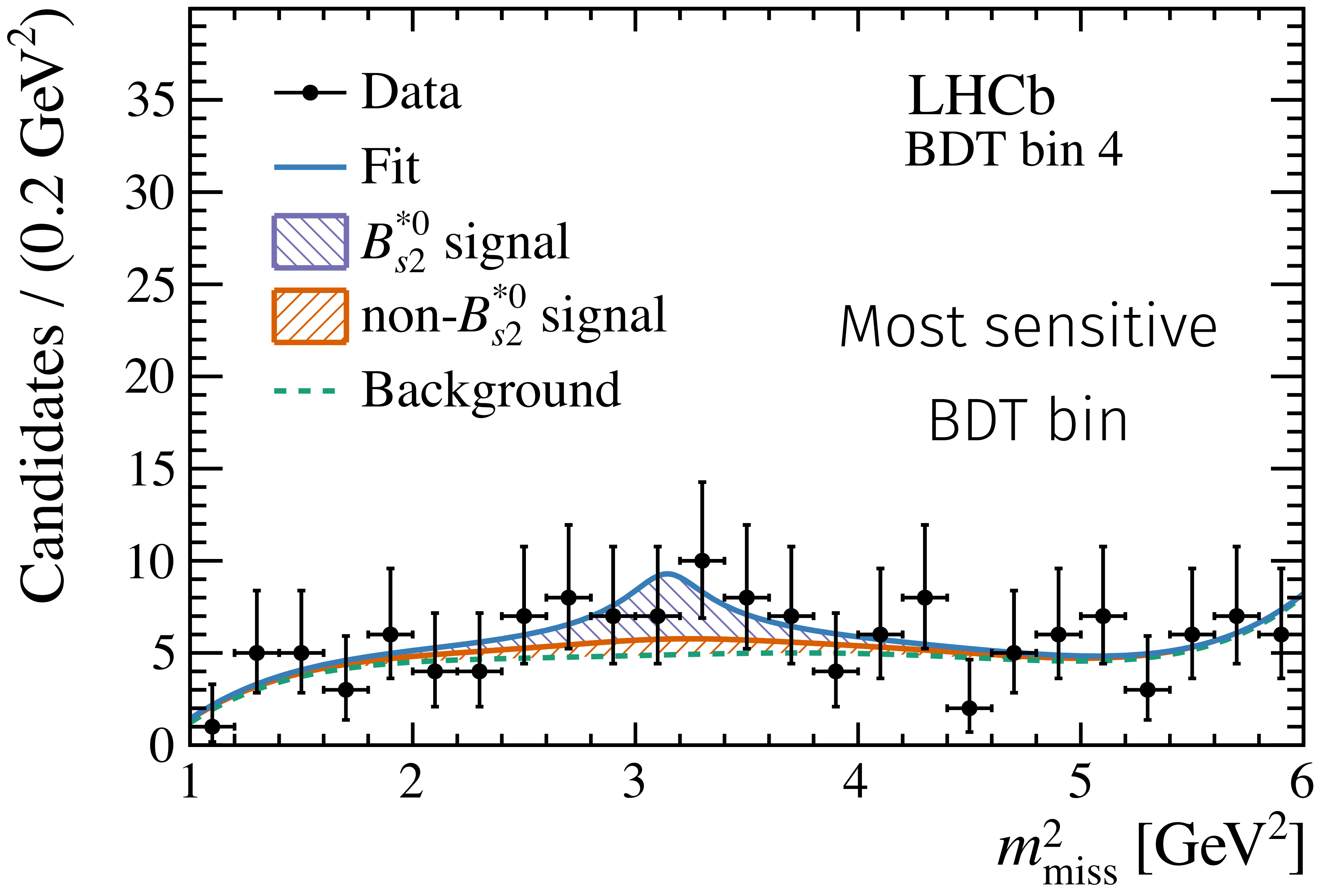
Results

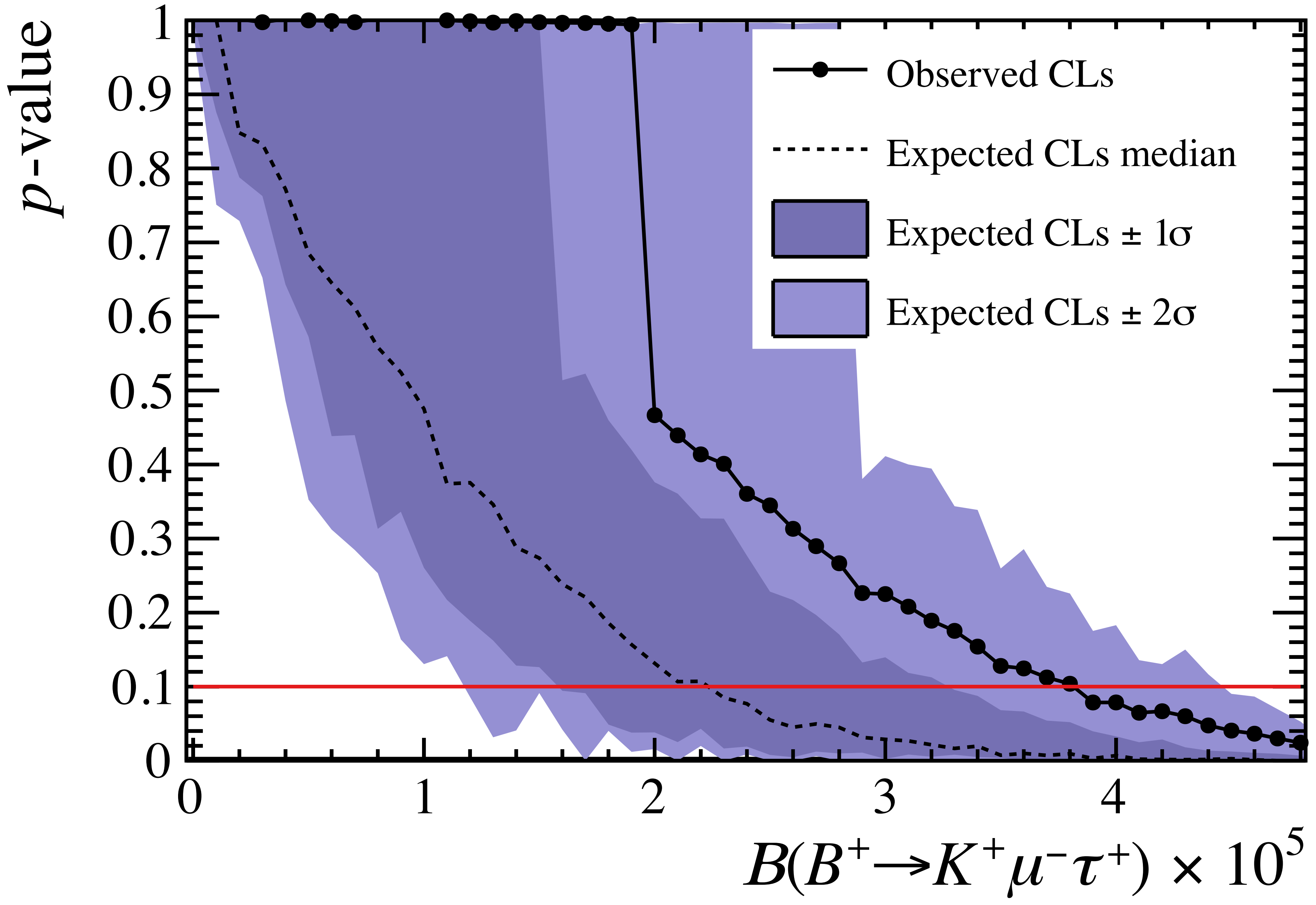
$\mathcal{B}(B^+ \to K^+\mu^-\tau^+) = (1.9 \pm 1.5) \times 10^{-5}$

compatible with zero

- Analysis statistically dominated
- Fit to data in 4 bins of BDT output
- $\mathcal{B}(B^+ \to K^+\mu^-\tau^+) < 3.9 \times 10^{-5}$ @ 90% CL close to BaBar limit



Most sensitive BDT bin



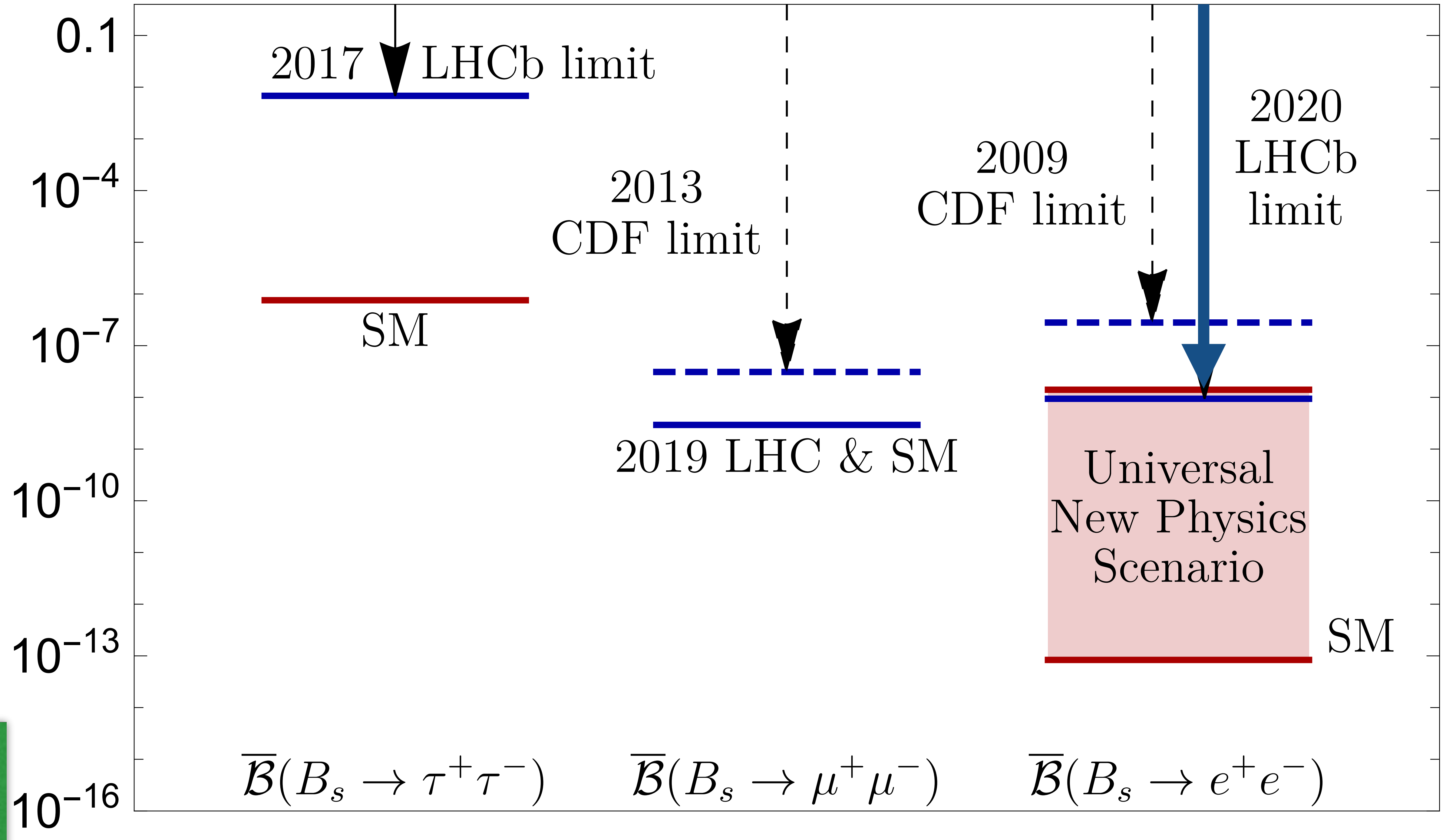
New method established: competitive limits already with current data set

Summary

New results presented today

- Limits on $\mathscr{B}(B^0_{(s)} \to e^+e^-)$ improve by 30x: Constrain universal (pseudo) scalar NP scenarios
- New approach to reconstruct $B^+ \to K^+\mu^-\tau^+$ from B^{*0}_{s2} decays competitive to current limits!

[Fleischer et al., JHEP 05 (2017) 156]



- Still 2x more data on tape than analysed for $B^0_{(s)} \to e^+e^-$
- Exciting future with LHCb Upgrade!

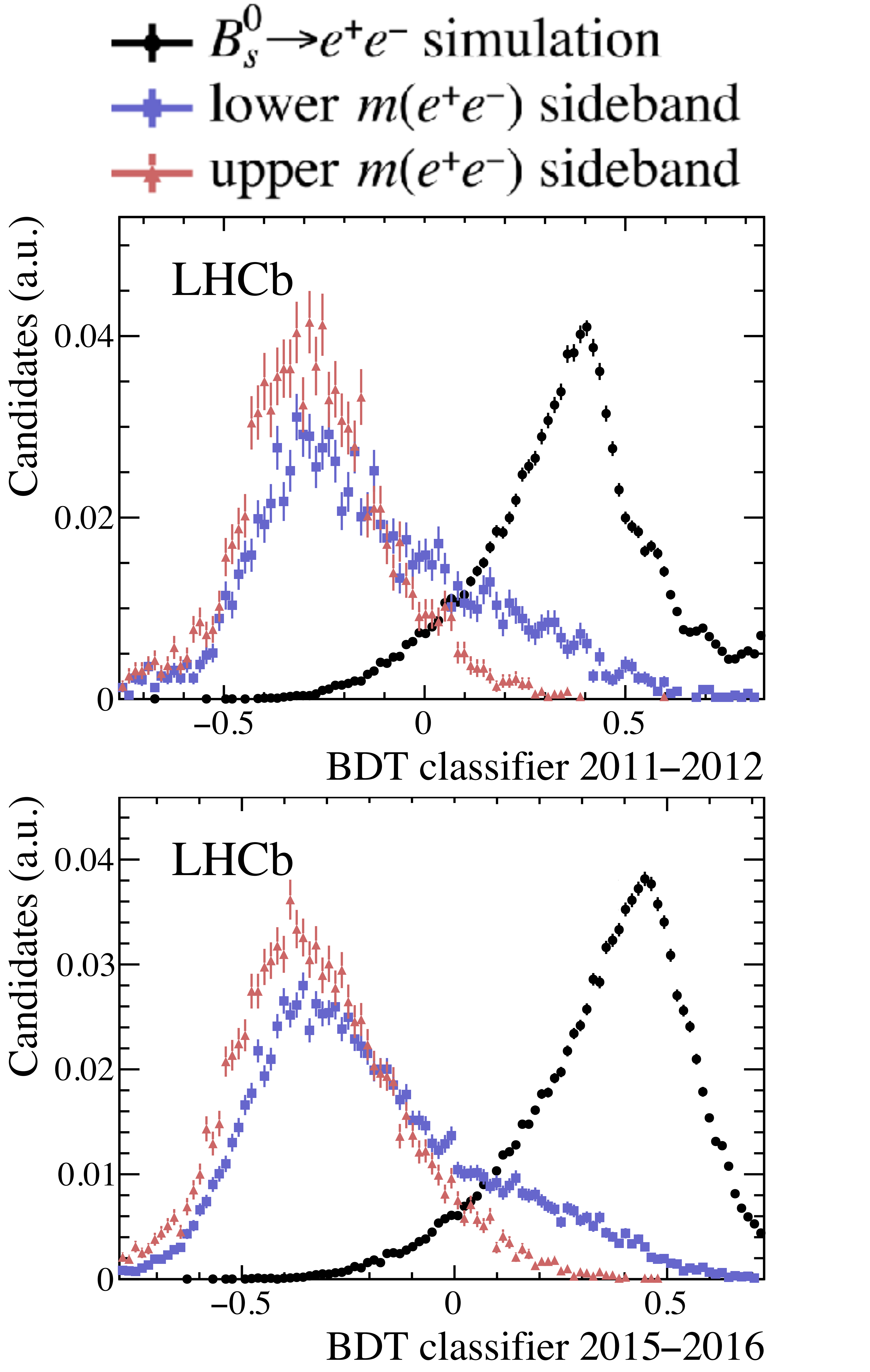
Also hope for contributions from Belle 2, CMS, ATLAS!

Thank you!

arXiv 2003.03999

Selection of $B^0_{(s)} \to e^+e^-$ candidates

- Suppress misidentification
  - Stringent particle identification requirements
  - Only electrons emit bremsstrahlung
- Reduce random track combinations with Decision Tree (BDT)
  - Train $B^0_s \to e^+e^-$ simulation vs. upper $m(e^+e^-)$ sideband
  - Vertex and track isolation criteria
  - B kinematics
  - Decay topology



arXiv 2003.03999

Systematic uncertainties of $B^0_{(s)} \to e^+e^-$ analysis

- Analysis is statistically dominated → systematic effects negligible
- Dominant systematic uncertainties (differ by year and bremsstrahlung category):
  - b-hadron fragmentation fraction ratio f_s/f_d → 5.8%
  - Data driven trigger and particle identification efficiency estimation → up to 5.3%
  - Uncertainty on the background estimates in the signal region → 14%

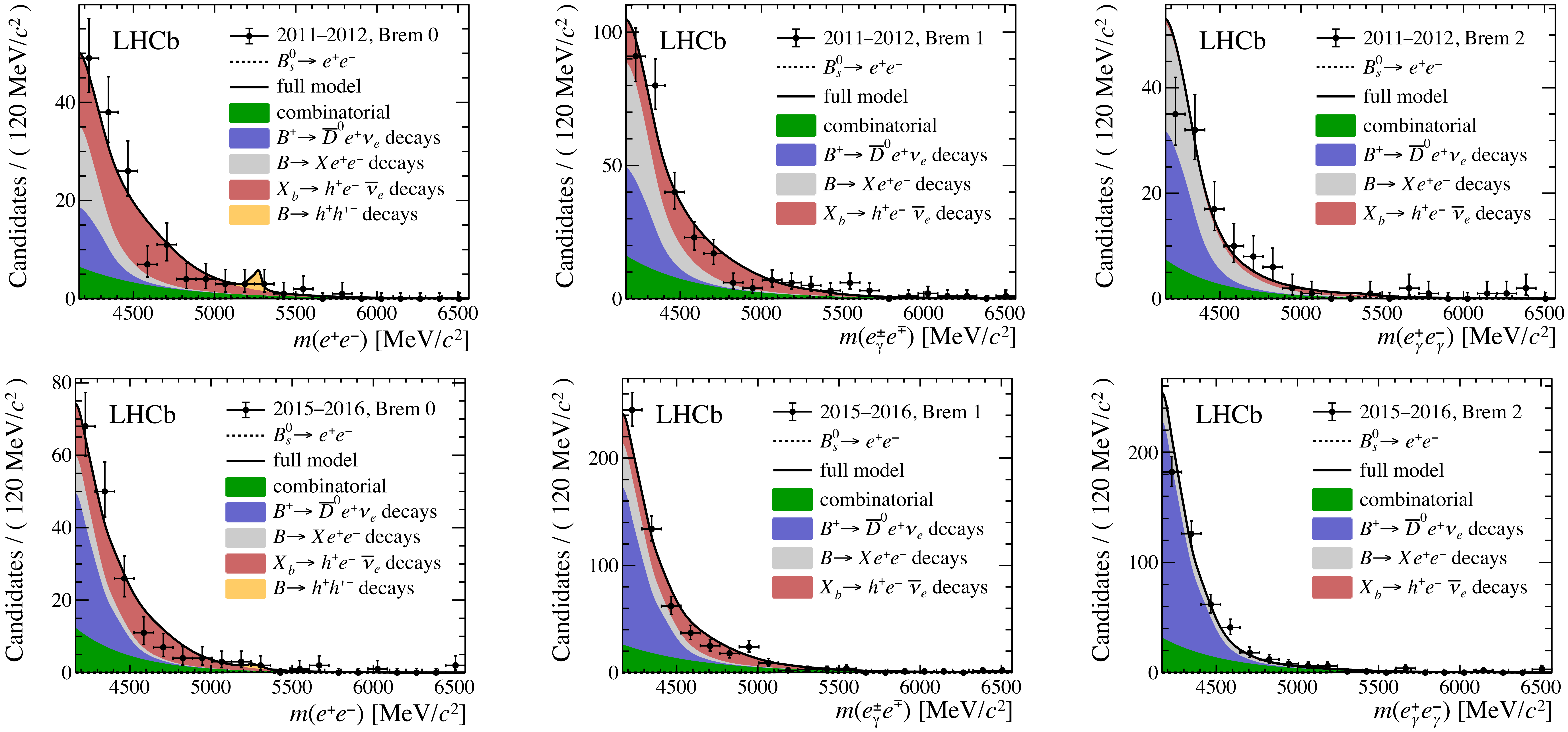
Neglecting $B^0 \to e^+e^-$

Branching fraction $\mathscr{B}(B_s^0 \to e^+e^-) = (2.4 \pm 4.4) \times 10^{-9}$

Brem 0 **Brem 1** **Brem 2**

Run 1

Run 2



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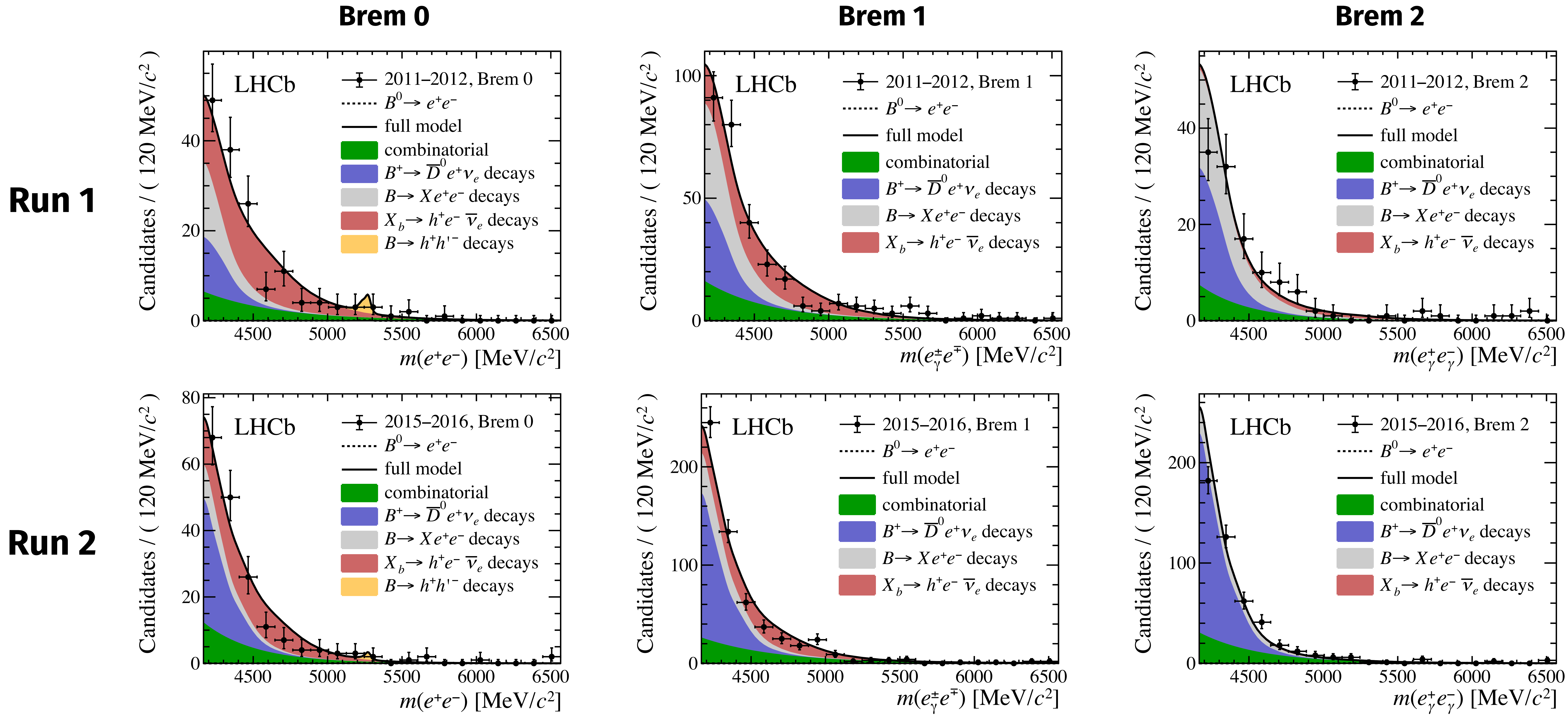
Branching fraction $\mathcal{B}(B^0 \to e^+e^-) = (0.30 \pm 1.29) \times 10^{-9}$



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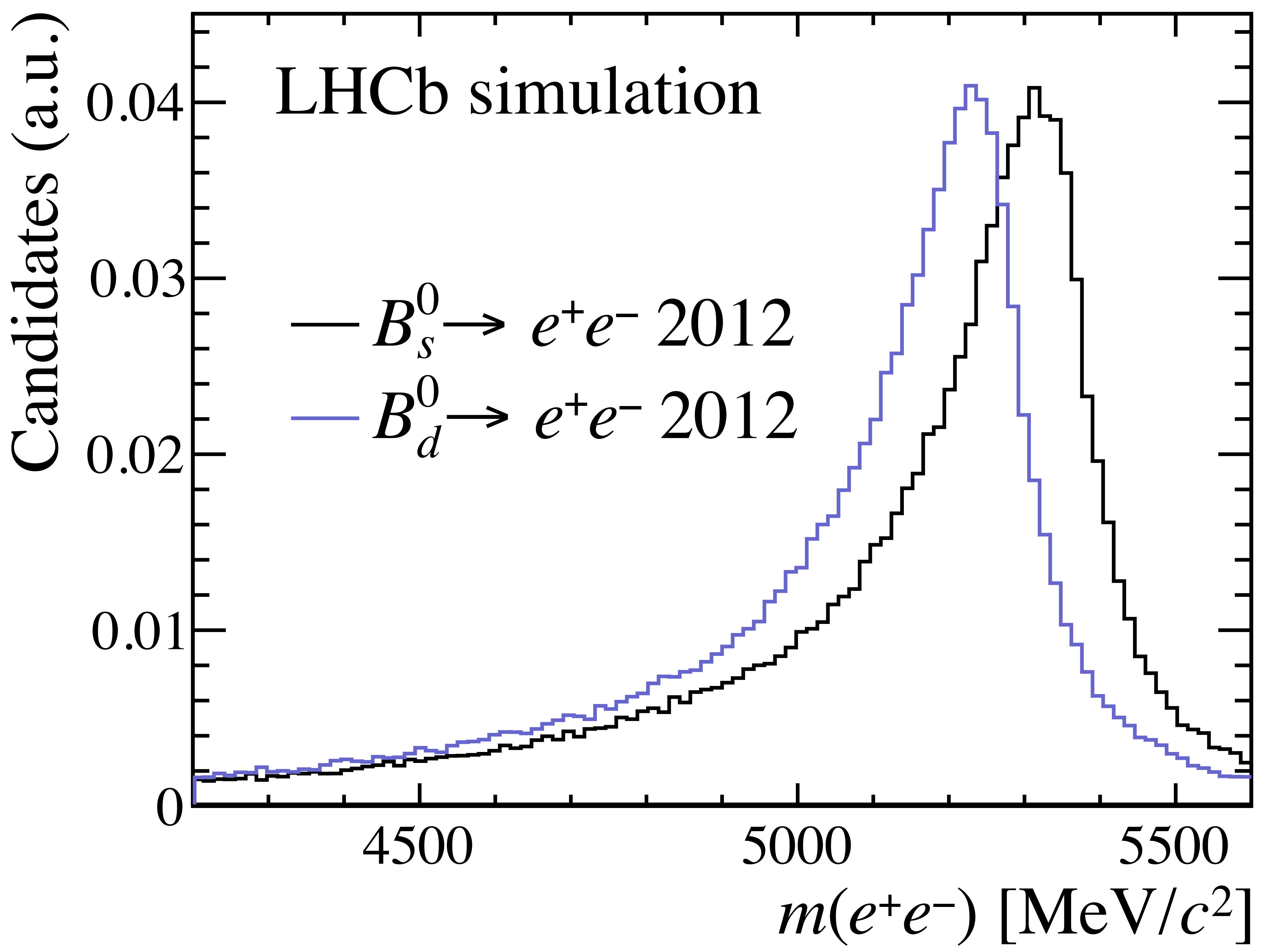
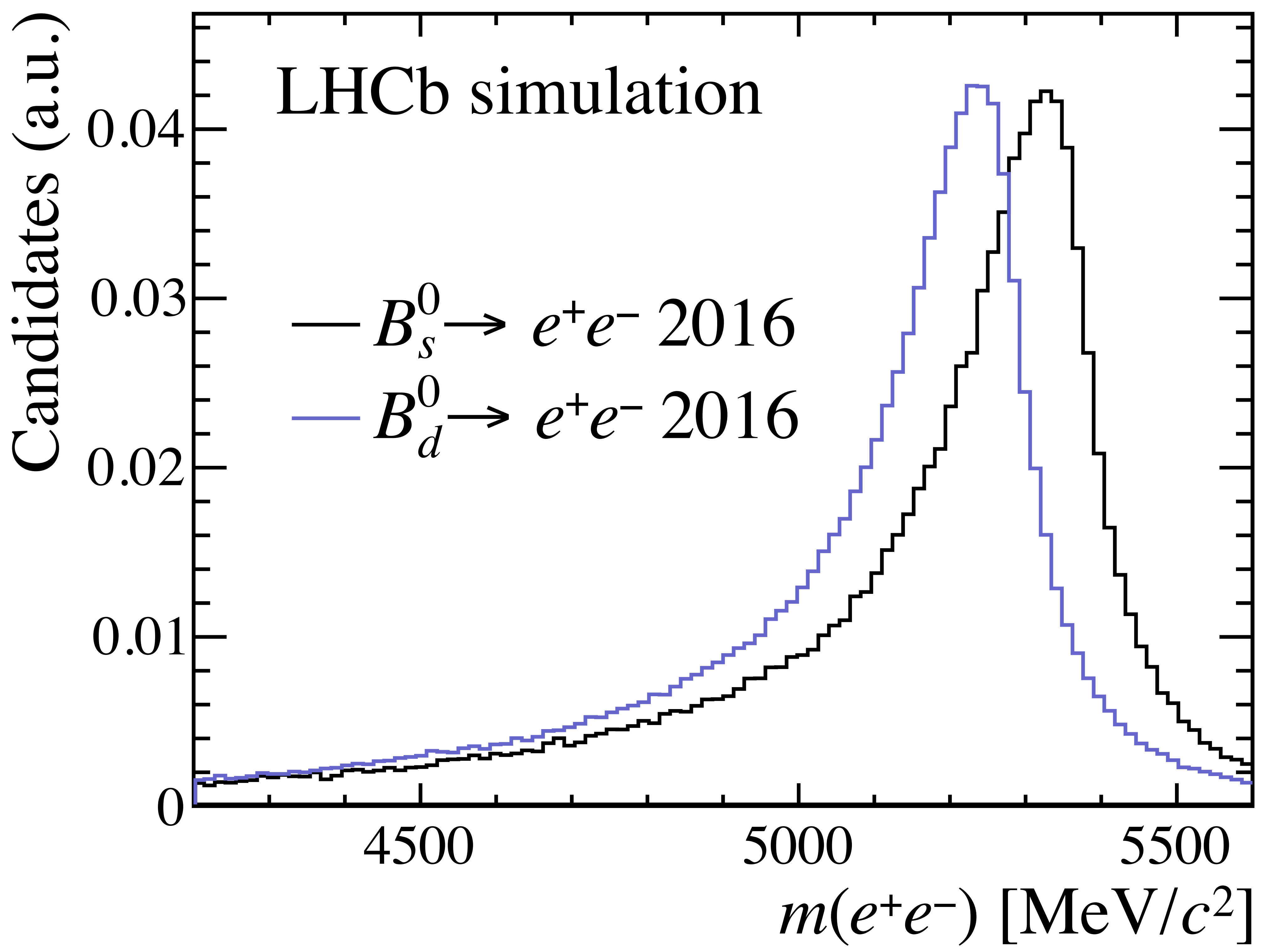
Limit on either $\mathcal{B}(B_d^0 \to e^+e^-)$ or $\mathcal{B}(B_s^0 \to e^+e^-)$

Large overlap of the mass distributions, so the fit cannot distinguish between $B_d^0 \to e^+e^-$ and $B_s^0 \to e^+e^-$





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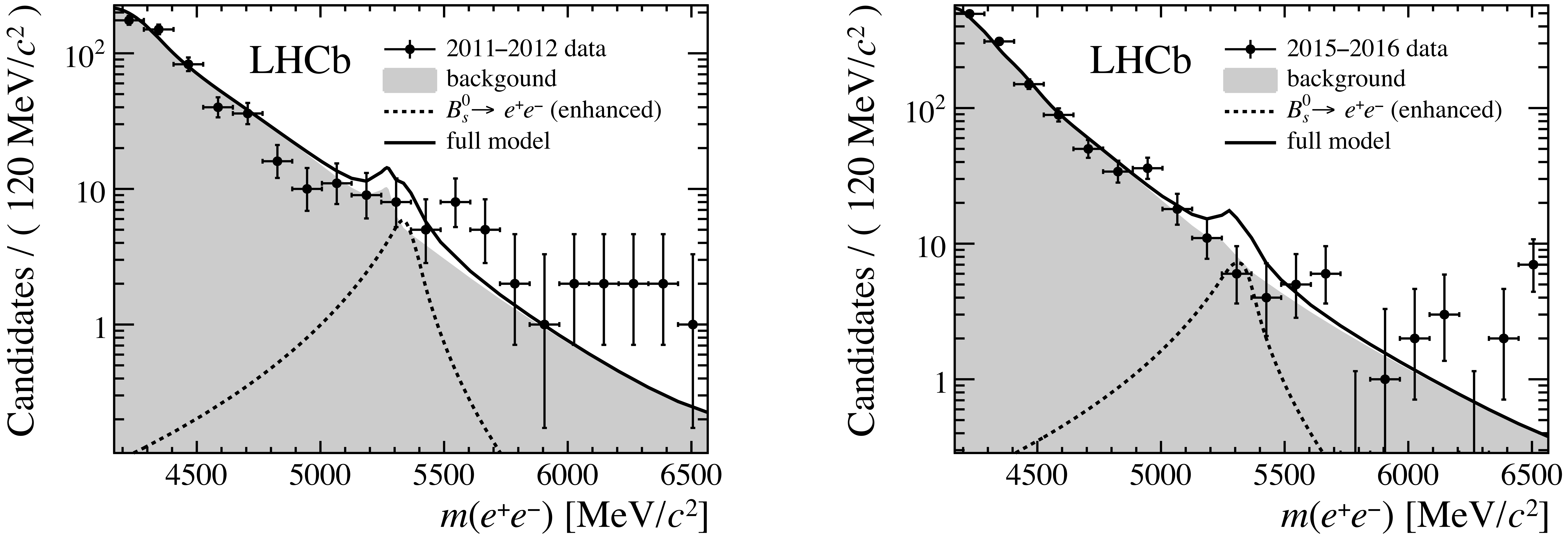
$m(e^+e^-)$ distributions with enhanced $\mathcal{B}(B_s^0 \to e^+e^-)$

Enhancing to the maximally allowed value in **[JHEP 05 (2017) 156]**

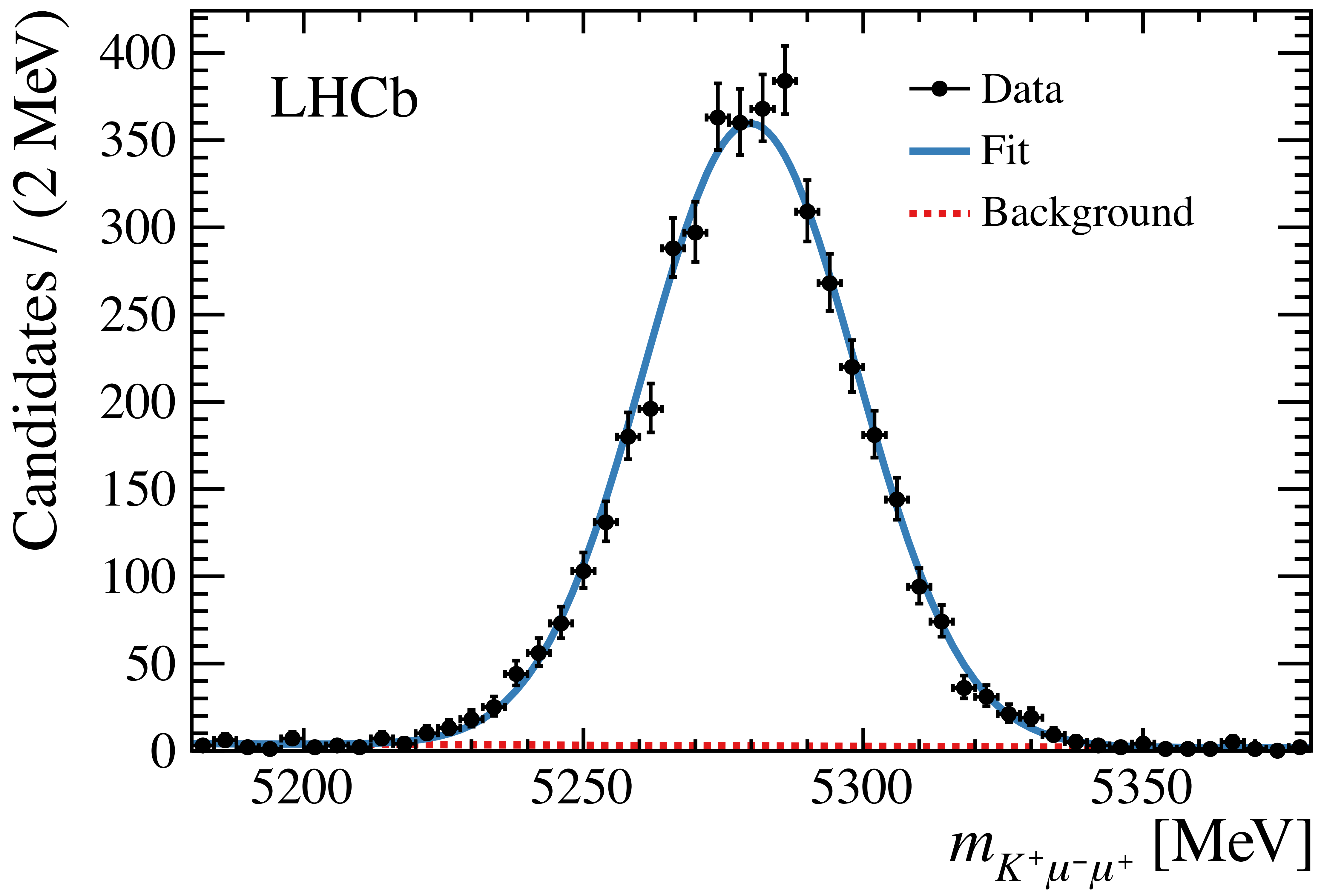
$$\mathcal{B}(B_s^0 \to e^+e^-) = 1.4 \times 10^{-8}$$

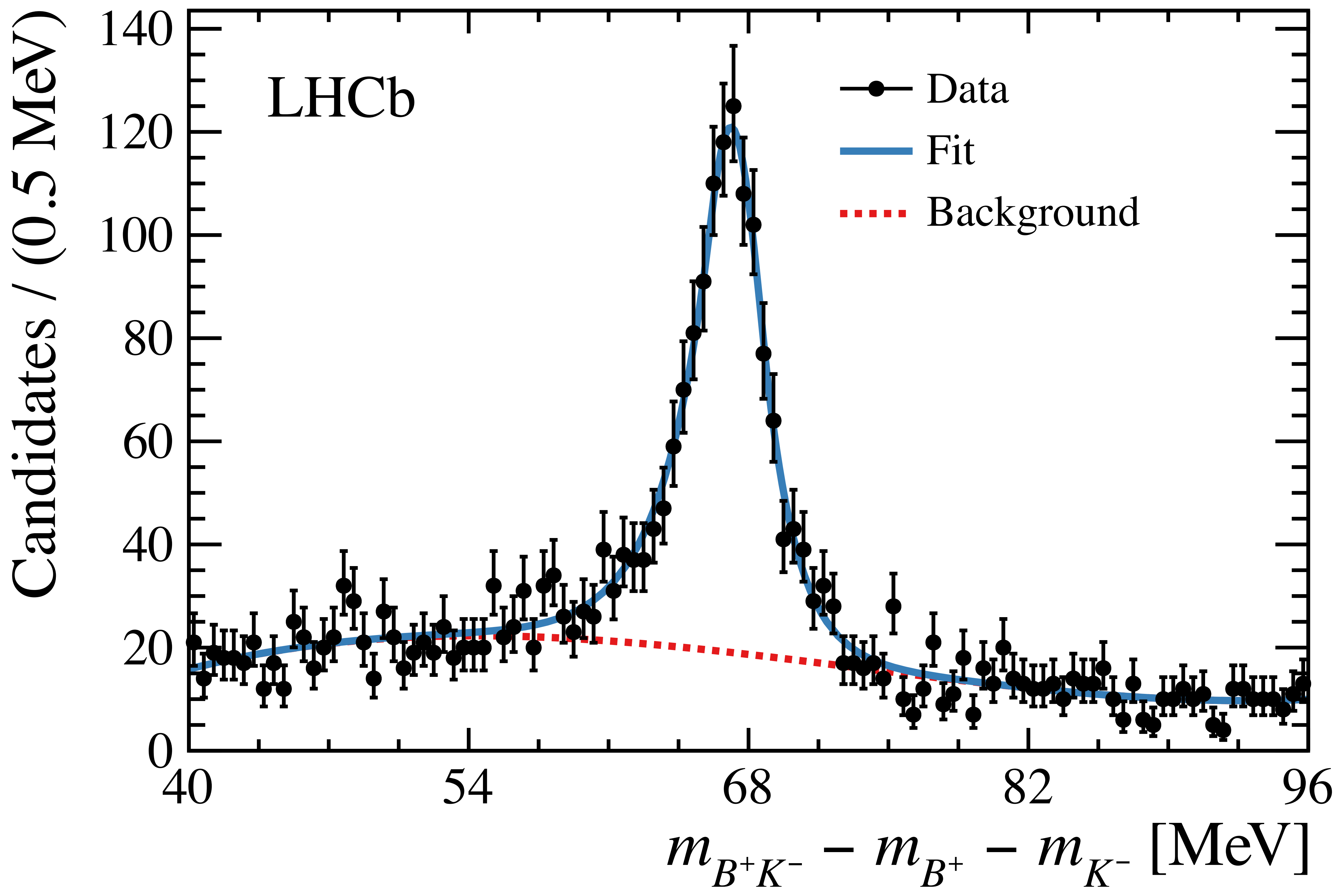


arXiv 2003.04352

$B^+ \to K^+\mu^-\tau^+$ analysis: fit to normalisation mode

The fit to the normalisation mode yields 4240 ± 70 candidates and is additionally to normalisation also used to determine the selected fraction of B^+ decays from B_{s2}^{*0}.





Systematic uncertainties of $B^+ \to K^+\mu^-\tau^+$ analysis

- Analysis is statistically dominated
- Systematic uncertainties arise from:
  - Background shape modelling
  - Modelling of B_{s2}^{*0} kinematics (5%)
  - Uncertainty of B_{s2}^{*0} fraction (7%)

arXiv 2003.04352

$B^+ \to K^+\mu^-\tau^+$ fits in bins of the BDT

Fraction of non-B_{s2}^{*0} signal candidates is taken into account, but makes up only a small part and is not very peaking in m_{miss}^2