Search for BSM Higgs bosons at LHCb

Antonio Romero Vidal

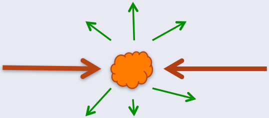
Universidade de Santiago de Compostela

Spanish LHC network meeting
Madrid, May 8th, 2017

Search for New Physics (NP)

High energy (direct) approach

- Energy in particle collisions large enough to create new real particles.
- Particles appear as "peaks" in a given distribution.
- Approach followed by ATLAS and CMS.



High precision (indirect) approach

- Presicion of the measurement is high enough to detect NP effects due to new virtual particles.
- Indirect measurements can access higher energy scales.
- Approach followed by LHCb and B-factories.

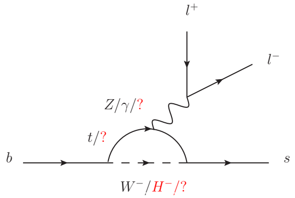
Search for BSM Higgs bosons at LHCb

Selected flavour physics results

- Test of lepton flavour universality (LFU):
  - Measurement of R_K using $B^+ \to K^+ l^+ l^-$ decays.
  - NEW: measurement of $R_{K^{*0}}$ using $B^0 \to K^{*0} l^+ l^-$ decays.
  - Measurement of $R(D^*)$ using leptonic $\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau$ decays.
  - Measurement of $R(D^*)$ using hadronic $\tau^- \to \pi^- \pi^+ \pi^- (\pi^0) \nu_\tau$ decays.

R_K and $R_{K^{*0}}$ using $B^+ \to K^+\mu^+\mu^-$ and $B^0 \to K^{*0}\mu^+\mu^-$ decays

- $b \to sl^+l^-$ decays proceed via FCNC transitions. In the SM only occur at loop order.
- New particles may appear in loops, affecting their branching fractions and angular distributions.

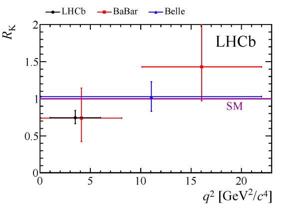


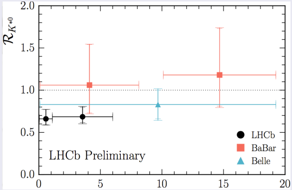
- The ratios $R_K = \frac{\mathcal{B}(B^+\to K^+\mu^+\mu^-)}{\mathcal{B}(B^+\to K^+e^+e^-)}$ and $R_{K^{*0}} = \frac{\mathcal{B}(B^0\to K^{*0}\mu^+\mu^-)}{\mathcal{B}(B^0\to K^{*0}e^+e^-)}$ are predicted by SM to be ~ 1 with negligible theoretical uncertainties.
- At LHCb, experimentally very challenging: different trigger efficiencies for muons and electrons and bremsstrahlung.

R_K and $R_{K^{*0}}$ results

LHCb results

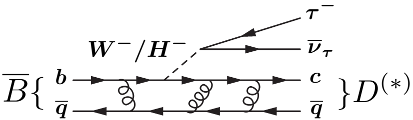
- R_K [PRL 113 151601]:
  $R_K(1 < q^2 < 6\ \text{GeV}/c^2) = 0.745^{+0.090}_{-0.074}\ (\text{stat}) \pm 0.036\ (\text{syst})$
- Compatible with SM at 2.6σ level.
- $R_{K^{*0}}$:
  - low q^2: $2.2 - 2.4\sigma$
  - central q^2: $2.4 - 2.5\sigma$
- Other similar modes for the same test: $B_s^0 \to \phi l^+ l^-$, $\Lambda_b \to \Lambda l^+ l^-$.





$B \to D^{(*)}\tau\nu$

- Powerful channel to test lepton universality.
- In the SM, the only difference between $B \to D^{(*)}\tau^-\nu$ and $B \to D^{(*)}\mu^-\nu$ is the lepton mass.



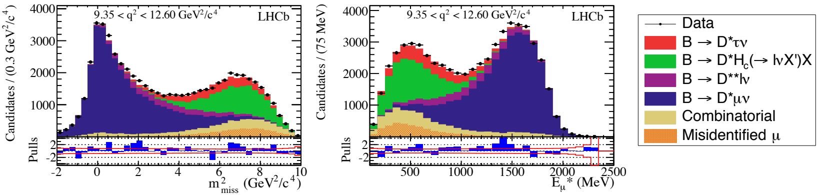
- $R(D^{(*)})$ predicted with high precision in the SM (form factors uncertainties cancel in the ratio).

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}l\nu)} \quad (l = e, \mu)$$

- $R(D^{(*)})$ could be enhanced by contributions from new particles (H^+).

$B \to D^{(*)}\tau\nu$ at LHCb

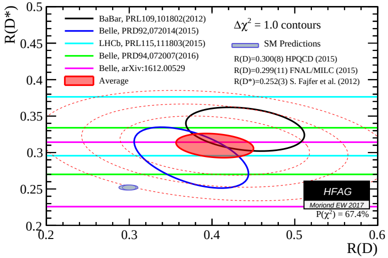
- τ decay reconstructed from the $\tau \to \mu\nu\nu$ at LHCb. Very clean from the experimental point of view (same visible final state).
- $R(D^*)$ extracted by exploiting the kinematic properties of the decay: 3D fit to m^2_{miss}, E^*_μ and q^2 at LHCb.



- LHCb: $R(D^*) = 0.336 \pm 0.027\ (stat) \pm 0.030\ (syst)$ [PRL 115 (2015) 111803].
- $R_{SM}(D^*) = 0.252 \pm 0.003$ [arXiv:1203.2654].
- LHCb measurement 2.1σ deviation from the SM.
- Good agreement with other measurements.

$B \to D^{(*)}\tau\nu$ summary

- LHCb+Belle+Babar (HFAG): $R(D)$ and $R(D^*)$ exceed the SM predictions by 1.9σ and 3.3σ respectively.
- $R(D) - R(D^*)$ combination is at 4.0σ level.
- Still to come at LHCb:
  - High activity in this field.
  - Update of $R(D^*)$ including $R(D)$.
  - Measurement of $R(D^*)$ using hadronic 3-prong $\tau^- \to \pi^-\pi^+\pi^-\nu$ decays.
  - Also ongoing same measurement using $\Lambda_b \to \Lambda_c\tau\nu$, $B_s^0 \to D_s^{(*)}\tau\nu$, $B_c^+ \to J/\psi\tau\nu$ and $B^0 \to D^-\tau\nu$.



- New results from Belle using hadronic $\tau^- \to \pi^-\nu$ and $\tau^- \to \rho^-\nu$ decays more consistent with the SM.
- $R(D^*) = 0.276 \pm 0.034^{+0.029}_{-0.026}$ (0.6σ from SM) [BELLE-CONF-1608, arXiv:1608.06391].

$R(D^*)$ using $\tau^- \to \pi^-\pi^+\pi^-(\pi^0)\nu_\tau$ decays (ongoing)

- $R(D^*)$ can also be measured by using hadronic $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ decays.
- Experimentally convenient to measure:

$$R_{had}(D^*) = \frac{\mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\tau)}{\mathcal{B}(B^0 \to D^{*-}\pi^+\pi^-\pi^+)}$$

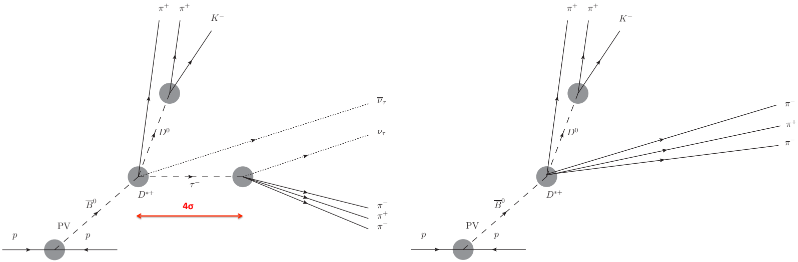
- Both decays share the same visible final state $(D^{*-}\pi^+\pi^-\pi^+)$. Most of the systematic uncertainties cancel in the ratio.
- Then:

$$R(D^*) = R_{had}(D^*) \times \frac{\mathcal{B}(B^0 \to D^{*-}\pi^+\pi^-\pi^+)}{\mathcal{B}(B^0 \to D^{*-}\mu^+\nu_\mu)}$$

- $\mathcal{B}(B^0 \to D^{*-}\pi^+\pi^-\pi^+)$ and $\mathcal{B}(B^0 \to D^{*-}\mu^+\nu_\mu)$ external inputs, known with $\sim 4\%$ and $\sim 2\%$ precision.

$R(D^*)$ using $\tau^- \to \pi^-\pi^+\pi^-(\pi^0)\nu_\tau$ decays (ongoing)

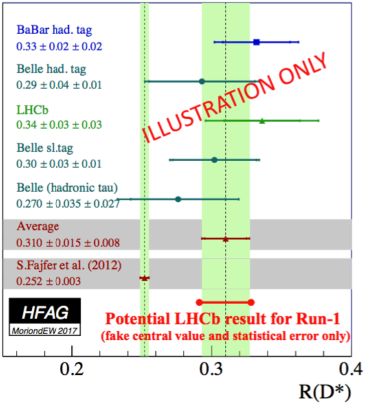
- The good LHCb vertex resolution allows to separate the B^0 and τ vertices.
- Most dominant background $B \to D^{*-}\pi^+\pi^-\pi^+X(\pi^{0\prime}s)$ (BF ~ 100 times larger than signal).



- Applying a 4σ cut in the distance $\tau_z - B^0_z$, $B \to D^{*-}\pi^+\pi^-\pi^+X$ contribution reduced by 3 orders of magnitude.

$R(D^*)$ using $\tau^- \to \pi^-\pi^+\pi^-(\pi^0)\nu_\tau$ decays (ongoing)

- Remaining background after 4σ cut: $B \to D^{*-} H_c X$, with $H_c \to \pi^+\pi^-\pi^+ Y$ (non-negligible lifetime).
- Signal can be extracted by a 3D fit to the τ decay time, q^2 and the output of a BDT.
- BDT:
    - 3π dynamics.
    - $D^* 3\pi$ dynamics.
    - Isolation variables (missing neutral enery).
- Precision in signal yield $\sim 7\%$.
- Results expected in one month from now.



Conclusions

- Flavour physics is a powerful tool for detecting NP contributions. In particular, in the search for BSM Higgs bosons.
- No evidence for NP has been found so far.
- However, a few interesting tensions with the SM are observed (i.e. $R(D^{(*)})$, R_K and $R_{K^{*0}}$).
- Measurement of $R(D*)$ using 3-prong hadronic τ decays to be published very soon.
- Other analyses, as a simultaneous analysis of $R(D)$ and $R(D^*)$; $R(J/\psi)$, $R(D_s)$ and $R(\Lambda_c)$ ongoing.
- Precision will increase with run-II data and the LHCb Upgrade.

THANK YOU VERY MUCH!