

$B \rightarrow D^* \tau \nu$ at LHCb

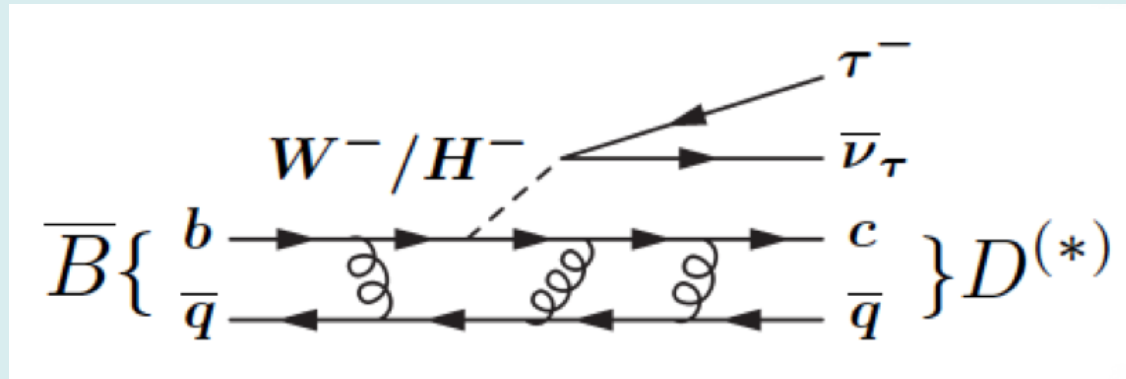
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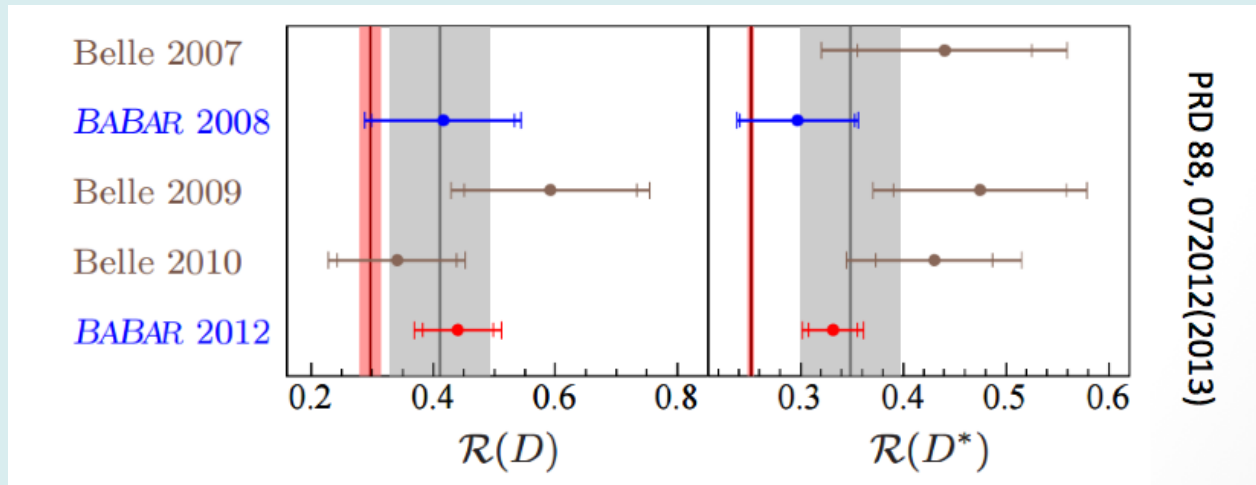
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Motivation

Lepton universality requires equal couplings between the gauge bosons and the three lepton families. No deviation of such behaviour has yet been observed although some hints of lepton non-universality effects in $B^+ \rightarrow K^+ e^+ e^-$ and $B^+ \rightarrow K^+ \mu^+ \mu^-$ decays have been seen [1]. A large class of models that extend the Standard Model propose additional interactions involving enhanced couplings to the third family that would violate this principle. Semileptonic decays of b hadrons to τ leptons provide a sensitive probe for these effects. The presence of additional charged Higgs bosons can have significant effect on the rate of $\bar{B}^0 \rightarrow D^{*+} \tau^- \bar{\nu}$ [2].



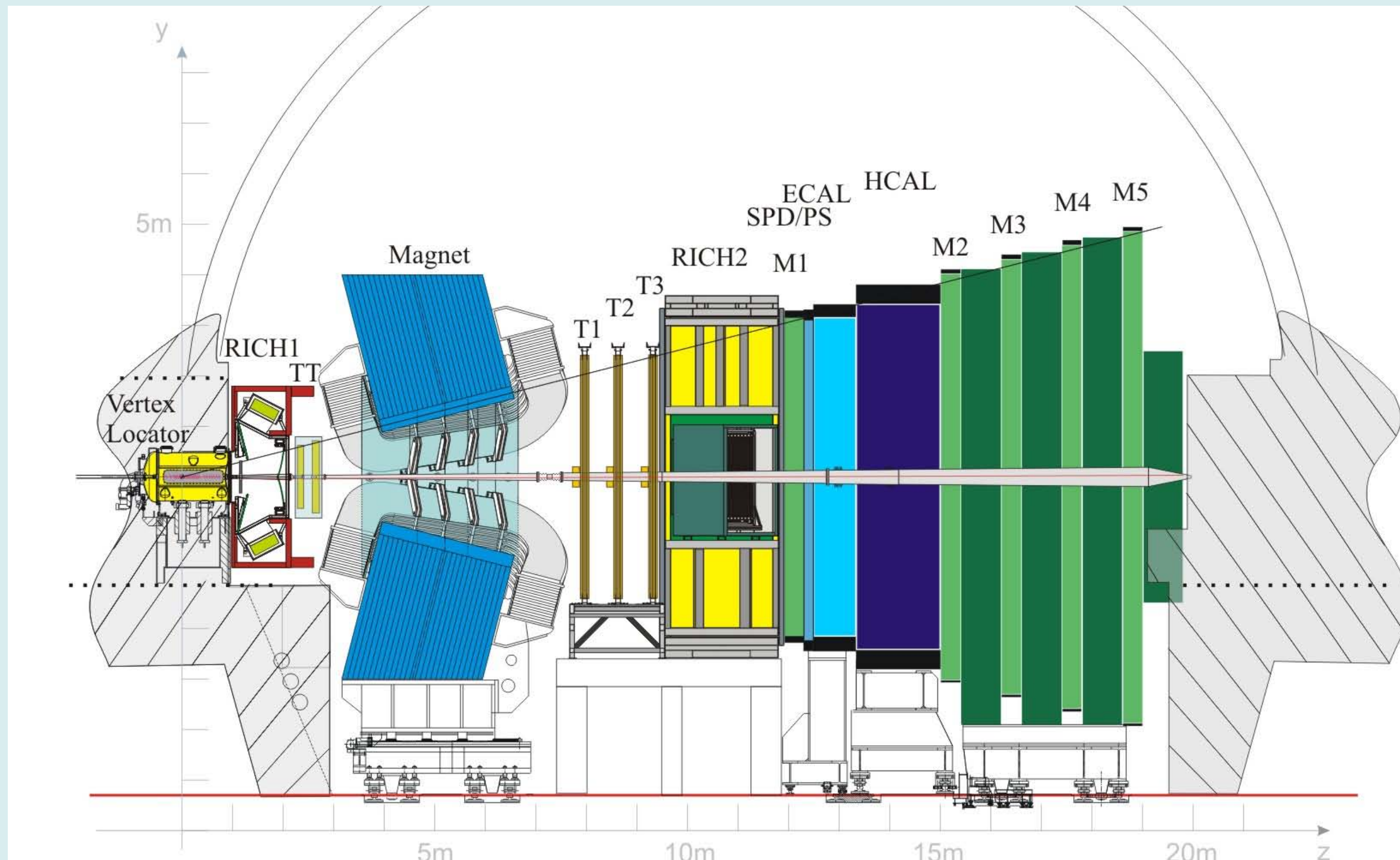
BaBar and Belle have recently reported updated measurements of the ratios [3, 4]:
 $\mathcal{R}(D^*) \equiv \mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \tau^- \bar{\nu}) / \mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \mu^- \bar{\nu})$
 and $\mathcal{R}(D) \equiv \mathcal{B}(\bar{B}^0 \rightarrow D^+ \tau^- \bar{\nu}) / \mathcal{B}(\bar{B}^0 \rightarrow D^+ \mu^- \bar{\nu})$
 which show deviations from the Standard Model predictions as shown in the figure below.



Within the Standard Model, these ratios differ from unity mainly because of phase-space effects due to the difference in charged lepton masses. In this work we present the first measurement of $\mathcal{R}(D^*)$ in hadron collisions at the LHC with data collected by LHCb in 2011 and 2012.

The LHCb Detector

The LHCb detector [5] is a single-arm forward spectrometer covering the pseudo-rapidity range $2 < \eta < 5$, designed for the study of particles containing b or c quarks. The detector includes a high-precision tracking system consisting of a silicon-strip vertex detector surrounding the pp interaction region, a large-area silicon-strip detector located upstream of a dipole magnet with a bending power of about 4 Tm, and three stations of silicon-strip detectors and straw drift tubes placed downstream of the magnet. The tracking system provides a measurement of momentum, p , of charged particles with a relative uncertainty that varies from 0.5% at low momentum to 1.0% at 200 GeV/c. The minimum distance of a track to a primary vertex (PV), the impact parameter, is measured with a resolution of $(15+29/p_T)\mu\text{m}$, where p_T is the component of the momentum transverse to the beam, in GeV/c. Different types of charged hadrons are distinguished using information from two ring-imaging Cherenkov detectors. Photons, electrons and hadrons are identified by a calorimeter system consisting of scintillating-pad and preshower detectors, an electromagnetic calorimeter and a hadronic calorimeter. Muons are identified by a system composed of alternating layers of iron and multi-wire proportional chambers.



Trigger selection

- ▶ no hardware trigger requirement of μ p_T to preserve distinct kinematic distributions for the signal and normalization channels.
- ▶ one high p_T particle in the event independent of the $D^{*+}\mu$.
- ▶ software trigger: accept $D^0 \rightarrow K^- \pi^+$ with candidates satisfying $p_T > 2$ GeV/c.
- ▶ $K^- \pi^+$: $p > 5$ GeV/c and at least one with $p_T > 1.5$ GeV/c.
- ▶ reconstructed mass consistent with the known D^0 mass.

Offline Selection

- 1 well identified K^- and π from D^0 decay.
- 2 D^0 mass within 3σ of measured value.
- 3 $D^0 \pi^+$ must form a vertex.
- 4 $\Delta m = m(D^0 \pi^+) - m(D^0)$ within 2.5σ of the resolution.
- 5 μ well identified with $3 < p < 100$ GeV/c forming a vertex with the D^0 and well separated from the primary vertex.
- 6 $D^{*+}\mu$ should have invariant mass < 5280 MeV/ c^2 and their momentum vector must point to the primary vertex.
- 7 MVA trained to select a sample coming from a B meson.

Data Sample

The data analysed in this work correspond to the integrated luminosity of 1.0 fb^{-1} and 2.0 fb^{-1} collected at proton-proton center-of-mass energies of 7 TeV (2011) and 8 TeV (2012) respectively. The signal channel $\bar{B}^0 \rightarrow D^{*+} \tau^- \bar{\nu}$ with $\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$ and the normalization channel $\bar{B}^0 \rightarrow D^{*+} \mu^- \bar{\nu}$ produce identical visible states and are reconstructed by a common procedure.

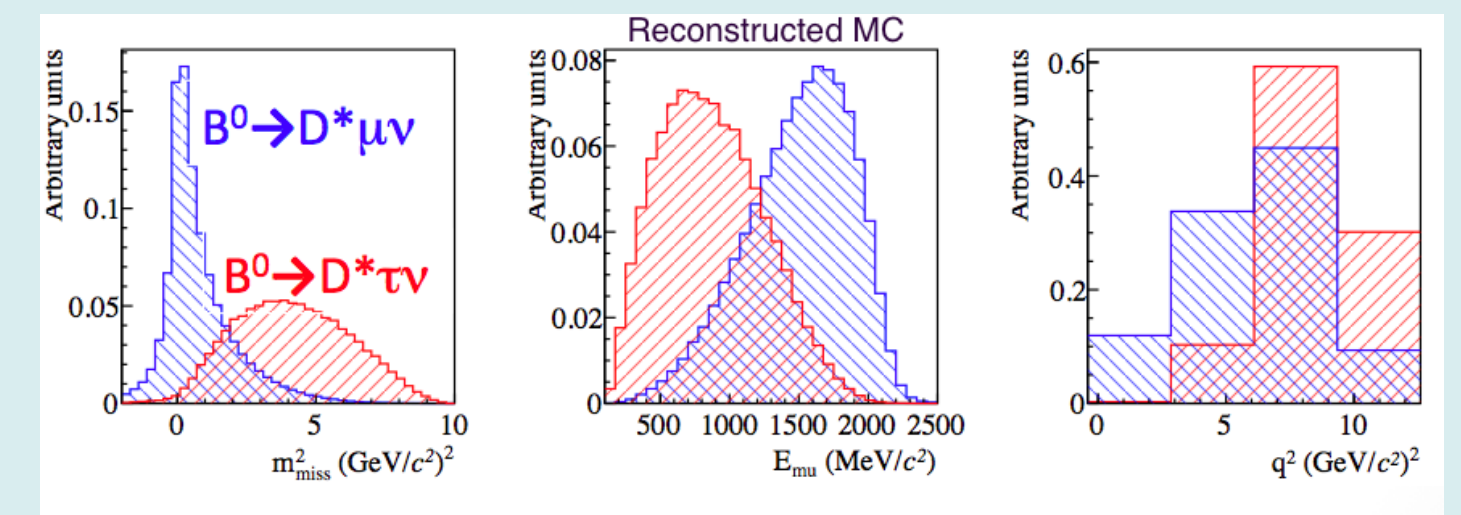
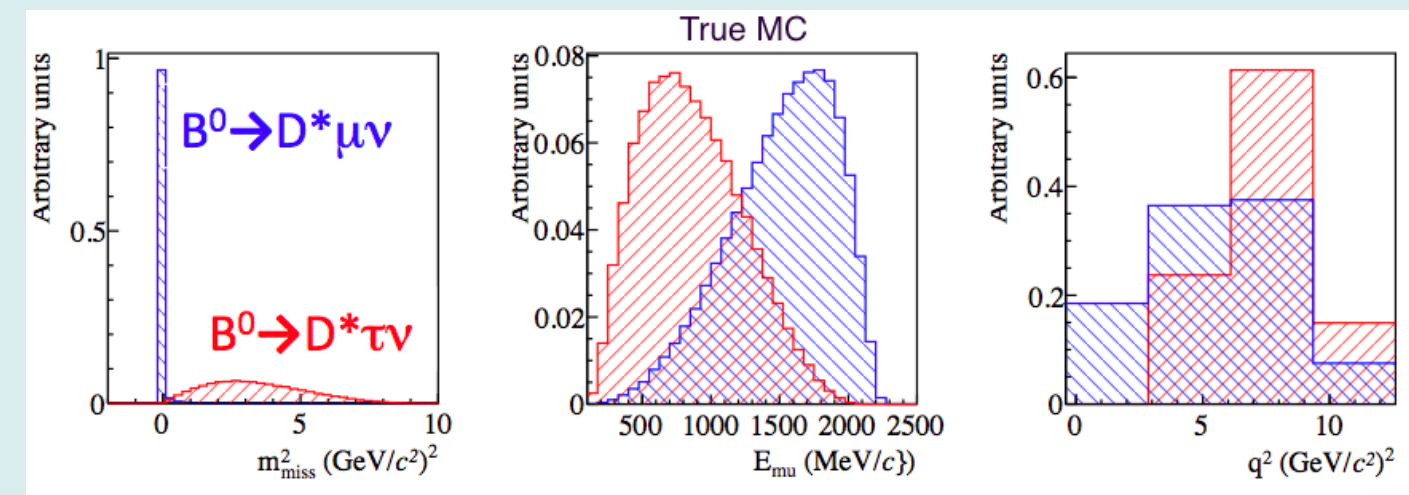
References

- [1] LHCb collaboration, R. Aaij et al., Test of lepton universality using $B \rightarrow K^* \ell^+ \ell^-$ decays, Phys. Rev. Lett. 113(2014) 151601, arXiv:1406.6482.
- [2] M. Tanaka, Charged Higgs effects on exclusive semileptonic B decays, Z. Phys. C67 (1995) 321, arXiv:hep-ph/9411045.
- [3] Belle collaboration, A. Matyja et al., Observation of $B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$ decay at Belle, Phys. Rev. Lett. 99 (2007) 191807, arXiv:0706.4429.
- [4] BaBar collaboration, B. Aubert et al., Observation of the semileptonic decays $B \rightarrow D^* \tau^- \bar{\nu}_\tau$ and evidence for $B \rightarrow D^* \tau^- \bar{\nu}_\tau$, Phys. Rev. Lett. 100 (2008) 021801, arXiv:0709.1698.
- [5] LHCb collaboration, A. A. Alves Jr. et al., The LHCb Detector at the LHC, JINST 3 (2008) S08005.

Separation of the signal from the normalization channel

- ▶ Three variables calculated in the B rest frame:
- ▶ $m_{\text{miss}}^2 = (p_B^\mu - p_D^\mu - p_\mu^\mu)^2$
- ▶ $q^2 = (p_B^\mu - p_D^\mu)^2$
- ▶ the muon energy E_μ

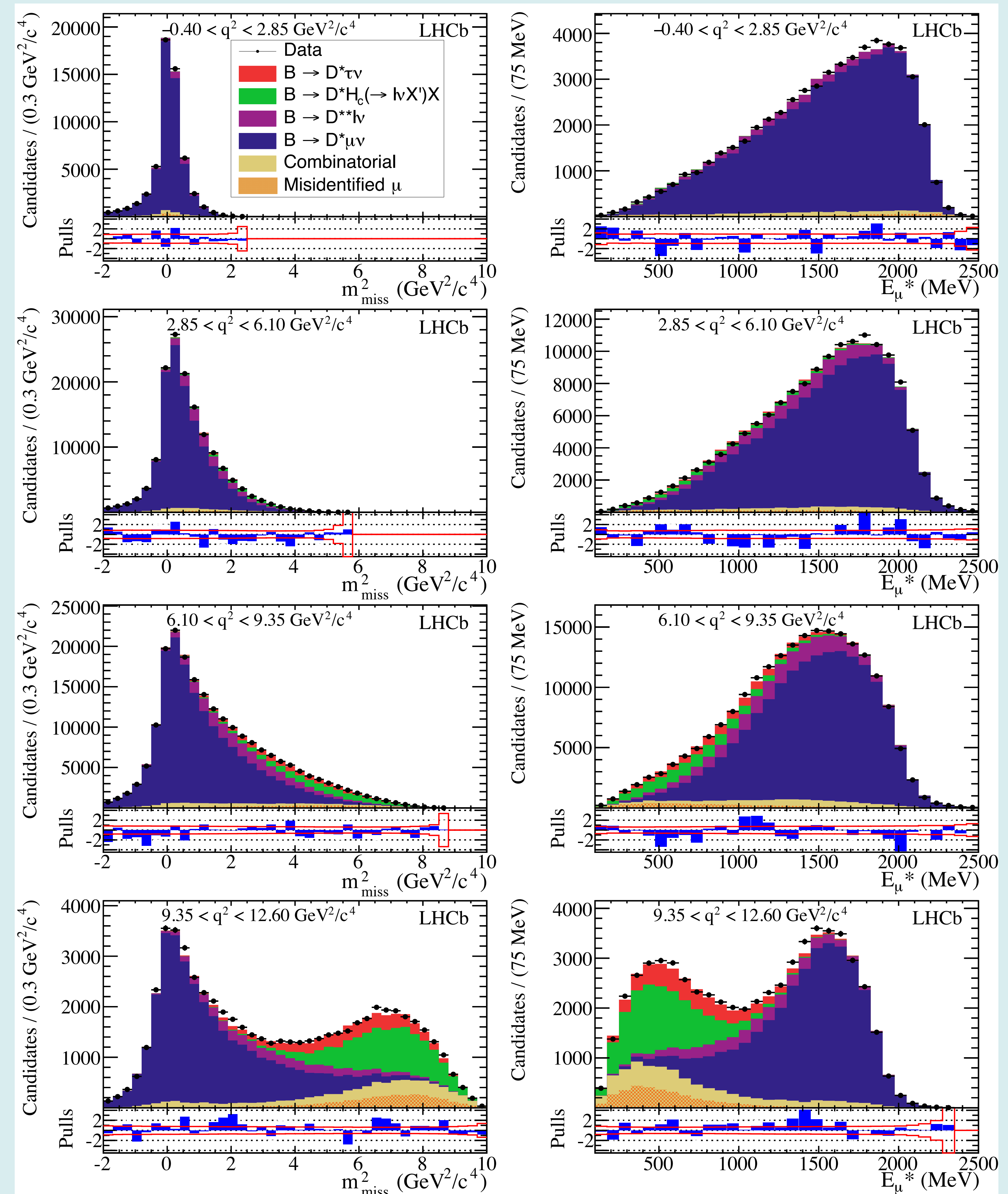
These variables are plotted for simulated events in the figures below. In one case, the true values are shown and in the other, the reconstructed variables obtained using the definition of the B rest frame.



To calculate the B rest frame, the B momentum vector in the laboratory frame is determined from the unit vector connecting the B decay point and the primary vertex. The z (beam axis) component is approximated by $(p_B)_z = \frac{m_B}{m_{\text{reco}}} (p_{\text{reco}})_z$, where m_{reco} and p_{reco} are the mass and momentum of the reconstructed final state particles.

Results (LHCb-PAPER-2015-025, arXiv:1506.08614)

The binned m_{miss}^2 , q^2 and E_μ distributions in data are fitted with a maximum likelihood method with three dimensional templates representing the signal, the normalization and the background sources.



Conclusions

The ratio of branching fractions $\mathcal{R}(D^*)$ is measured to be 0.336 ± 0.027 (stat) ± 0.030 (syst). This is in good agreement with previous measurements and is 2.1 standard deviations greater than the SM expectation of 0.252 ± 0.003 . **This is the first measurement of any decay of a b hadron into a final state with tau leptons at a hadron collider.**

