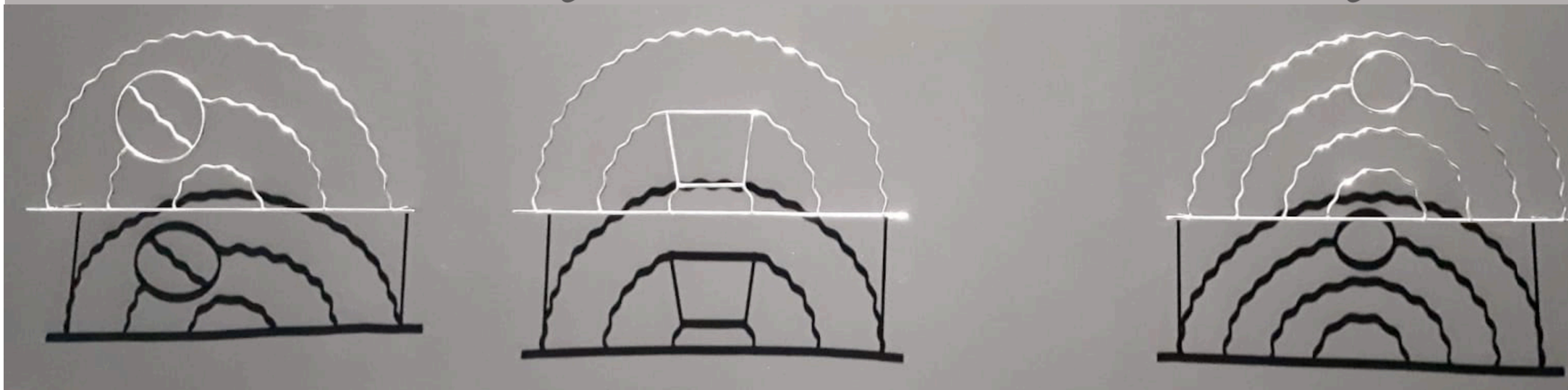
Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI

Paris, LPNHE, 8 July 2019
GDR-InF workshop:
QED corrections to (semi) leptonic B decays

Impact of radiative corrections on measurements of lepton flavour universality in B to Dlν decays

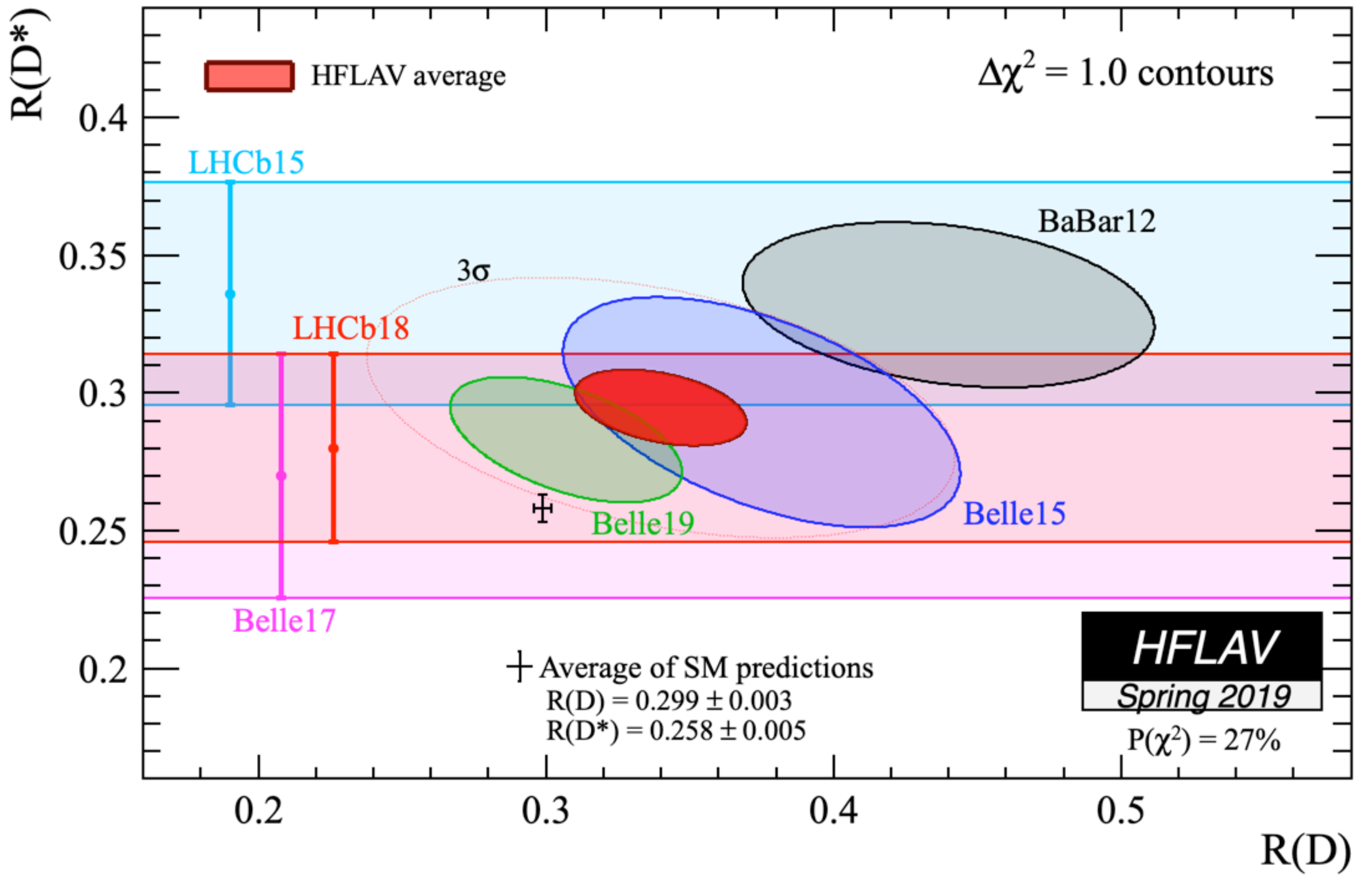


[Photo: courtesy Danilo Domenici]

Stefano Calì, Suzanne Klaver,
Marcello Rotondo, and Barbara Sciascia

[https://hflav.web.cern.ch/]

Introduction - broad picture



- Deviation from the SM of the combined $R(D^+)$ and $R(D^0)$ is about 3.1 sigma.
- Radiative corrections to $B \rightarrow D\ell\nu$, decays may have an impact on both predictions and measurements of lepton flavour universality observables $R(D^+)$ and $R(D^0)$

Introduction - our study

Impacts of radiative corrections on measurements of lepton flavour universality in $B \to D\ell\nu_\ell$ decays

Stefano Calí, Suzanne Klaver, Marcello Rotondo, Barbara Sciascia

(Submitted on 7 May 2019 (v1), last revised 27 May 2019 (this version, v2))

Radiative corrections to $B \to D\ell\nu_\ell$ decays may have an impact on both predictions and measurements of lepton flavour universality observables $\mathcal{R}(D^+)$ and $\mathcal{R}(D^0)$. In this paper, a comparison between recent calculations of the effect of soft-photon corrections on $\mathcal{R}(D^+)$ and $\mathcal{R}(D^0)$, and those generated by the widely used package PHOTOS is given. The impact of long-distance Coulomb interactions, which are not simulated in PHOTOS, is discussed. Furthermore, the effect of high-energy photon emission is studied through pseudo-experiments using the LHCb environment as a case study. It is found that the bias here may be as high as 7%. However, the bias on $\mathcal{R}(D)$ depends on individual analyses, and future high precision measurements require an accurate evaluation of these QED corrections.

Comments: 8 pages, 21 figures, to be submitted to EPJC; updated version contains clarifications
Subjects: **High Energy Physics - Phenomenology (hep-ph)**; High Energy Physics - Experiment (hep-ex)
Cite as: arXiv:1905.02702 **[hep-ph]**
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From: Suzanne Klaver [view email]
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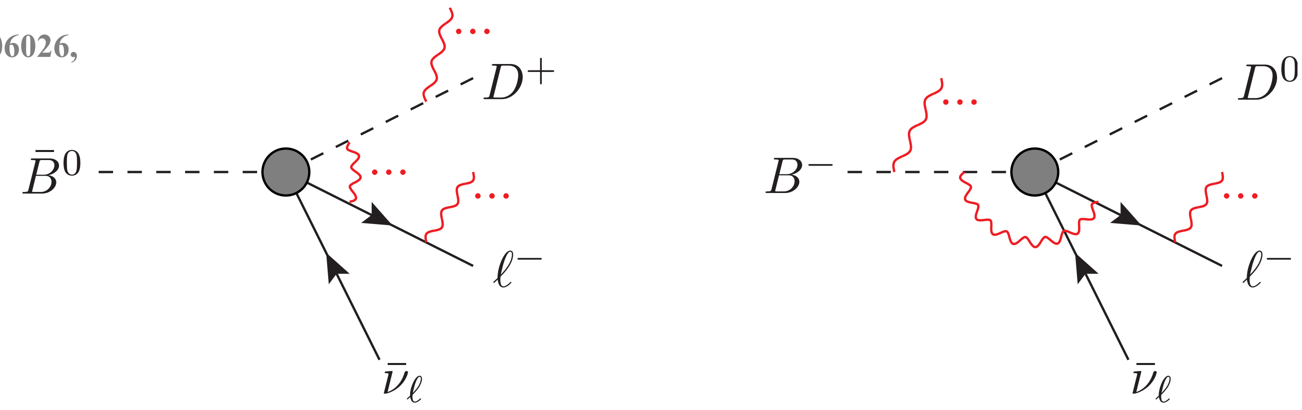
[v2] Mon, 27 May 2019 15:22:40 UTC (175 KB)

Feedback from EPJC received, reply sent out today.

- Comparison between recent calculations [Phys.Rev.Lett. 120 (2018) 26, 261804] of the effect of soft-photon corrections on $R(D^+)$ and $R(D^0)$, and those generated by the widely used package PHOTOS.
- Impact of long-distance Coulomb interactions (not simulated in PHOTOS).
- Effect of high-energy photon emission studied through pseudo-experiments. [LHCb environment taken as a case study]

Radiative corrections and **PHOTOS**

[Comput. Phys. Commun. 79 (1994) 291,
Eur. Phys. J.C45 (2006) 97, arXiv:hep-ph/0506026,
Phys.Rev.Lett. 120 (2018) 26, 261804]



Radiative corrections

- thought to be negligible at the level of precision of both measurements and predictions of R(D)

PHOTOS

- universal MC algorithm that simulates QED corrections;
- includes both soft and hard photon corrections, but doesn't include Coulomb corrections;
- has successfully been tested for various processes involving W, Z and B decays;
- photons emission depending on hadron structure is not included.

New study (S. de Boer et al.) *[see T. Kitahara contribution]*

- soft-photon corrections different for μ and τ decays (do not cancel in the R(D) ratios);
- doesn't include the hard photon corrections
- includes Coulomb corrections (relevant only for D^+ and similar modes)

The generated $B \to D\ell\nu_\ell$ samples

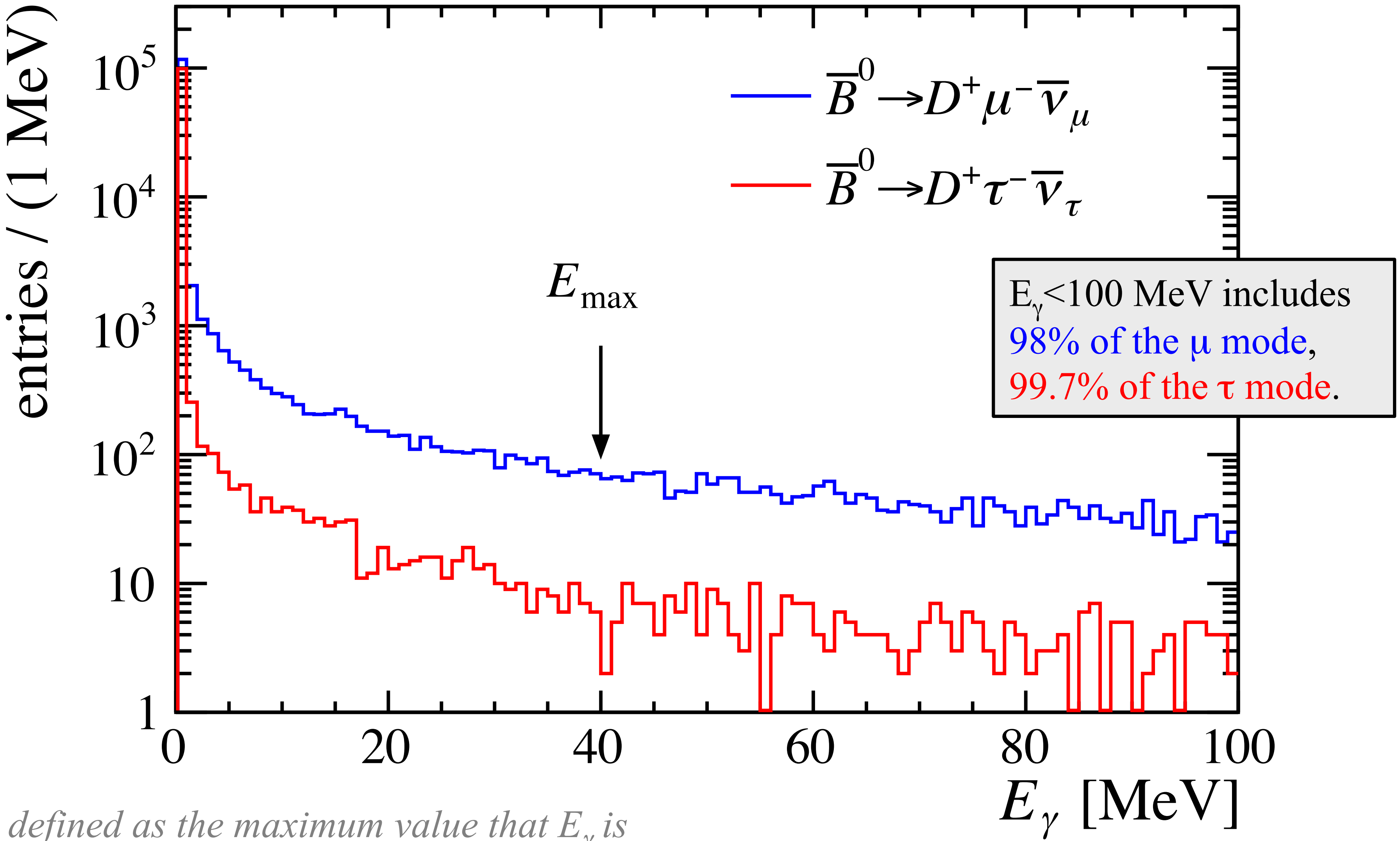
- Generated 3M events in 4 samples
  - $\overline{B}^0 \to D^+\ell^-\overline{\nu}_\ell$ and $B^- \to D^0\ell^-\overline{\nu}_\ell$, with $\ell^- = \mu^-, \tau^-$
  - generator level only, no detector reconstruction
  - PHOTOS version 3.56, "Option with interference is active"
- Calculate the four-momentum carried away by the radiative photons as:

$$p_\gamma = p_B - (p_D + p_{\ell^-} + p_{\bar{\nu}_\ell})$$

  - Like in the paper, we only consider radiation from the D and not of its daughters.
- QED corrections are defined as relative variation of the branching ratio due to events lost because $E_\gamma > E_{max}$:

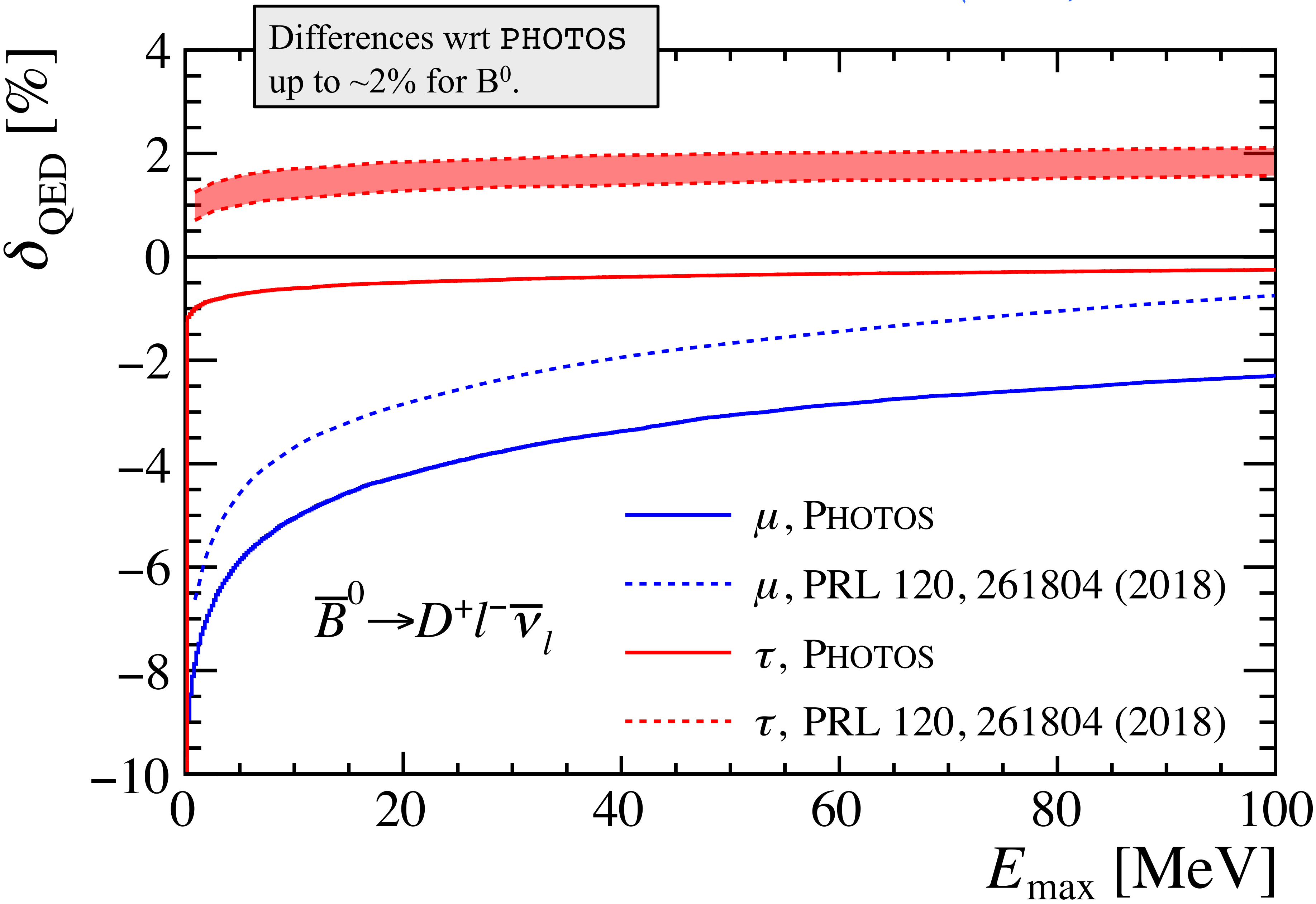
$$\delta_{\text{QED}} = \frac{\int_0^{E_{\max}} N(E_\gamma)dE_\gamma}{\int_0^{\infty} N(E_\gamma)dE_\gamma} - 1$$

Radiated energy: the E_{max} variable

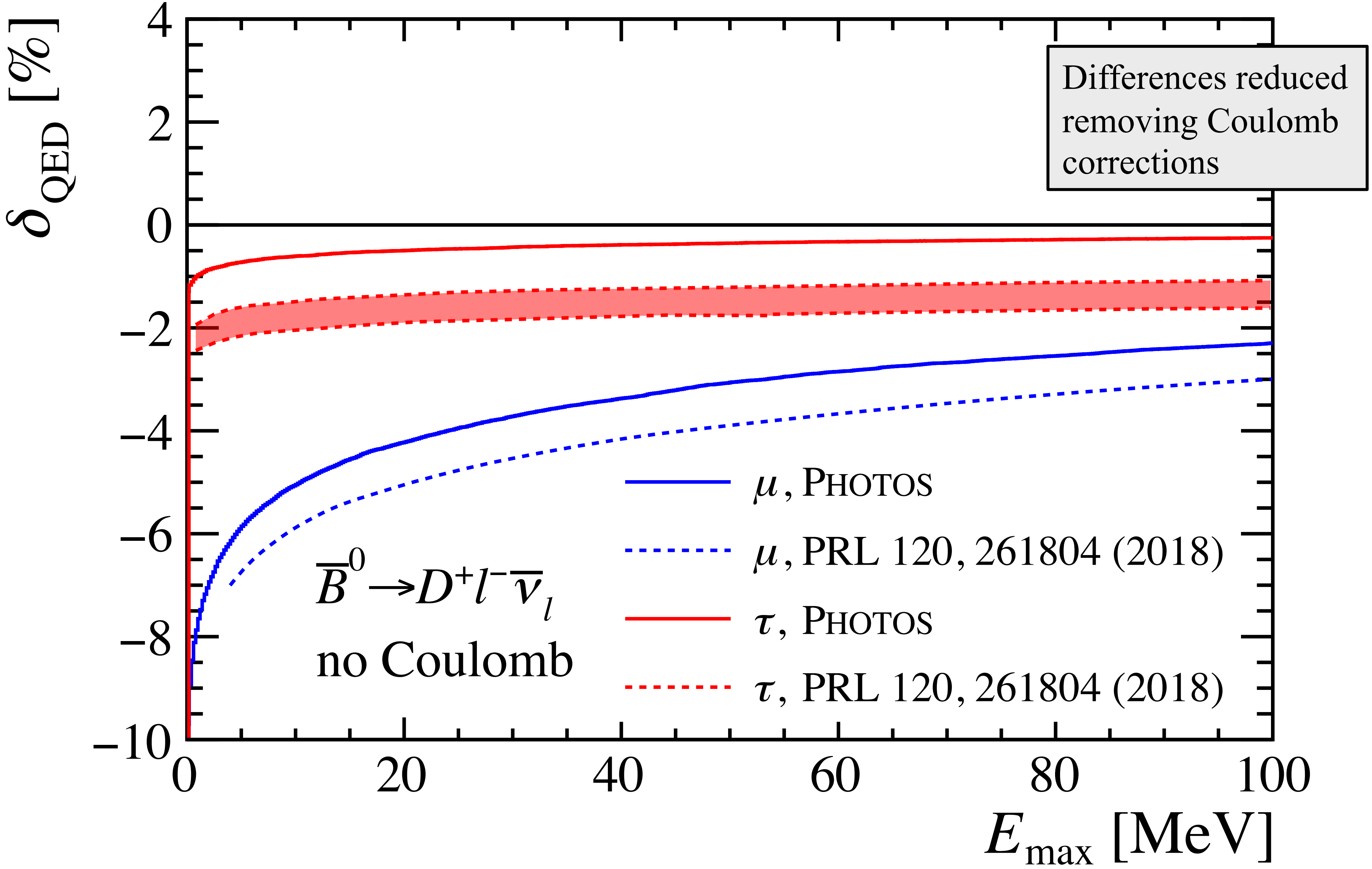


E_{max} is defined as the maximum value that E_γ is allowed to have to consider $B \rightarrow D\ell\nu_\ell(\gamma)$ as signal.

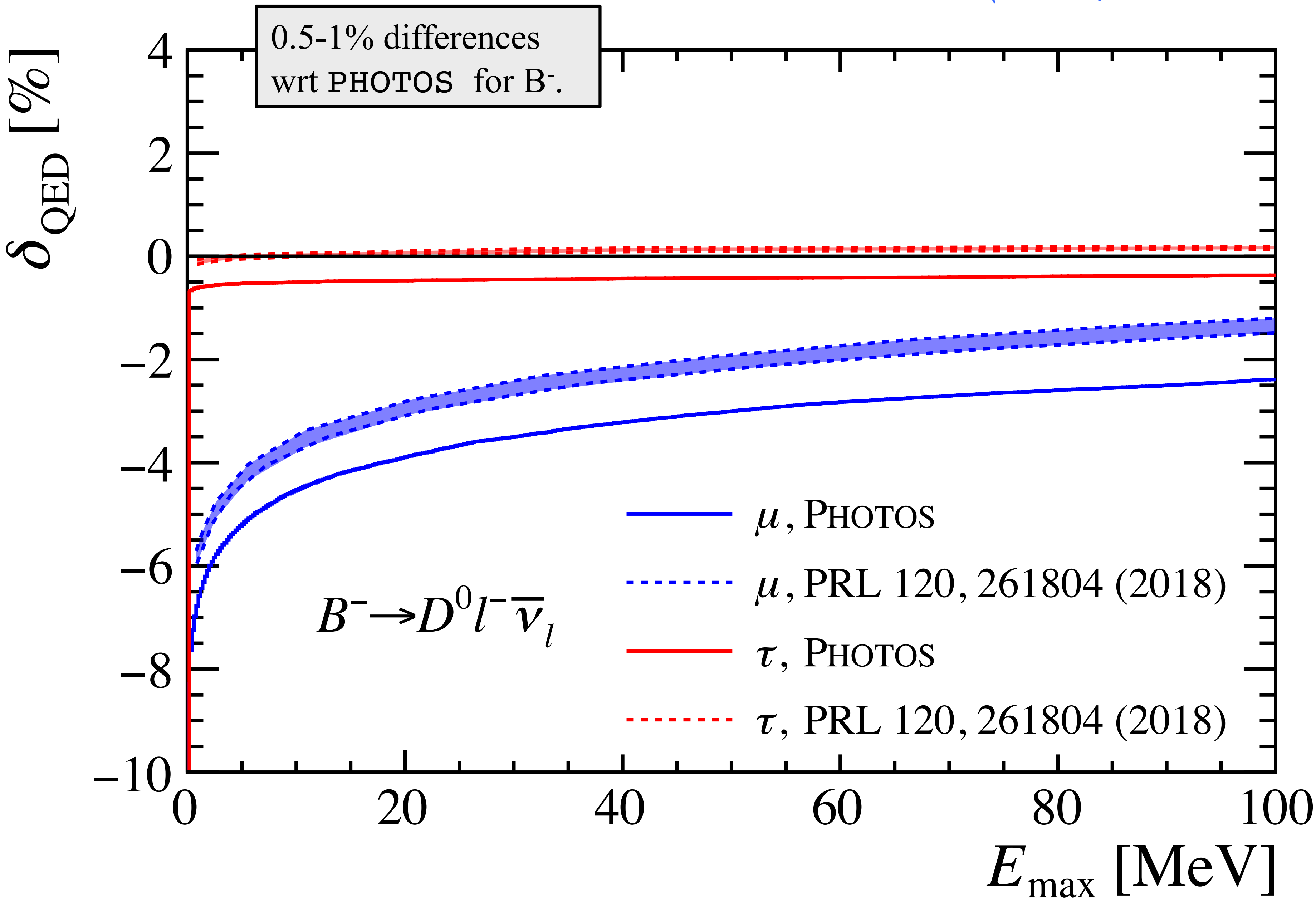
Results (BF, $B^0 \rightarrow D^+$)



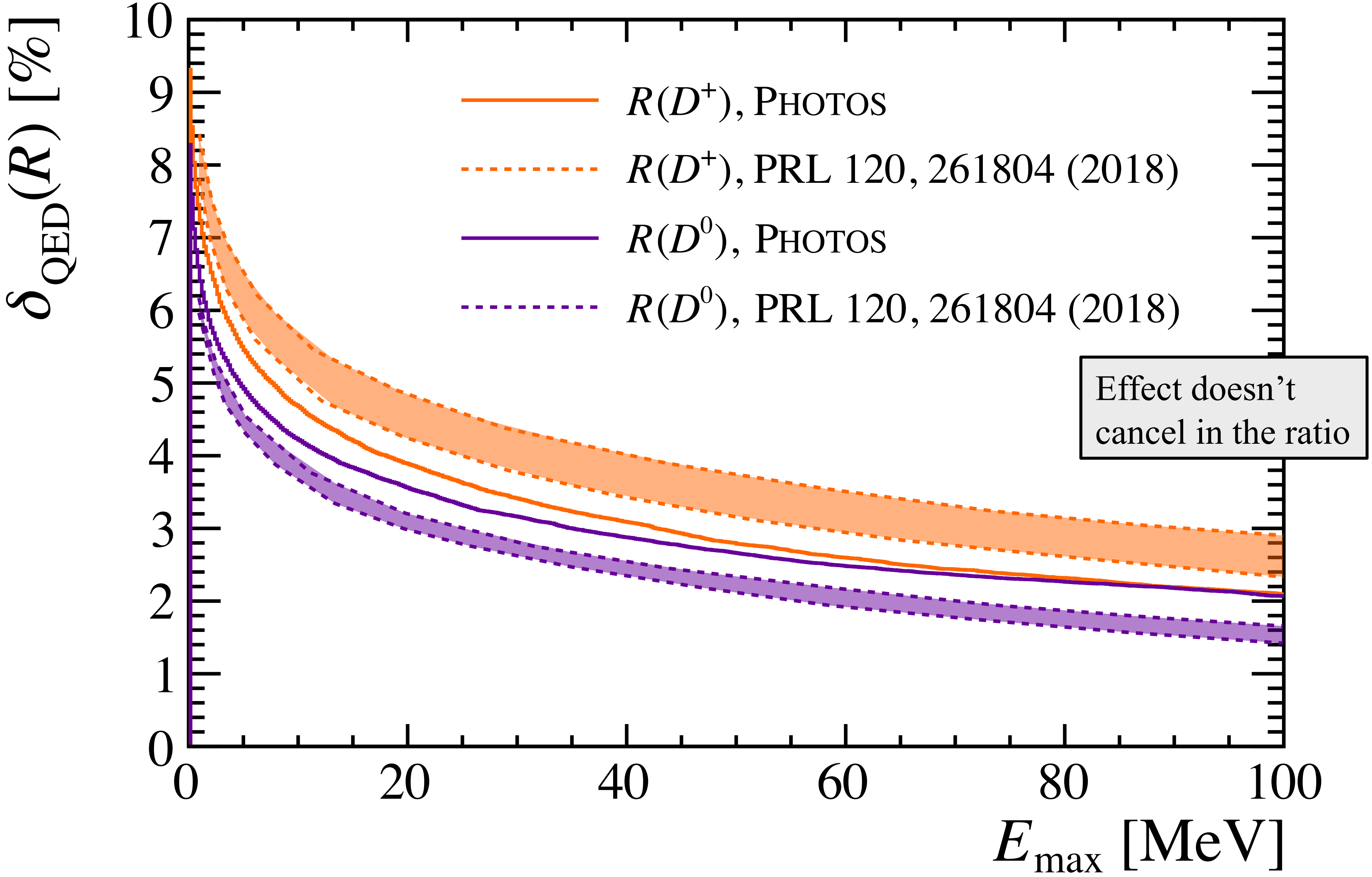
Results (BF, $B^0 \rightarrow D^+$) - no Coulomb correction



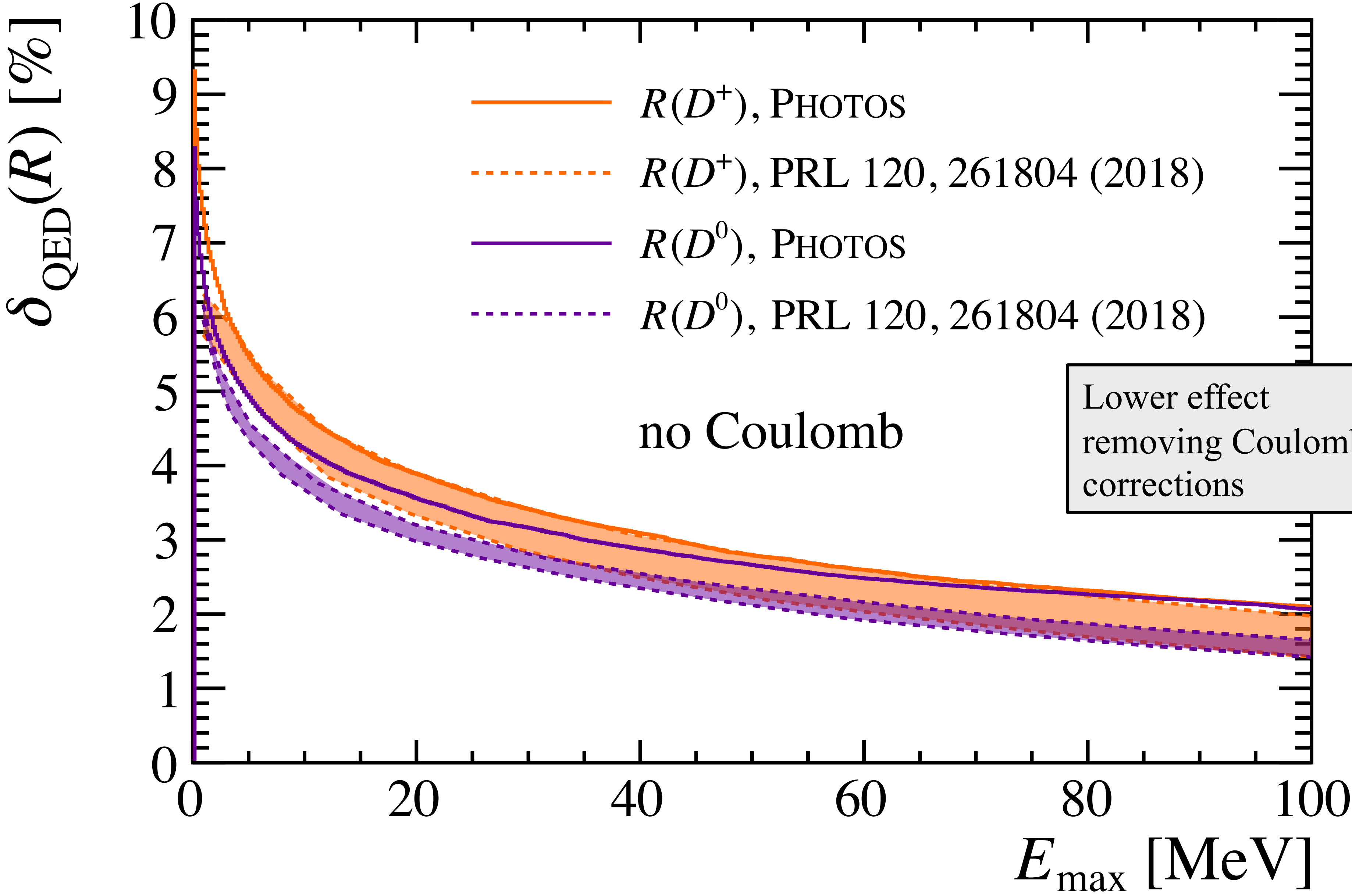
Results (BF, $B^- \to D^0$)



Results (Ratios)

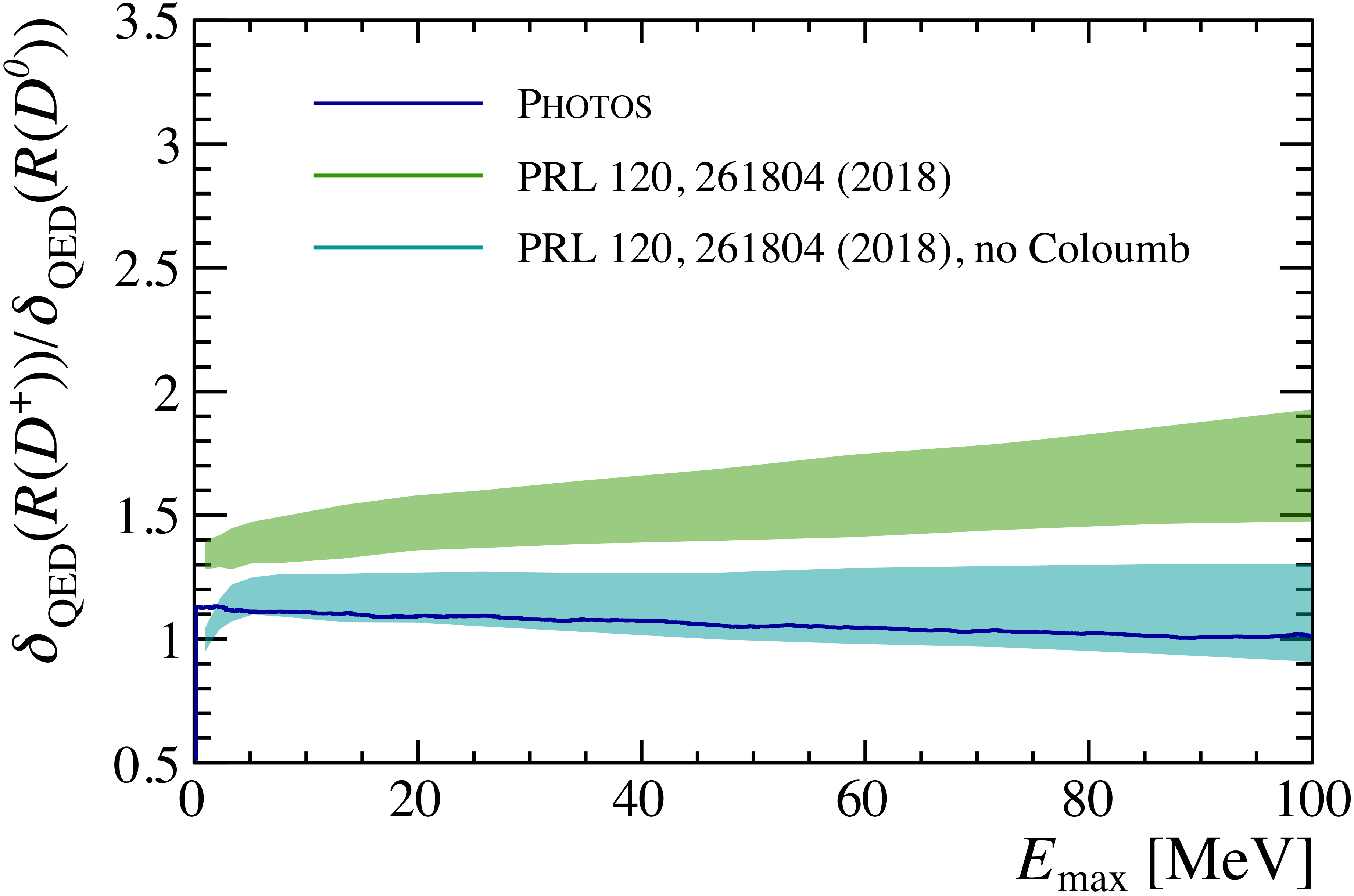


Results (Ratios) - no Coulomb corrections



Lower effect removing Coulomb corrections

Results (Ratios of ratios)

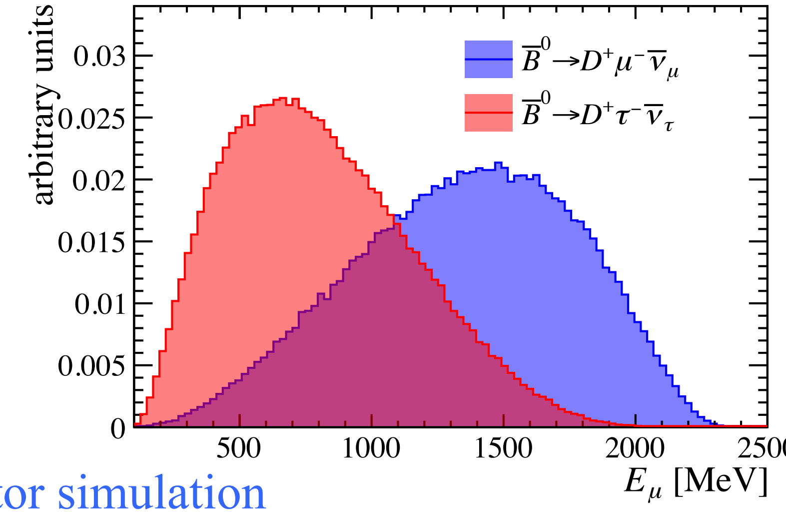


The effect on real measurements

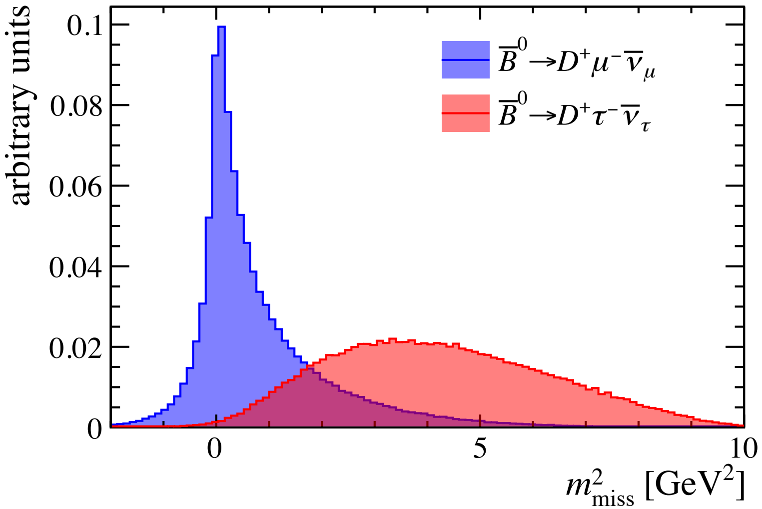
Estimate the effect on measurements of mis-modeling QED corrections in MC

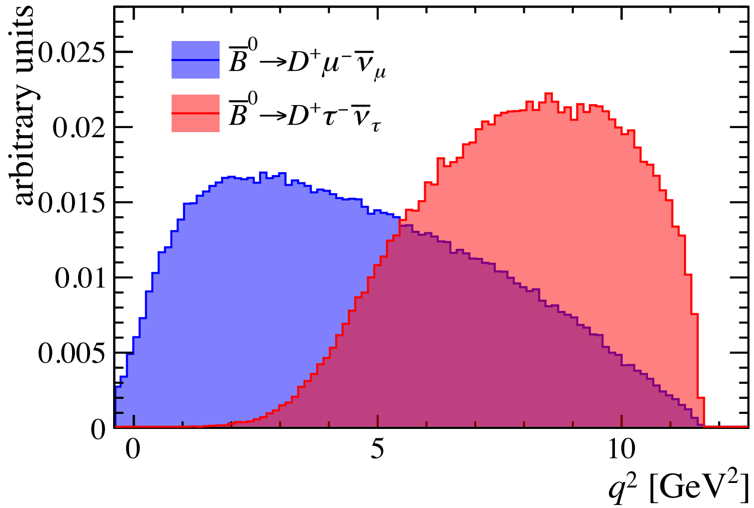
LHCb-like selection [**based on JHEP 02 (2017) 021**] applied on generated samples:

- Simulate vertex resolution by smearing the pp (±13, ±13, ±70 μm) and B decay (±20, ±20, ±200 μm) vertexes
- Simulate LHCb acceptance: 1.9 < η < 4.9, p > 5 GeV, p_T > 250 MeV on kaons, pions and muons, distance between pp and B vertex > 3 mm
- Reconstruct B meson momentum and related quantities using the LHCb rest frame approximation.



Distributions look very similar to those from full detector simulation



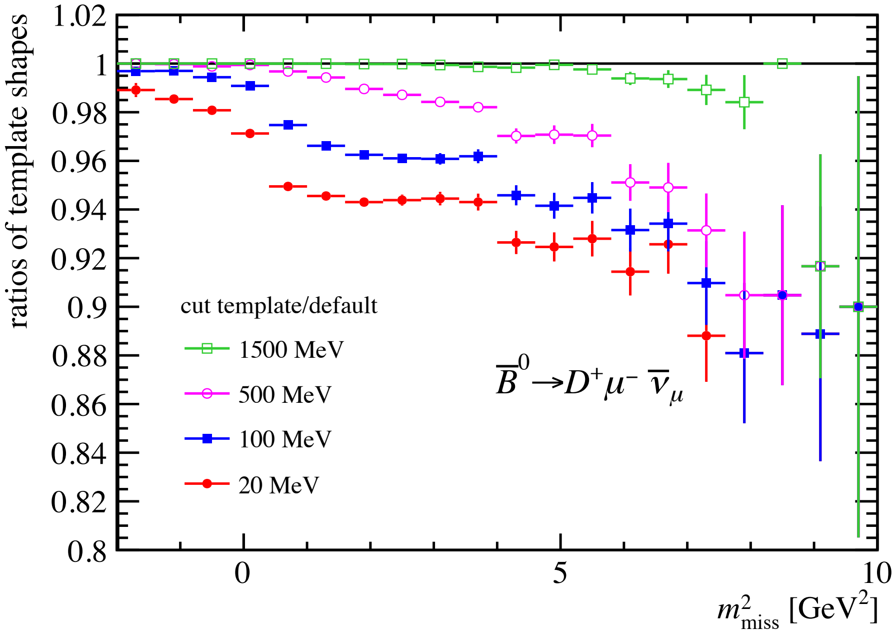


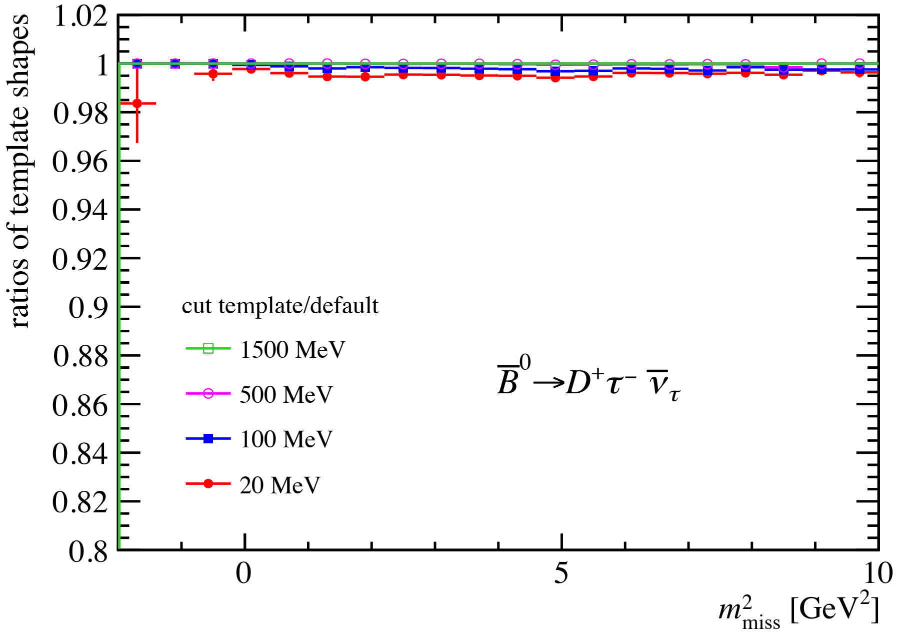
The effect on real measurements

Dummy analysis:

- very simplified: just signal and normalization samples
- generate 10.000 toy samples per decay mode with no cuts on E_{max}
- **generate templates with different cuts on E_{max}** (20, 100, 500, 800, and 1500 MeV)
- fit for R(D) using 3D templates (q^2, m_{miss}, E_ℓ) and study the effect
  [same as in muonic R(D*) LHCb measurement, **PRL 115 (2015) 111803**]

Applying different cuts on E_{max} changes shape of fit templates.
Most clearly visible on **missing mass** variable (strongly in the μ, barely in the τ decay modes).





Dummy analysis: results

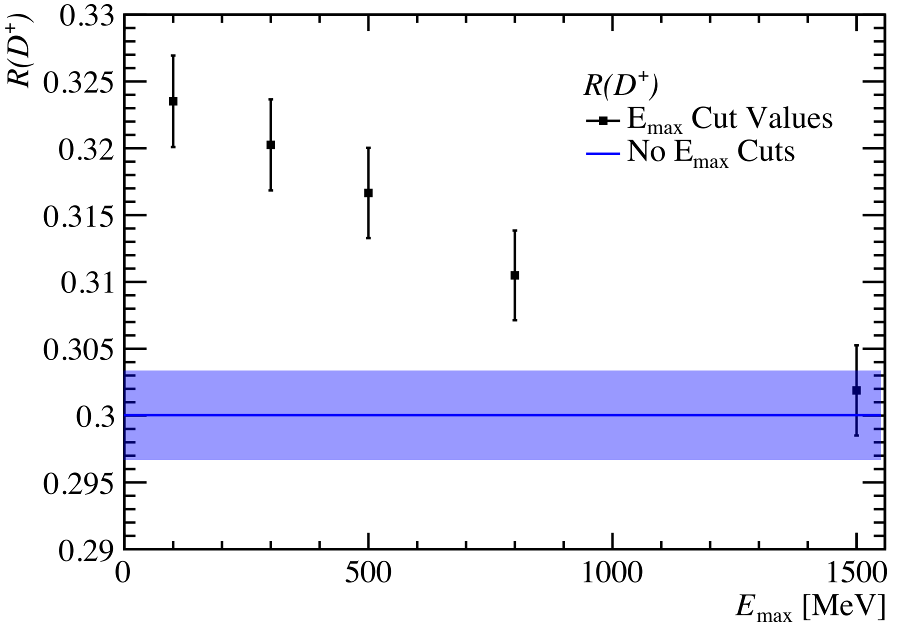
Effect of over- or underestimating radiative corrections in MC.

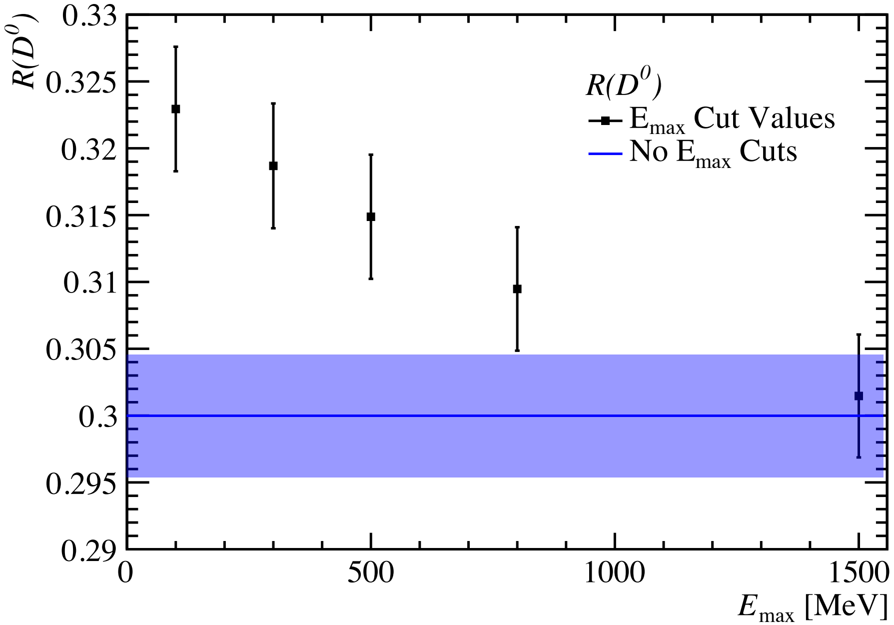
- By including cuts on E_{max} in the templates, but not toys (or vice versa)
- Done for cuts on E_{max}, at 100, 300, 500, 800, and 1500 MeV.

Change on R(D) is very similar for $R(D^+)$ and $R(D^0)$

Largest when applying a cut on E_{max} around 100 MeV, shifting R(D) by 0.02 or 7%

- Error bars reflect the statistics of generated MC samples





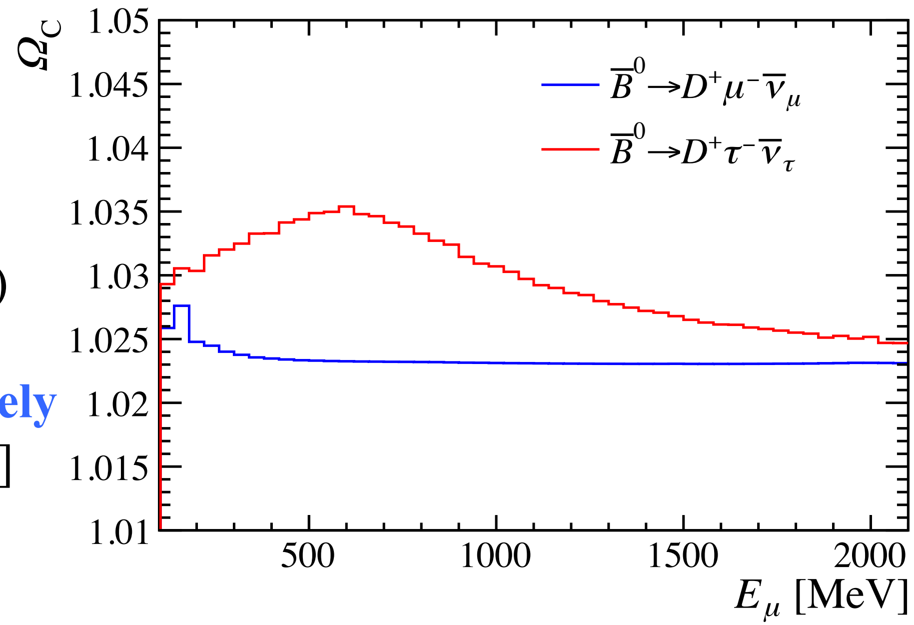
Effect of Coulomb corrections in toys

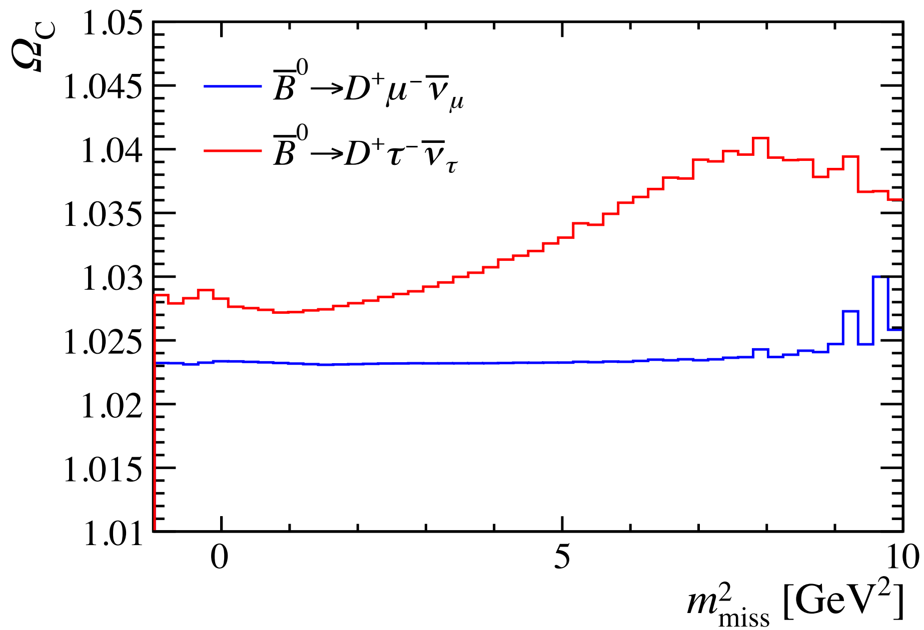
Coulomb correction as a function of fit variables:

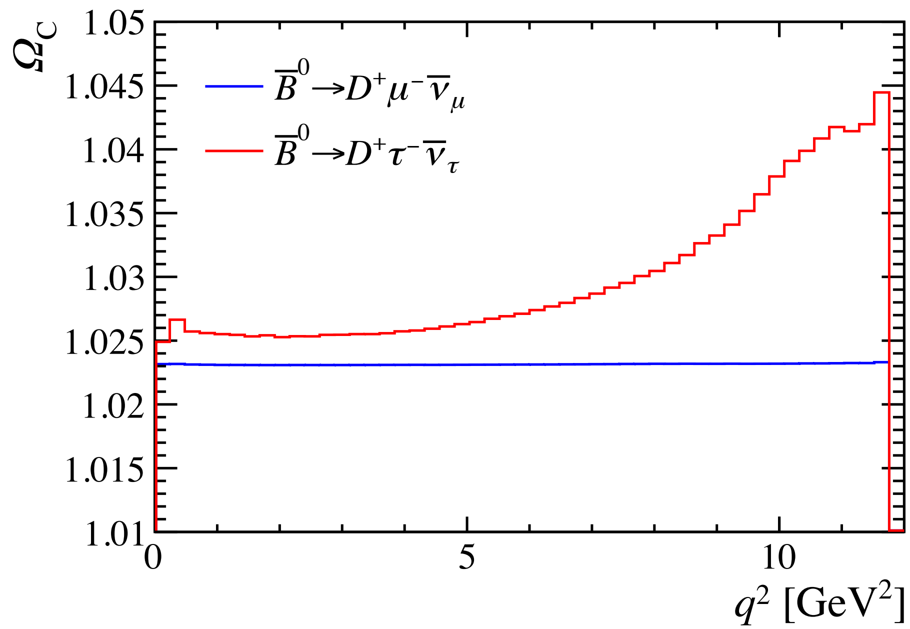
- This does not cancel in the ratios of R(D).
- LHCb-like analysis: **-0.003 shift on R(D^+)** (-1%)

Effect must be studied for each analysis separately

[depends on selection, reconstruction efficiency,…]



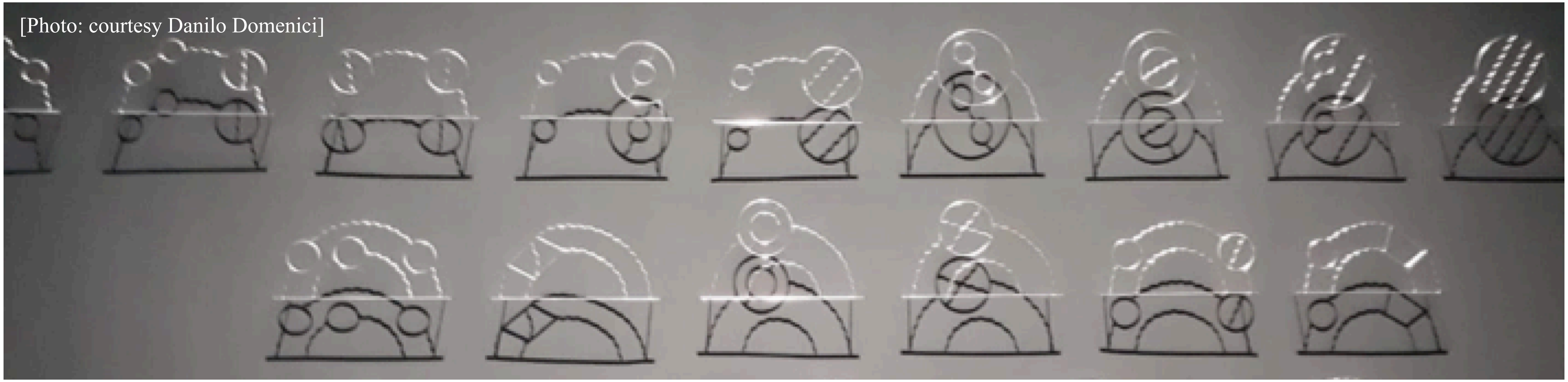




Acknowledgements We are grateful to S. de Boer, T. Kitahara, and I. Nisandzic for the fruitful collaboration, and U. Egede for the thoughtful comments. In addition, we thank the Semileptonics B decays working group of the LHCb collaboration, and in particular M. De Cian and L. Grillo, for their useful feedback throughout the development of this paper.

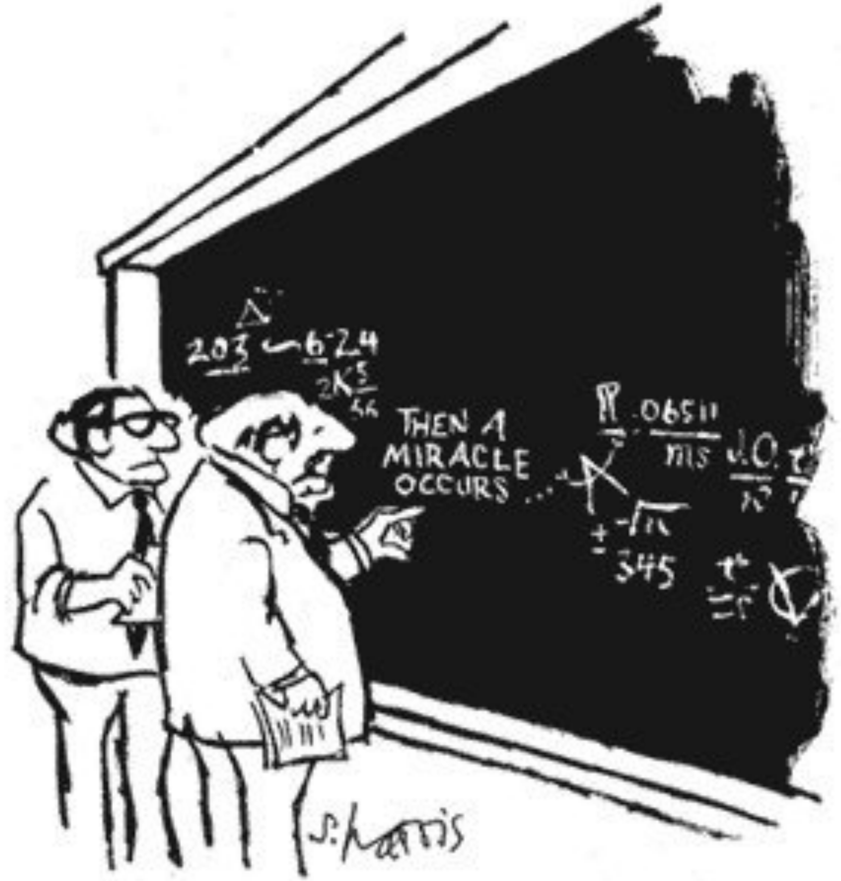
Conclusions

- Corrections described in de Boer et al. are not fully included in PHOTOS;
- **Coulomb corrections** affect kinematics of τ decays (corrections of 1% on LHCb-like analysis), must be studied for each analysis separately;
- **Cuts on photon energy** (not necessarily explicit) should be studied by analysts;
- **Mis-modeling QED corrections** can lead to a bias of ~7% in LHCb-like analysis;
- **Further input is needed from the theory community especially for future measurements with higher precision.**



[Photo: courtesy Danilo Domenici]

Back up



"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

Coulomb correction - details

Coulomb correction can be calculated as: $$\Omega_C = -\frac{2\pi\alpha}{\beta_{D\ell}} \frac{1}{e^{-\frac{2\pi\alpha}{\beta_{D\ell}}} - 1}$$

$$\alpha = 1/137$$

$$\beta_{D\ell} = \left[1 - \frac{4m_D^2 m_\ell^2}{(s_{D\ell} - m_D^2 - m_\ell^2)^2}\right]^{1/2}$$

$$s_{D\ell} = (p_D + p_\ell)^2$$

Used approximation (Atwood and Marciano): $\Omega_C = 1 + \alpha\,\pi \sim 1.023$
This holds for $\beta_{Dl} \sim 1$
Not true for $\beta_{D\tau} \sim 0.5 - 0.9$; implies Coulomb correction in the 2.5%-5% range

Private communication from Z.A. Was: "*No plans to include Coulomb correction to* `PHOTOS`*, because it forms to good approximation a separate class of corrections which can (and should) be integrated as correction to Born level matrix element.*"

The effect on real measurements (q^2, E_μ)

Dummy analysis:
- very simplified: just signal and normalization samples
- generate 10.000 toy samples per decay mode with no cuts on E_{max}
- **generate templates with different cuts on E_{max}** (20, 100, 500, 800, and 1500 MeV)
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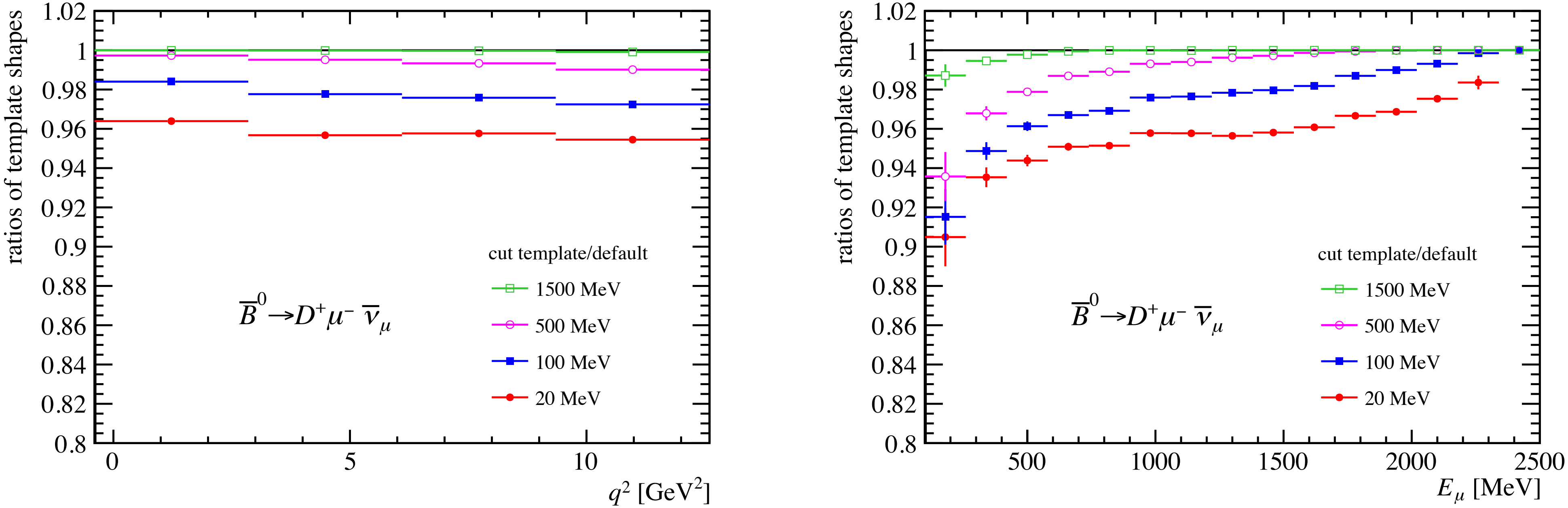
  [same as in muonic R(D*) LHCb measurement, **PRL 115 (2015) 111803**]

Applying different cuts on E_{max} changes shape of fit templates.
q^2 and E_μ are less affected.



Alternative strategy

- Outcome of the measured values of R(D) as a function of E_{max}, when templates are generated according to Photos predictions and the E_{max} cuts are applied on the pseudo-experiments.
- The error bars reflect the statistics of the generated MC samples. Specifically, they come by repeating the analysis 10.000 times and taking the spread of the outcomes as the statistical uncertainty.
- The blue bands correspond to fit results obtained with the same templates used to generate the pseudo-experiments