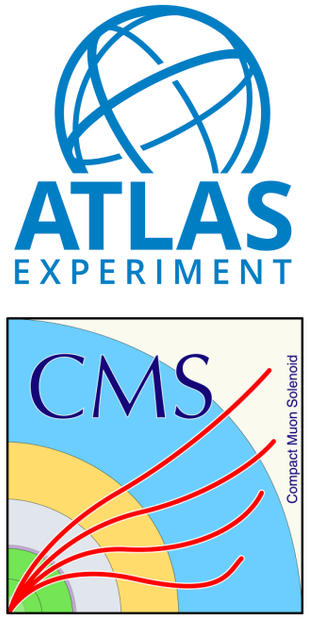
LHCb Heavy Flavour Results as probes for charged Higgs sector

by *Da Yu Tou*
On behalf of the *LHCb* experiment

Higgs Hunting Workshop
29 July 2019

Direct and Indirect Search for New Physics

Energy Frontier
Direct Search



Direct search for SUSY,
DM particles

Intensity Frontier
Indirect Search

Flavour physics,
precision test of SM

LPNHE PARIS

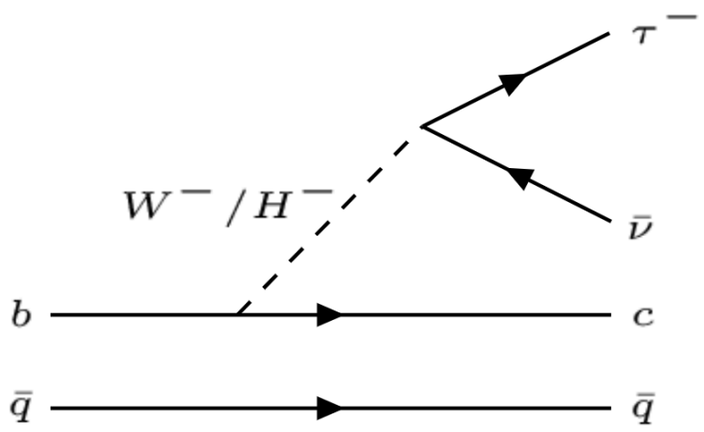
R(D*)-R(D) in General 2 Higgs Doublet Model

R(D) and R(D*)

- SM prediction very clean and precise due cancellation of Cabibbo-Kobayashi-Maskawa matrix element and form factor uncertainties.

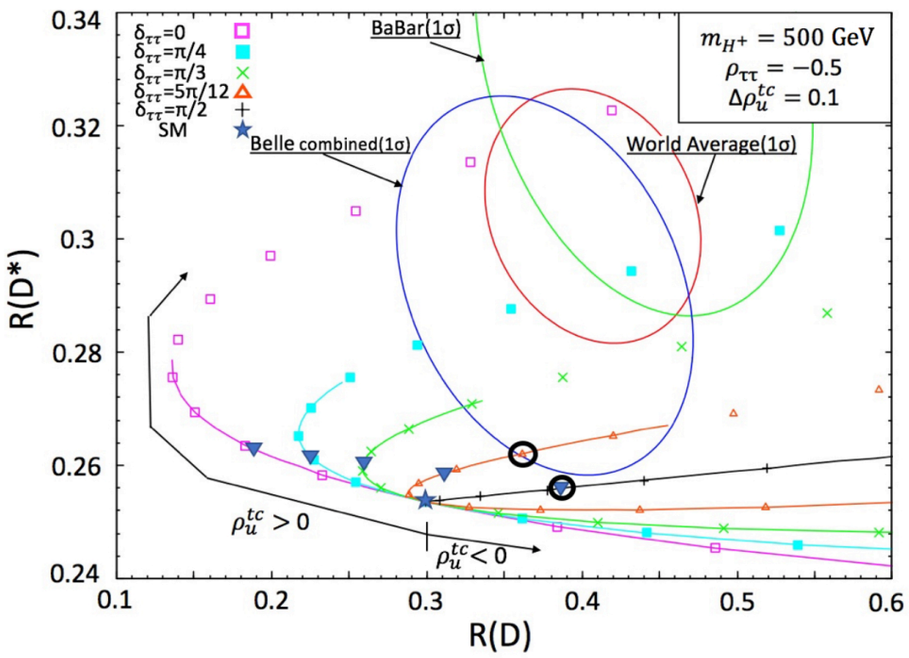
$$\mathscr{R}(D^*) = \frac{\mathscr{B}(\bar{B} \to D^{*+}\tau^-\nu_\tau)}{\mathscr{B}(\bar{B} \to D^{*+}\mu^-\nu_\mu)} = 0.252 \pm 0.003$$ [Phys. Rev. D 85, 094025]

- Several New Physics models can cause deviation from SM prediction, e.g. 2HDM.



A tree level diagram where a charged Higgs can contribute to $b \to c\tau\nu$ decays

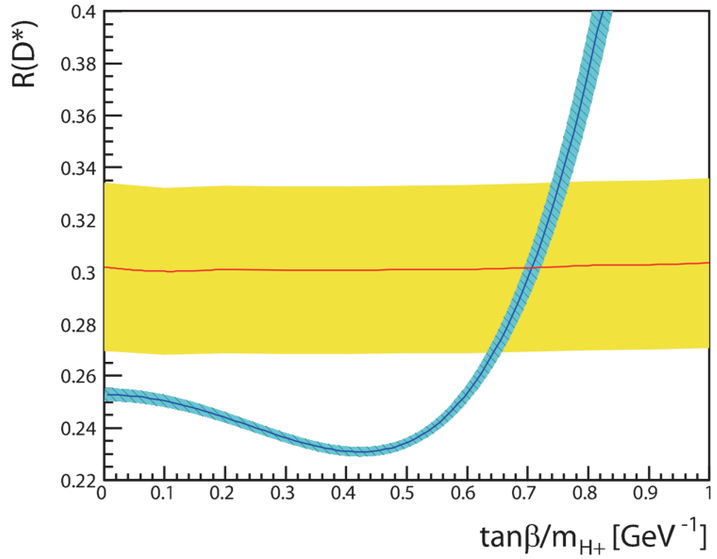
[arXiv:1710.05898]



Predictions for a scenario in general 2DHM framework

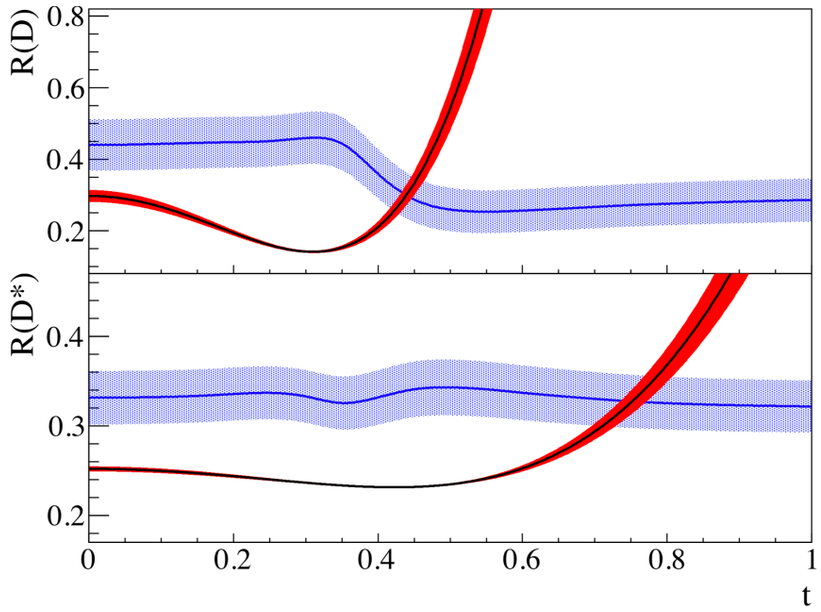
B-factory Measurements

- Belle and Babar performed compatibility test of Type II 2HDM with measurements of $R(D)$ and $R(D^*)$.



- Belle $R(D^*)$ is compatible with Type II 2HDM in the $\tan\beta/m_{H^+} = 0.7[\mathrm{GeV}^{-1}]$ region.

[Phys. Rev. D 94, 072007]



- BaBar compatibility test of $\tan\beta/m_{H^+}$ using $R(D)$ and $R(D^*)$ are incompatible with each other.

[SLAC-PUB-15028]

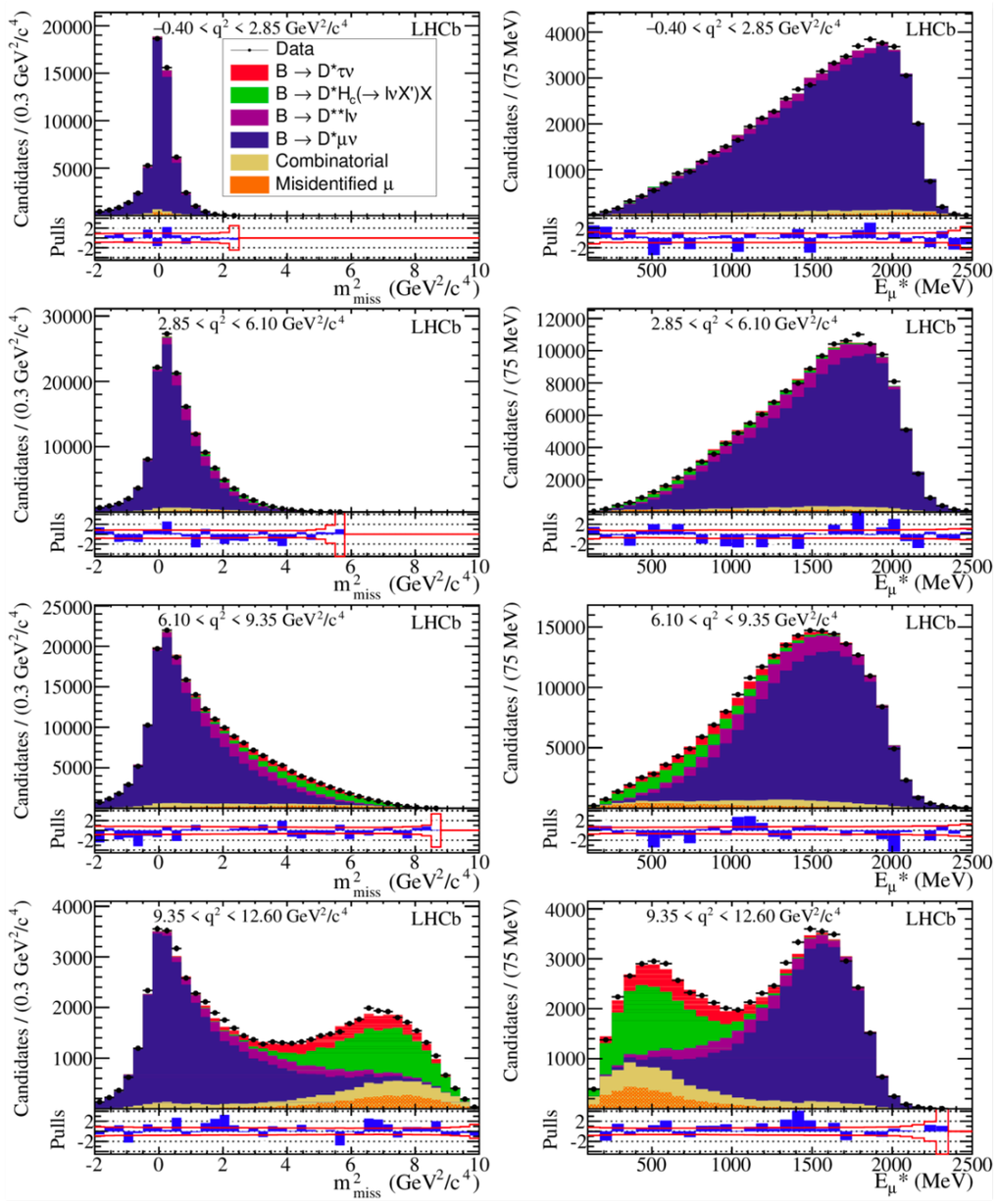
- These compatibility tests model are only valid for $m_{H^+} < 10$ **GeV** but $m_{H^+} < 10$ **GeV** has been excluded by $B \to X_s\gamma$. [Phys. Rev. Lett. 98, 022002]
- Type II 2HDM is excluded in the full $\tan\beta/m_{H^+}$ parameter space.

$R_{D^*}, \tau \to \mu\bar{\nu}_\mu\nu_\tau$ [Phys. Rev. Lett. 115, 111803]

- The $D^*\mu^+$ candidates are required to be isolated from the rest of the event using an MVA classifier.
- 3D template fit in m^2_{miss}, E^*_μ and q^2 is performed in 4 q^2 bin to extract the yields of $\bar{B} \to D^{*+}\tau^-\nu$ and $\bar{B} \to D^{*+}\mu^-\nu$.
- The pulls indicates that the templates are a good description of the components in the fit.
- Results :

  $R_{D^*} = 0.336 \pm 0.027(stat) \pm 0.030(syst)$

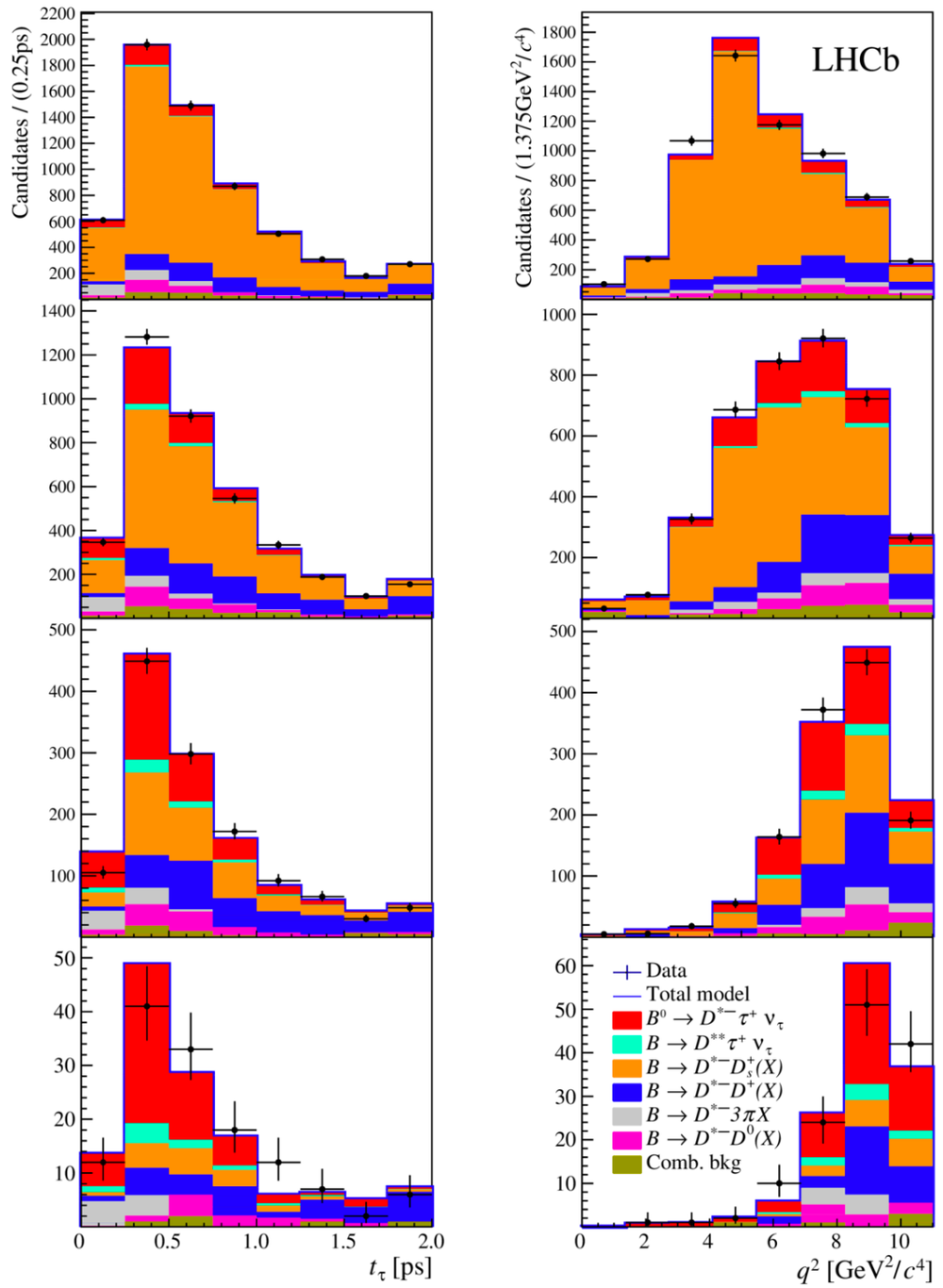
  Consistent to SM at 2.1σ



$R_{D^*}, \tau \to \pi^+\pi^-\pi^+\nu_\tau$ or $\tau \to \pi^+\pi^-\pi^+\pi^0\nu_\tau$

[Phys. Rev. Lett. 120, 171802]

- Use $B \to D^{*-}3\pi$ as normalisation channel to cancel systematic uncertainty.
- Measure $\frac{\mathcal{B}(\bar{B} \to D^{*+}\tau^-\nu)}{\mathcal{B}(\bar{B} \to D^{*+}3\pi)}$ from data, compute R_{D^*} using known branching fraction measurements of $\bar{B} \to D^{*+}3\pi$ and $\bar{B} \to D^{*+}\mu^-\nu$.
- The yield of the normalisation mode is measured by fitting the invariant mass $m(D^{*+}\pi^+\pi^-\pi^+)$.
- A 3D template fit in q^2,t_τ and BDT response is used to extract the yields of $\bar{B} \to D^{*+}\tau^-\nu$ (shown right).
- Results:
  $R_{D^*} = 0.291 \pm 0.019(stat) \pm 0.026(syst) \pm 0.013(BR)$
  Consistent with SM at 1.1σ

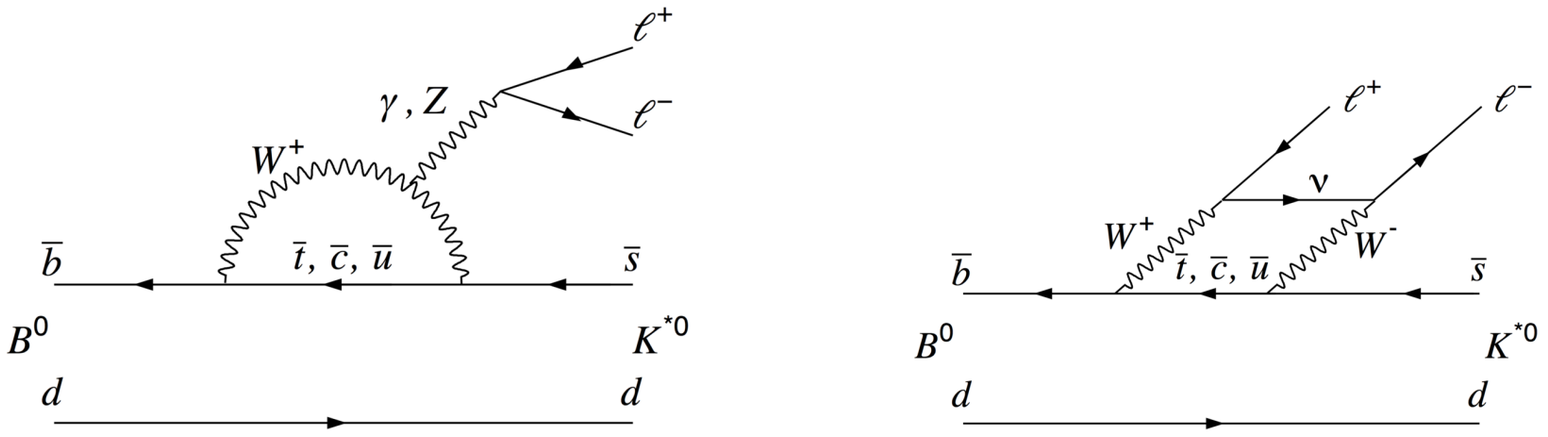


BDT response increases from top to bottom

R_K and R_{K*} in Type-III 2HDM

$b \to sll$ Decays

- Flavour changing neutral currents that proceed via electroweak or box diagram.



- Highly suppressed in the SM. Sensitive to new physics contribution enhancement of branching fraction.

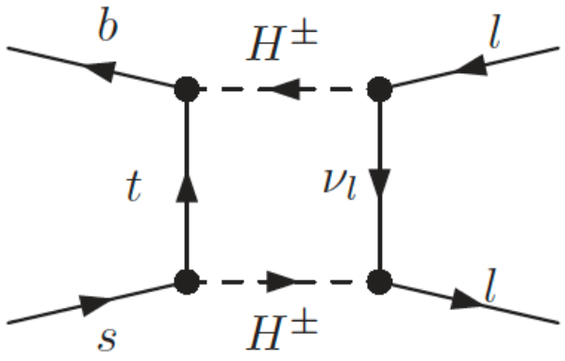
- SM predicts muons and electrons branching fraction ratio is close to unity.

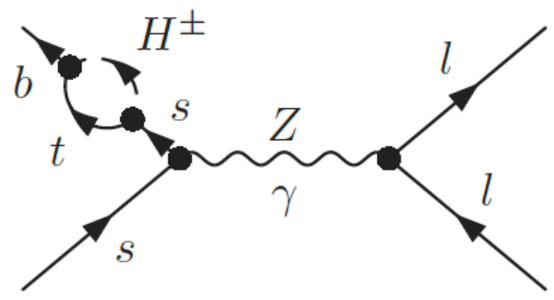
$$R_H = \frac{\mathcal{B}(B \to H\mu\mu)}{\mathcal{B} \to Hee}$$

$b \to sll$ Decays

[arXiv:1710.05898]

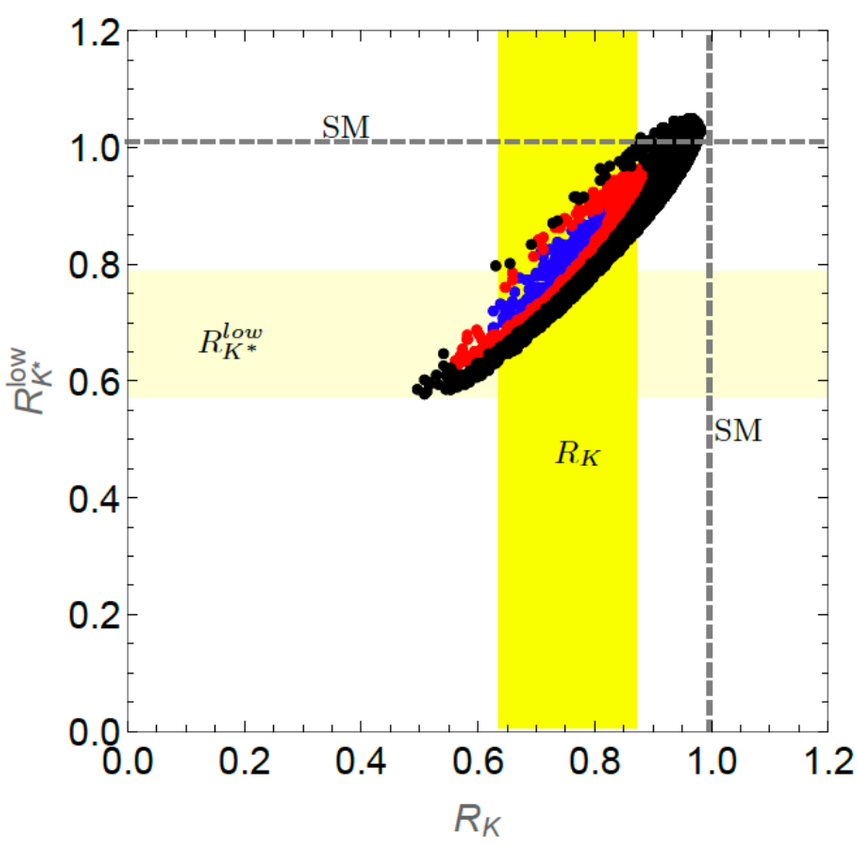
- Type III 2HDM might contribute to this process and cause lepton non-universality in $b \to sll$ decays.





- Type III 2HDM might contribute to this process and cause lepton non-universality in $b \to sll$ decays.

- Yellow bands are 1σ experimental results (Run 1 R_K results), while the scatter plots correspond to the expectation of Type III 2HDM.



LHCb Measurement of R_K and $R_{K^{*0}}$

- Electron channels suffer from Bremstrahlung radiation. We instead measure a double ratio. J/ψ modes proceeds via tree level in the SM and have branching fraction ratio of 1.

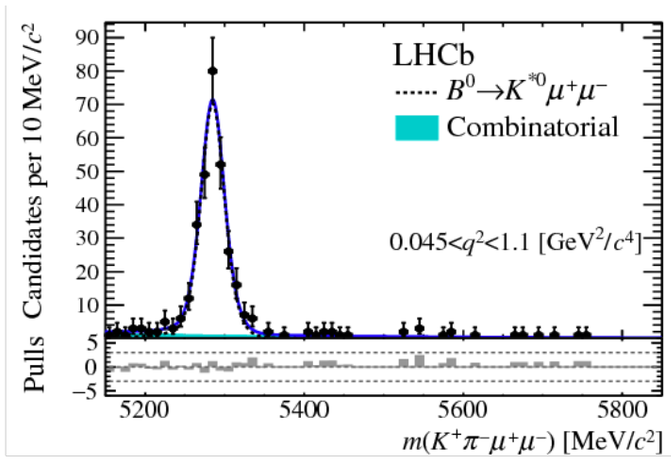
$$R_H = \frac{\mathscr{B}(B \to H\mu\mu)}{\mathscr{B}\left(B \to HJ/\psi \to (\mu\mu)\right)} \Big/ \frac{\mathscr{B}(B \to Hee)}{\mathscr{B}\left(B \to HJ/\psi \to (ee)\right)}$$

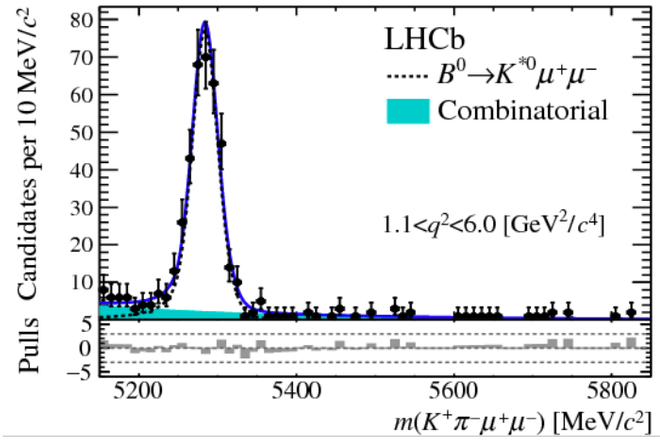
- Systematic uncertainties in efficiency calculations cancel due to similar kinematics between resonant and rare modes.

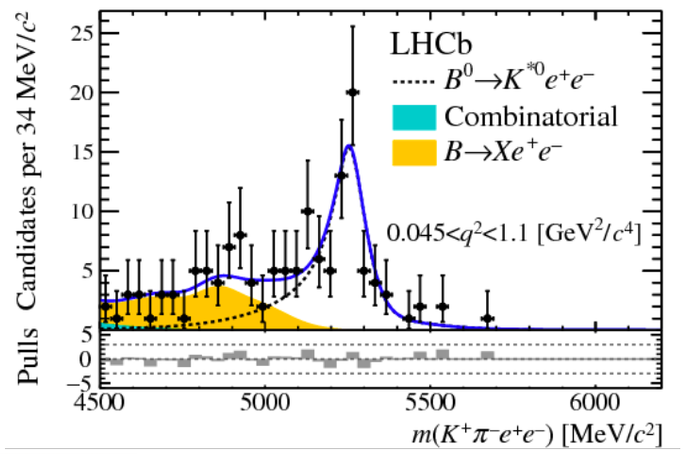
LHCb Run 1 Measurement of $R_{K^{*0}}$

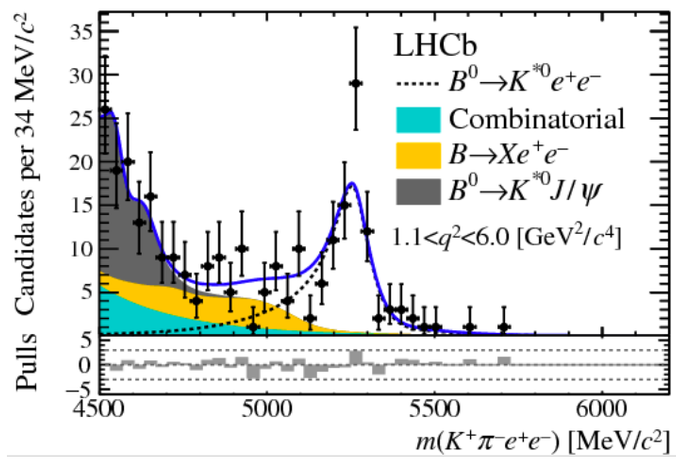
[JHEP08(2017)055]

- Fit $m(K^+\pi^-l^+l^-)$ after applying selections to extract yields for $B^0 \to K^+\pi^-l^+l^-$ decays in the two q^2[GeV^2/c^4] bins, q^2 is the four-momentum squared of the di-lepton system:
  - $0.045 < q^2 < 1.1$
  - $1.1 < q^2 < 6.0$
- Perform a log-likelihood scan of these fit to extract the value of $R_{K^{*0}}$ using the efficiencies determined from Monte Carlo.







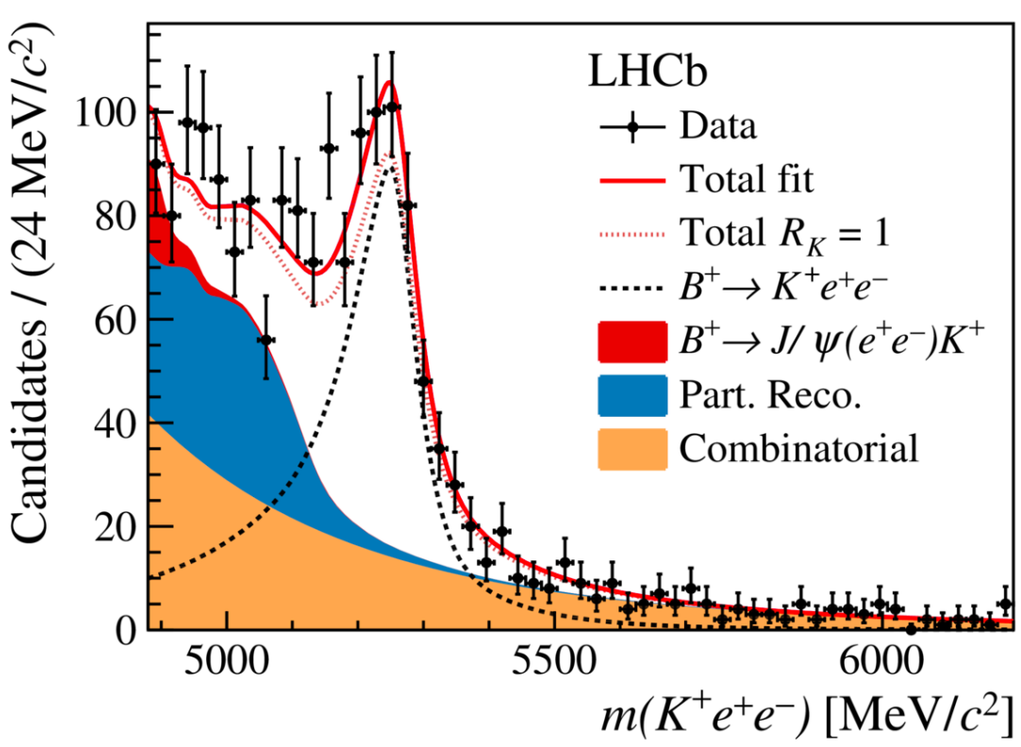


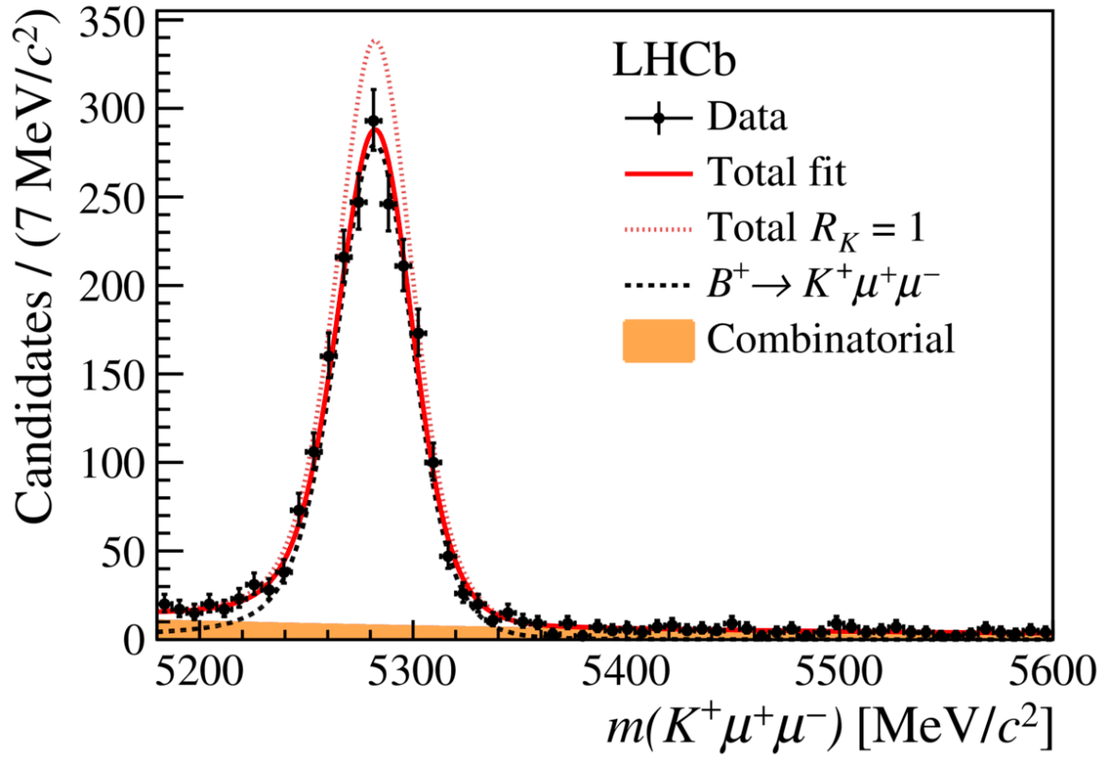
Fits to $m(K^+\pi^-l^+l^-)$

LHCb Run 1 and 15+16 Measurement of R_K

[Phys. Rev. Lett. 122, 191801]

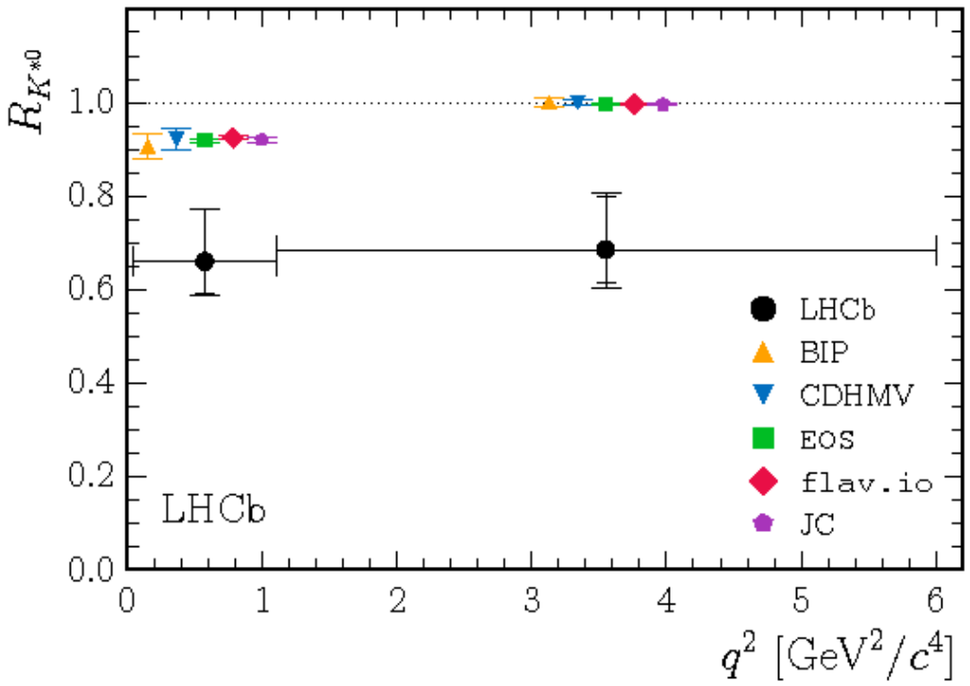
- Fit $m(K^+l^+l^-)$ after applying selections using efficiencies as constraint to directly extract R_K.
- Only fit $1.1 < q^2 < 6.0[\text{GeV}^2/\text{c}^4]$.





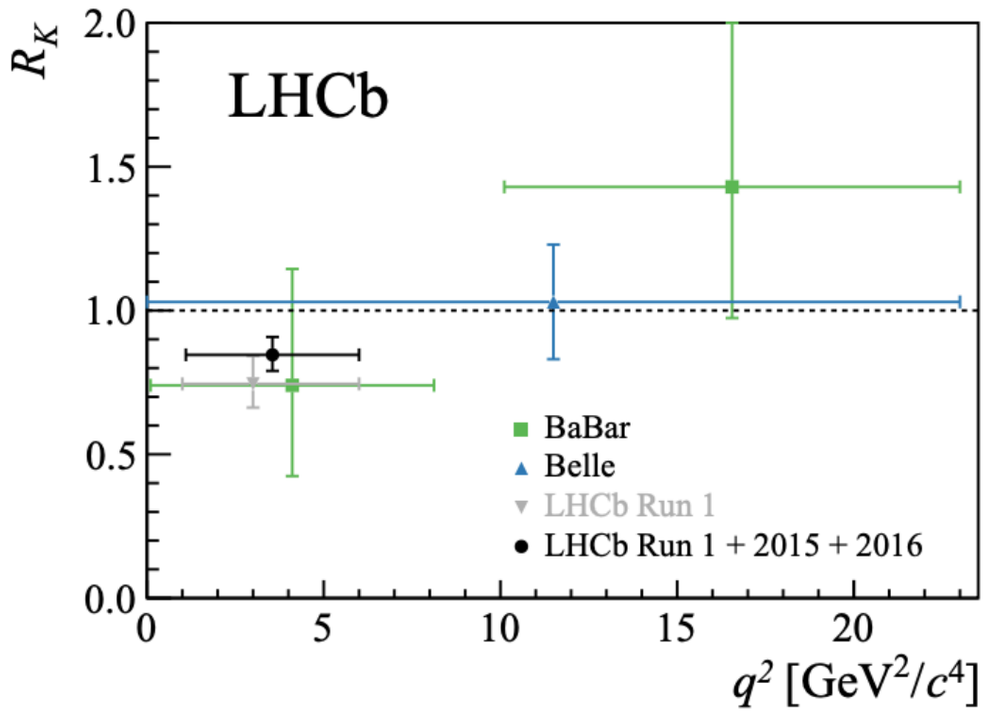
Fits to $m(K^+l^+l^-)$

Results



$$R_{K^{*0}} = \begin{cases} 0.66\ ^{+\ 0.11}_{-\ 0.07}\,(\text{stat}) \pm 0.03\,(\text{syst}) & \text{for } 0.045 < q^2 < 1.1\ \text{GeV}^2/c^4\,, \\ 0.69\ ^{+\ 0.11}_{-\ 0.07}\,(\text{stat}) \pm 0.05\,(\text{syst}) & \text{for } 1.1 \quad < q^2 < 6.0\ \text{GeV}^2/c^4\,. \end{cases}$$

- $R_{K^{*0}}$ Consistent to SM
- 2.2σ at $q^2 = 0.045 - 1.1\ \text{GeV}^2/c^4$
- 2.4σ at $q^2 = 1.1 - 6\ \text{GeV}^2/c^4$



$$R_K = 0.846^{+0.060(stat)+0.016(syst)}_{-0.054(stat)-0.014(syst)}$$

- R_K Consistent to SM at 2.5σ

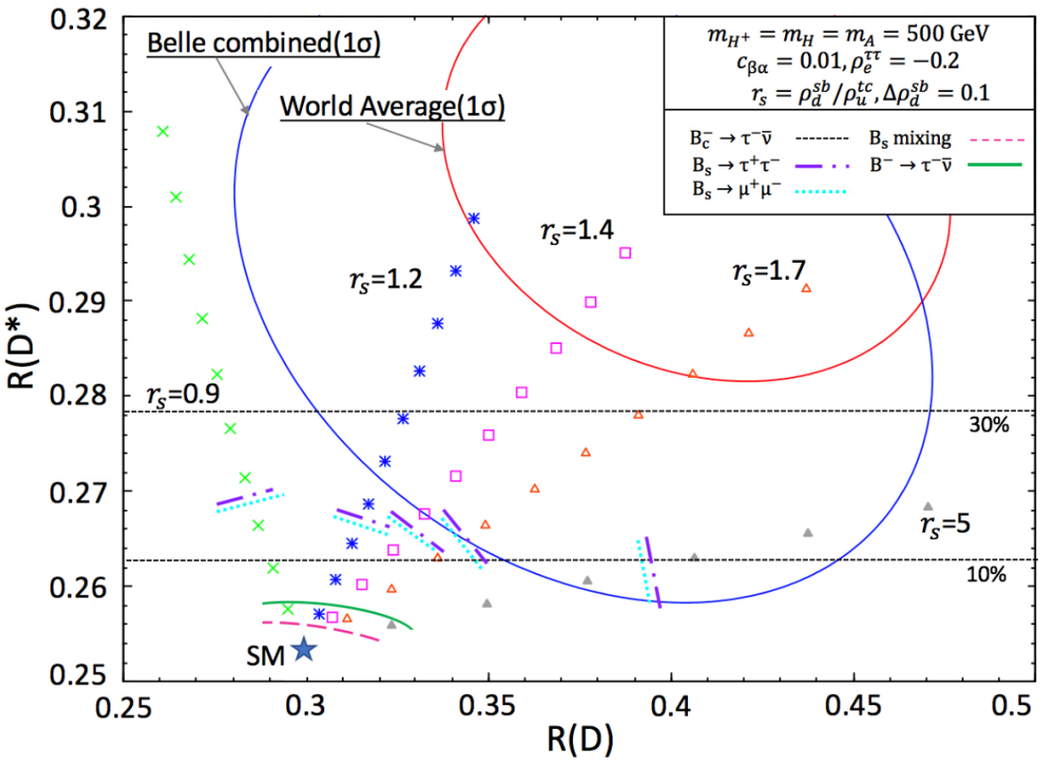
Summary

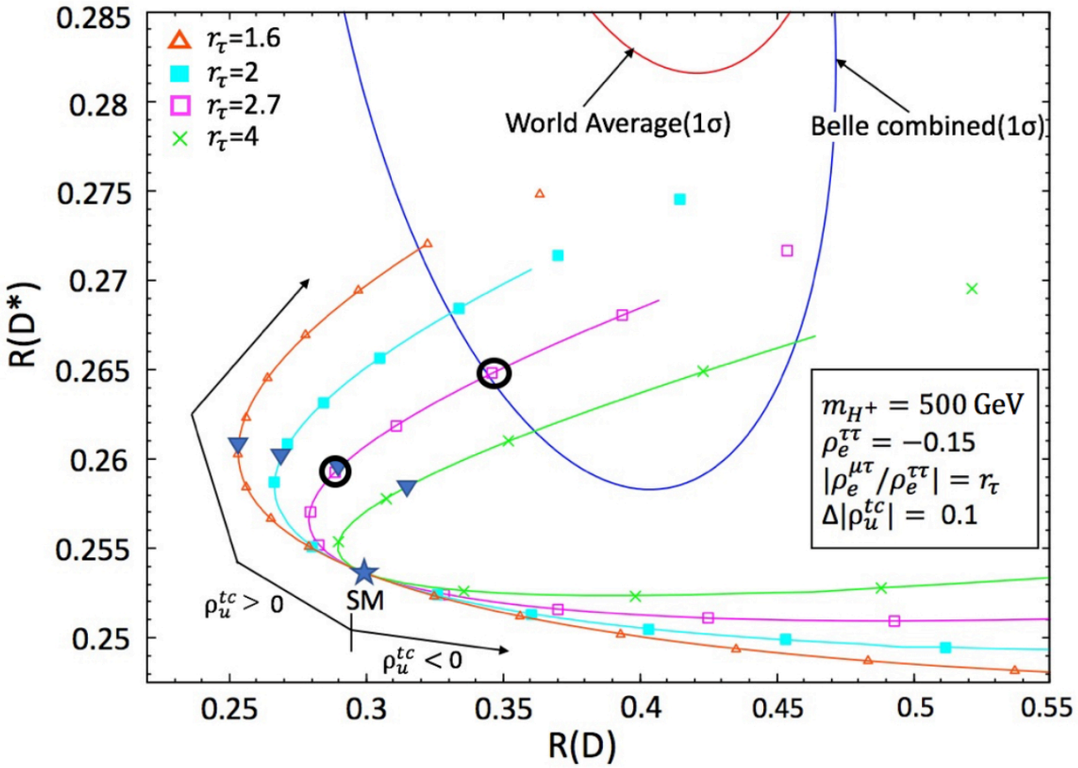
- 2HDM models predict deviation in R_{D*} and $R_{K^{(*)}}$ measurements.
- LHCb performed precision measurements of SM :
  - $R_{D*}, \tau \to \mu\bar{\nu}_\mu\nu_\tau$: 2.1σ
  - R_{D*}, τ three-prong decays : 1.1σ
  - R_K : 2.5σ
  - R_{K*} : 2.2σ at $0.045 < q^2 < 1.1$, 2.4σ *at* $1.1 < q^2 < 6.0$
- LHCb results consistent with the SM so far. Need better sensitivity to constrain SM and NP.

Thank You

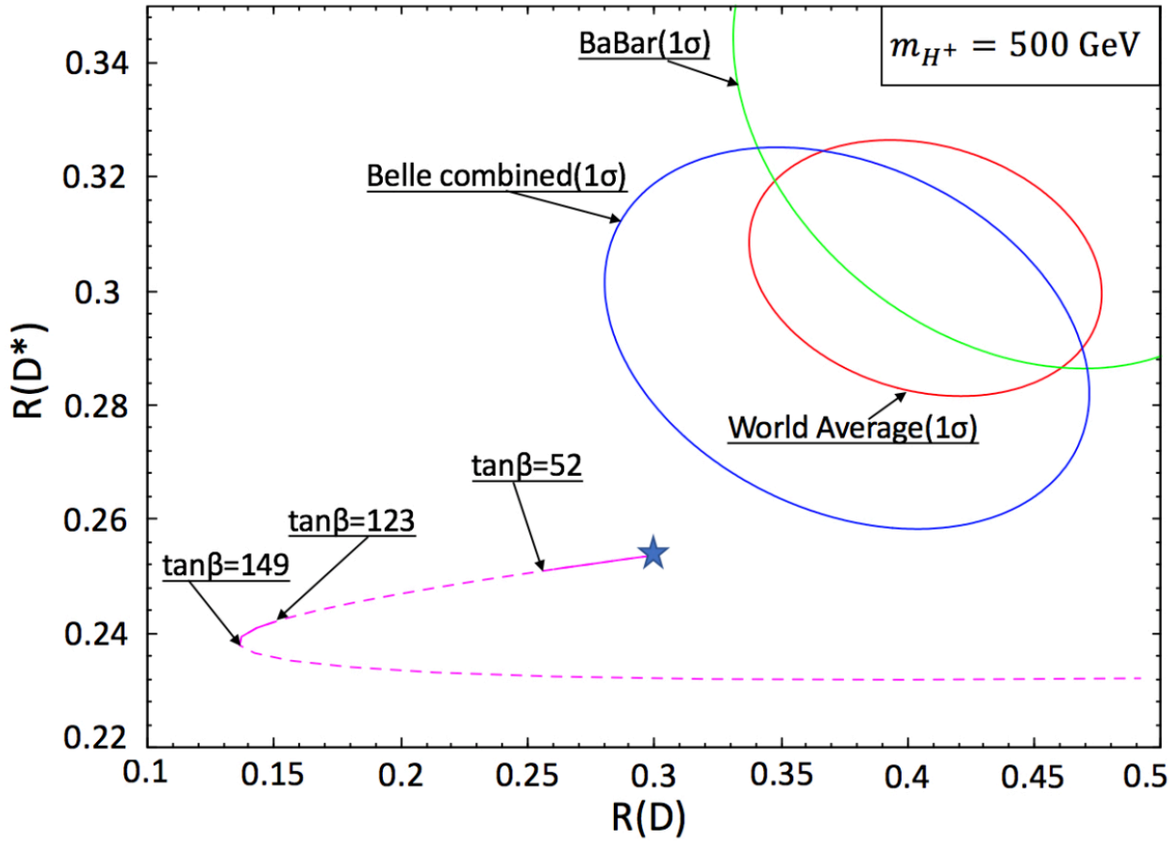
Back-Up

Other scenarios in general 2HDM

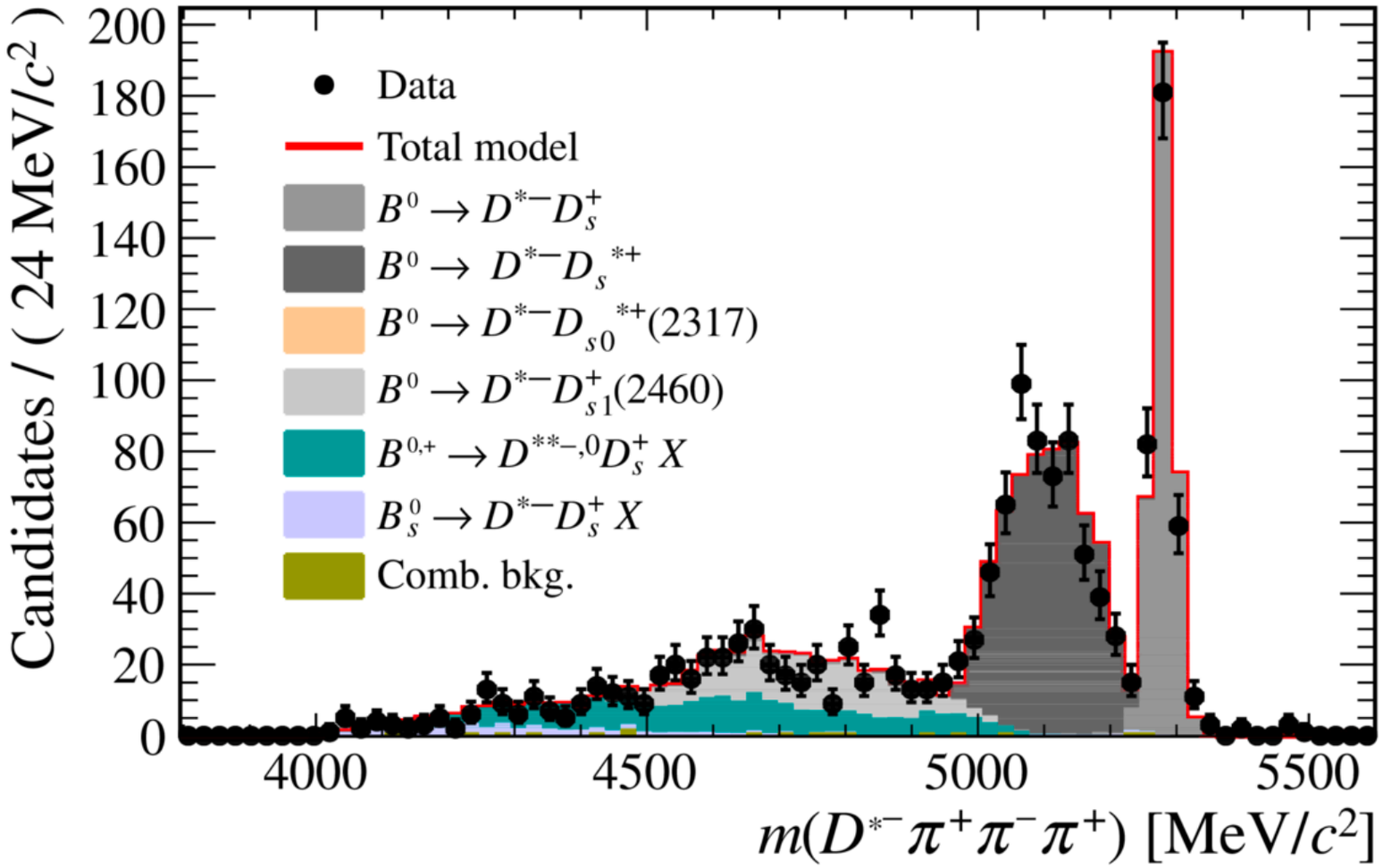




Type II exclusion of $R(D)$ and $R(D^*)$



Normalisation mode invariant mass



q^2 vs $m(K^+l^+l^-)$

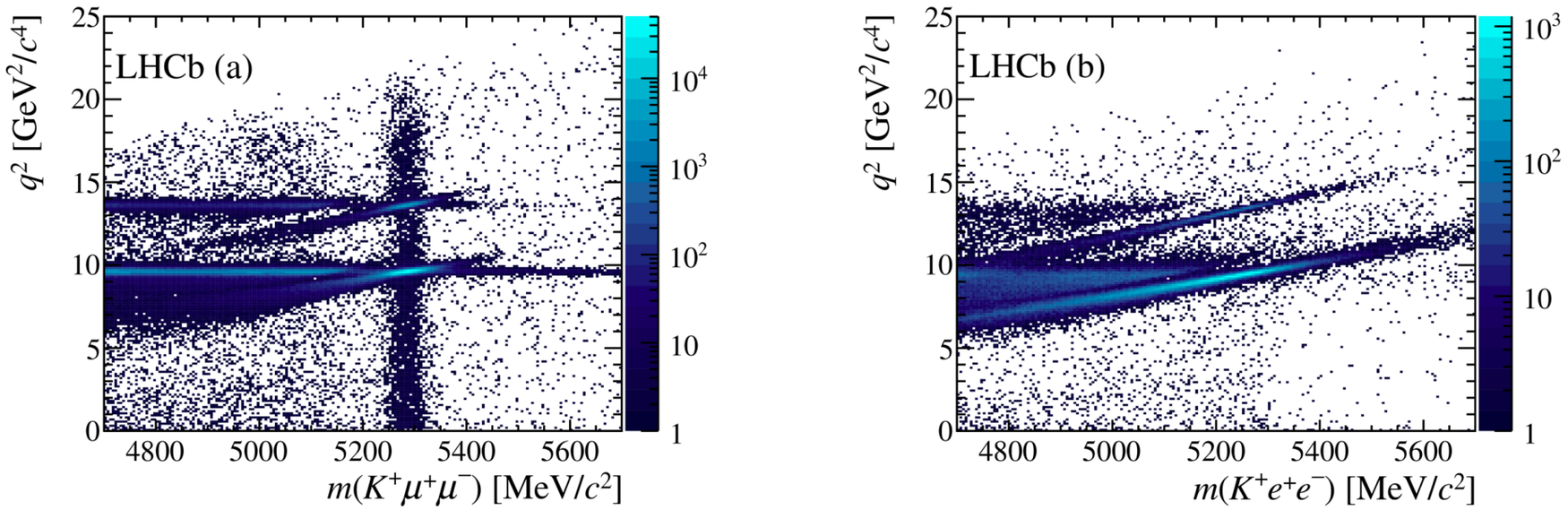


Figure : Dilepton invariant mass squared (q^2) against $K^+l^+l^-$ invariant mass for selected for $B^+ \to K^+\mu^+\mu^-$ candidates (left) and $B^+ \to K^+e^+e^-$ candidates (right). Bremsstrahlung radiation worsens the resolution in the electron mode.

Other Type III $b \to sll$ Feynman diagrams