Lepton Flavour Universality tests using semitauonic decays at LHCb

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CERN LHC seminar, 06/06/2017

Introduction
- Standard Model (CKM)
- Lepton universality (LFU)
- $R(D^{(*)})$ and BSM physics

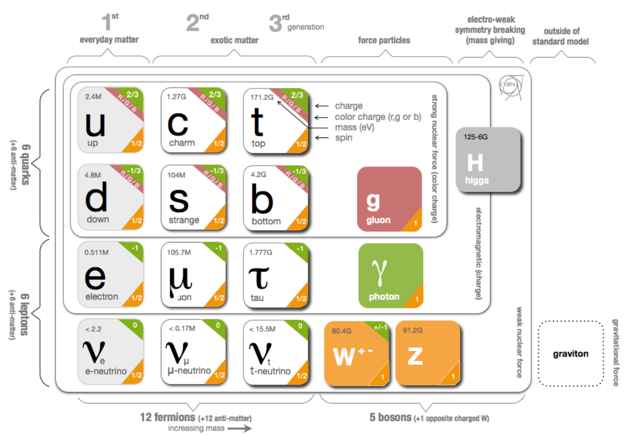
Status
- Previous $R(D^{(*)})$ measurements
- World average

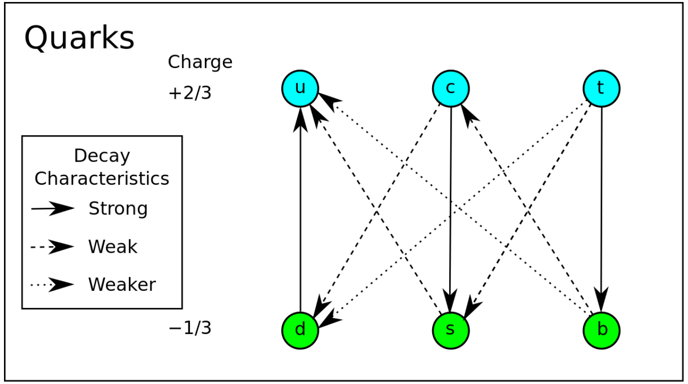
Method
- The LHCb experiment
- Analysis method
- Control samples

Results
- Fit results
- $R(D^{*})$ results
- Cross-checks
- Systematic uncertainties

Conclusions
- Prospects
- Conclusions

Standard Model CKM mechanism





- In the SM, quarks and leptons are divided in 3 families (or generations).

- Transitions between quarks (i.e b→c) of different flavour mediated by a W boson.

- Transitions between quarks of different families suppressed ($|V_{tb}| \sim 1$, $|V_{cb}| \sim 0.04$, $|V_{ub}| \sim 0.004$).

Lepton Flavour Universality

- In the SM, charged lepton flavours are identical copies of one another:
  - Amplitudes for processes involving e, μ, τ must be identical up to effects depending on lepton mass.
  - Lepton universality in the SM might be broken by mass-dependent couplings.

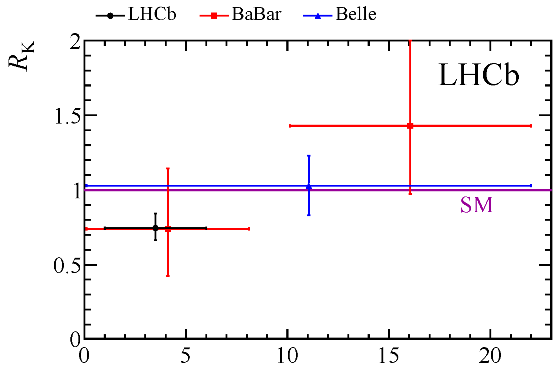
- Observation of violations of lepton universality would be a clear sign for new physics.

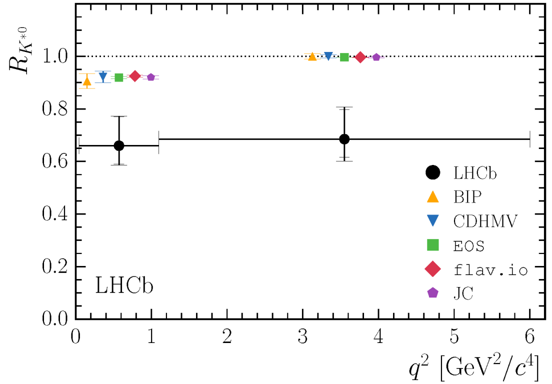
- Searches have been underway for violations in a number of different systems. For instance R_K and R_{K^*}:

$$R_{K^{(*)}} = \frac{BR(B \to K^{(*)}\mu\mu)}{BR(B \to K^{(*)}ee)}$$

- A lot of interest in this area generated by $b \to s\ell\ell$ LHCb measurements.

[PRL 113, 151601 (2014)] [arXiv:1705.05802]

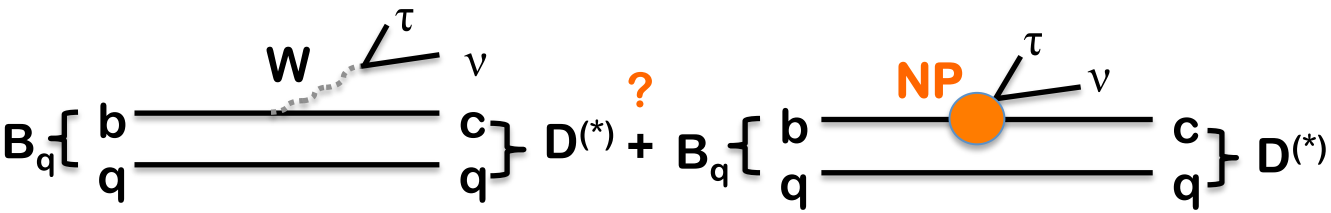




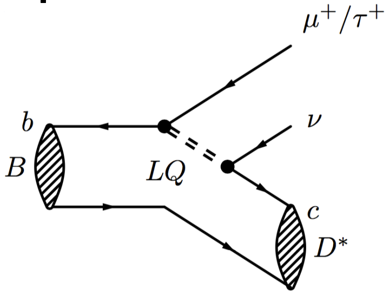
[S. Bifani LHC seminar, 18/04/2017]

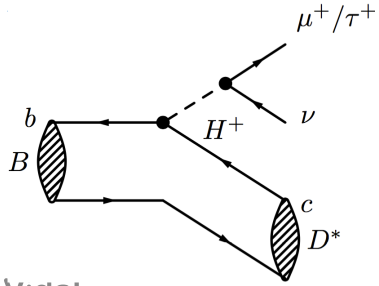
The $B^0 \to D^{*-}\tau^+\nu_\tau$ decay

- **Tree level transition** mediated by a W in the SM:



- New physics (NP) could couple only to the 3[th] generation (τ).
- Comparison between semitauonic (τ) and semimuonic (μ) decays sensitive to NP.
- If NP present → **Modified BR and angular distributions**.





Predictions on $R(D^*)$

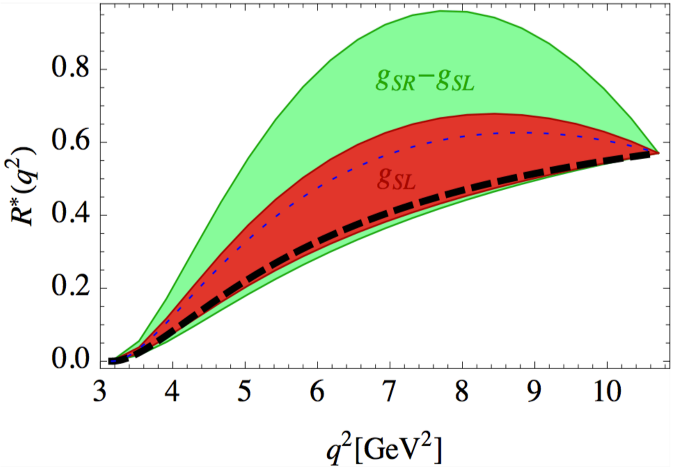
- What we want to measure:
  - $R(D^*) = BR(B^0 \to \mathbf{D^{*-}\tau^+\nu})/BR(B^0 \to \mathbf{D^{*-}\mu^+\nu})$

- Very clean SM prediction due to cancellation of $B \to D^*$ form-factor uncertainties.
  - $R_{SM}(D^*) = 0.252 \pm 0.003$

- Deviation from unity due to different μ/τ masses (available phase space).

- R(D*) enhanced/reduced in many NP scenarios (2HDM [Z.Phys. C67 (1995) 321-326] and leptoquarks [Z.Phys.C61:613-644,1994])

[PRD 85 094025 (2012)]

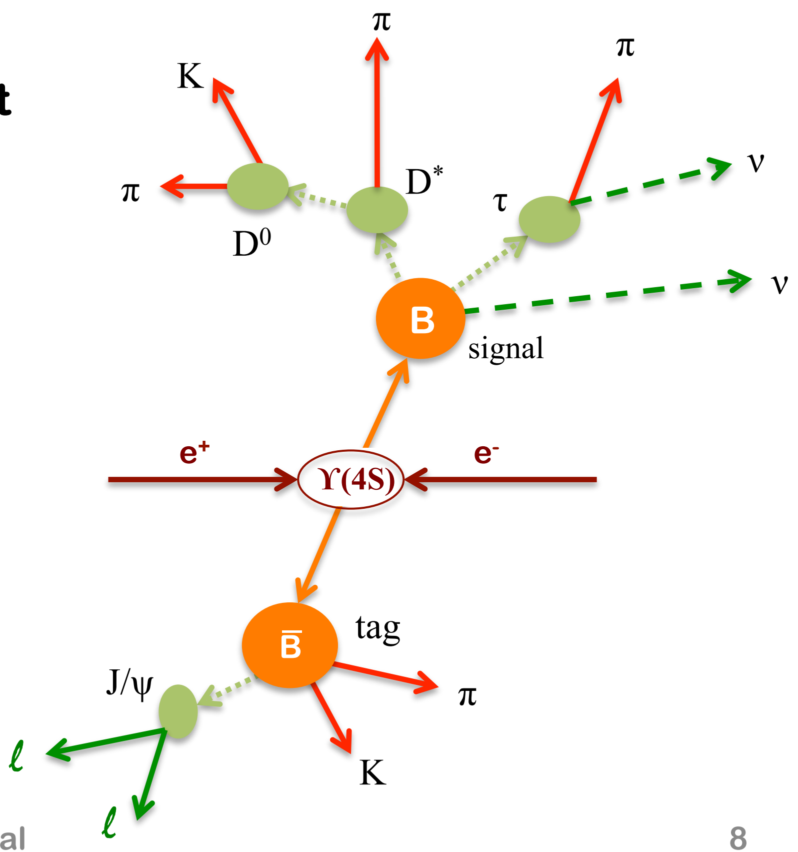


R(D*) in SM and 2 NP scenarios.

Experimental status

$R(D^{(*)})$ measurements at the B-factories

- e^+/e^- collisions producing $\Upsilon(4S) \to B\bar{B}$.
- **Using fully reconstructed B-tag and a constraint to the $\Upsilon(4S)$ mass, possible to measure the momentum of the B-signal.**
- **Then, the missing mass (neutrinos) can be measured with high precision.**
- **At B-factories, semitauonic B decays studied using:**
  - **Leptonic: $\tau\to\mu\nu\nu$ and $\tau\to e\nu\nu$. $R(D^{(*)})$ measured with respect to $[BR(B\to D^{(*)}\mu\nu)+BR(B\to D^{(*)}e\nu)]/2$.**
  - **Hadronic: $\tau\to\pi\nu$ and $\tau\to\rho\nu$.**
  - **Hadronic and semileptonic B-tag.**



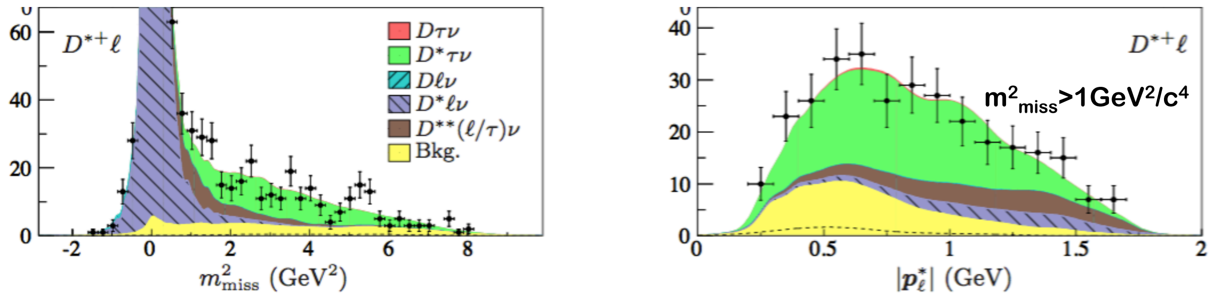
BaBar measurement

[Phys. Rev. D 88, 072012 (2013)]

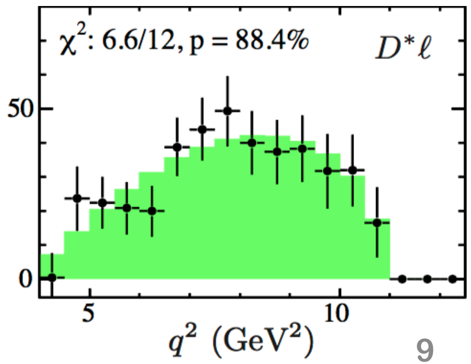
- Use of $\tau\to\mu\nu\nu$ and $\tau\to e\nu\nu$ to reconstruct the τ lepton.
- Simultaneous analysis R(D*) vs R(D) using $B^0\to D^{*-}\tau\nu$, $B^+\to D^{*0}\tau\nu$, $B^0\to D^+\tau\nu$, $B^+\to D^0\tau\nu$.
- Unbinned maximum likelihood fit to m^2_{miss} and $|p_\ell^*|$:
  - R(D) = 0.440 ± 0.058 ± 0.042 (2.0σ from SM).
  - R(D*) = 0.332 ± 0.024 ± 0.018 (2.7σ from SM).
  - Combination at 3.4σ above SM.

$m^2_{miss} = (p_B - p_{D*} - p_\ell)^2 = m^2_{3\nu}$
$|p_\ell^*|$: Lepton (e/μ) momentum in B rest frame.
$q^2 = (p_B - p_{D*})^2 = m^2_{W*}$

Fit projections on m^2_{miss} and $|p_\ell^*|$:



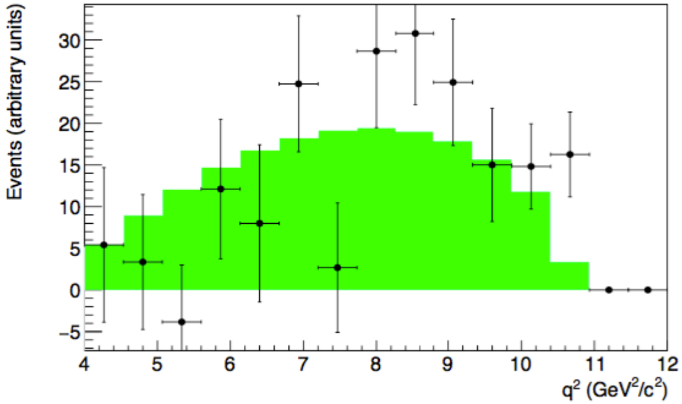
Measured q^2 distributions (m^2_{miss}>1.5GeV^2/c^4) vs SM:



Belle measurements

- $\tau \to \mu\nu\nu$ and $\tau \to e\nu\nu$, hadronic B-tag [Phys. Rev. D 92, 072014 (2015)]:
  - $R(D^*) = 0.293 \pm 0.038(\text{stat}) \pm 0.015(\text{syst})$
  - $R(D) = 0.375 \pm 0.064(\text{stat}) \pm 0.026(\text{syst})$
- $\tau \to \mu\nu\nu$ and $\tau \to e\nu\nu$, semileptonic B-tag [Phys. Rev. D 94, 072007 (2016)]:
  - $R(D^*) = 0.302 \pm 0.030(\text{stat}) \pm 0.011(\text{syst})$
- $\tau \to \pi\nu$ and $\tau \to \rho\nu$, [Phys. Rev. Lett. 118, 211801 (2017)]:
  - $R(D^*) = 0.270 \pm 0.035(\text{stat})^{+0.028}_{-0.025}(\text{syst})$
  - $P_\tau(D^*) = -0.38 \pm 0.51(\text{stat})^{+0.21}_{-0.16}(\text{syst})$
- All $R(D^{(*)})$ measurements consistent but above SM.

Measured q^2 distributions (m^2_{miss}>0.85GeV^2/c^4) vs SM:

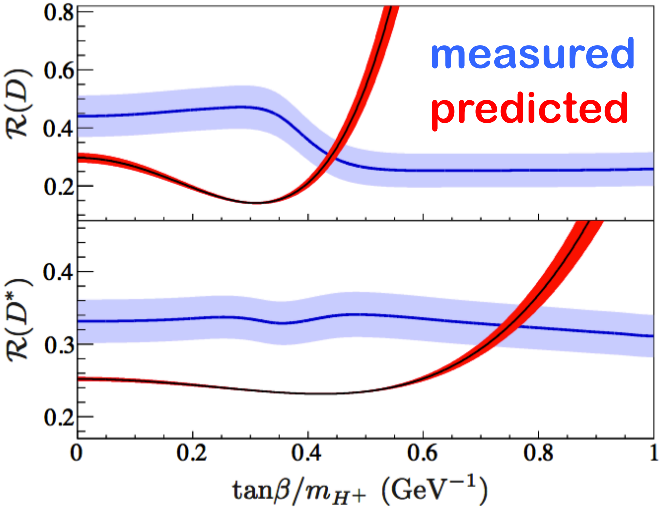


[Phys. Rev. D 92, 072014 (2015)]

B-factories results: interpretation

BaBar:

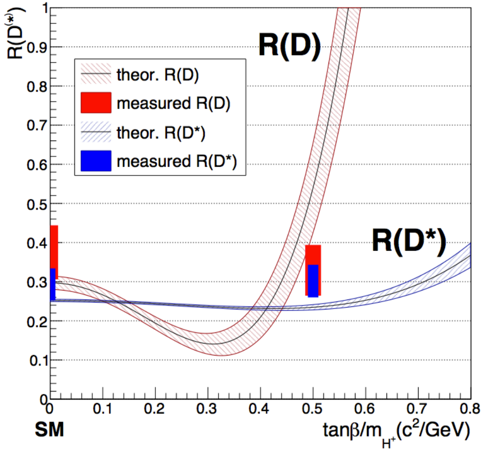
[Phys. Rev. D 88, 072012 (2013)]



BaBar measurement disfavours Type-II 2HDM.

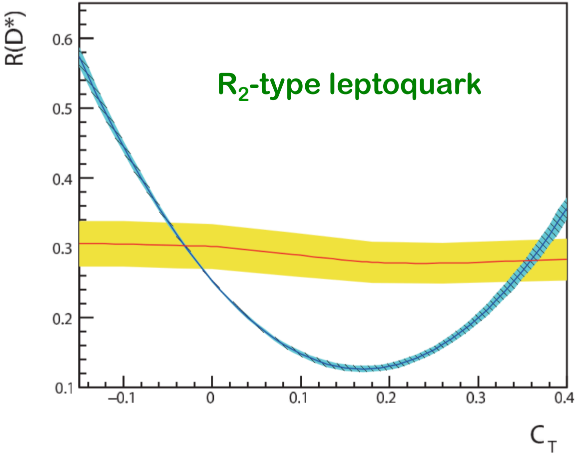
Belle:

[Phys. Rev. D 92, 072014 (2015)]



Compatible with Type-II 2HDM in the region around $\tan\beta/m_{H+} = 0.5\ c^2/GeV$

[Phys. Rev. D 94, 072007 (2016)]



Studied 2 types of leptoquark models. Results allow additional contributions from scalar and vector operators.

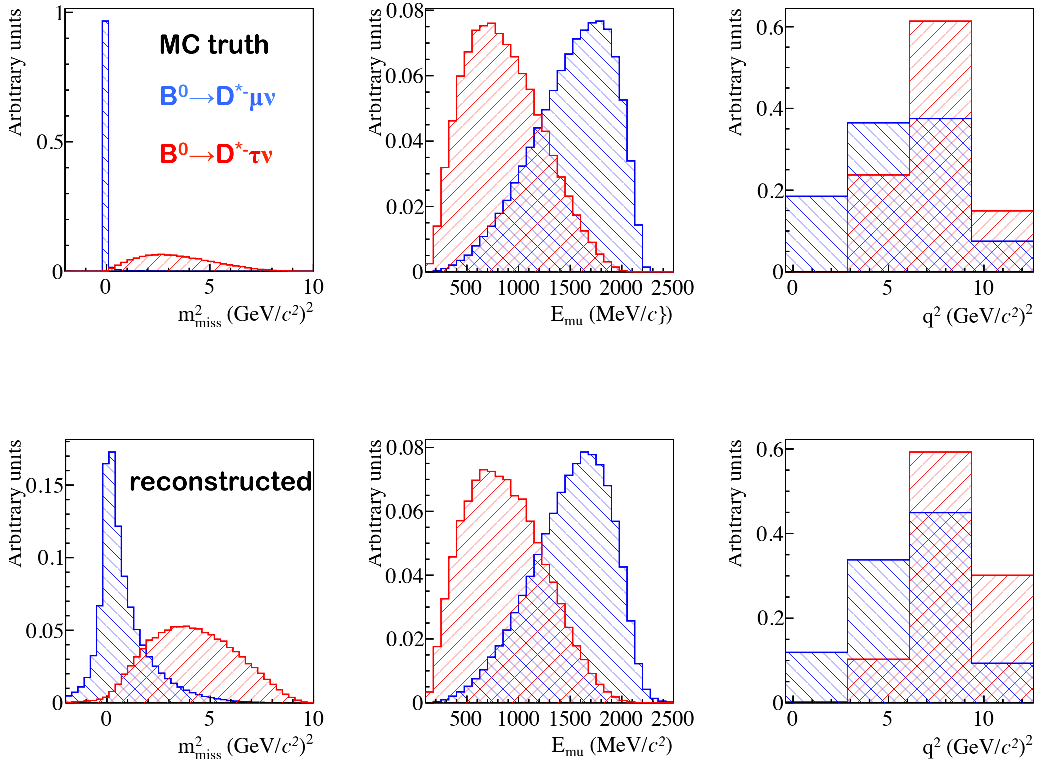
LHCb muonic R(D*)

[Phys. Rev. Lett. 115, 111803 (2015)]

- First measurement of R(D*) in a hadron collider.
- τ reconstructed with $\tau \rightarrow \mu\nu\nu$.
- Difficult, due to missing kinematic constraints ($\Upsilon(4S)$).
- B boost along z >> boost of decay products in B rest frame.
- The B momentum approximated by:

$$(\gamma\beta_z)_B = (\gamma\beta)_{D^*\mu} \Rightarrow (p_z)_B = \frac{m_B}{m(D^*\mu)}(p_z)_{D^*\mu}$$

- 18% resolution on p_B good enough to preserve signal and background discrimination in m^2_{miss}, E_μ^* and q^2.



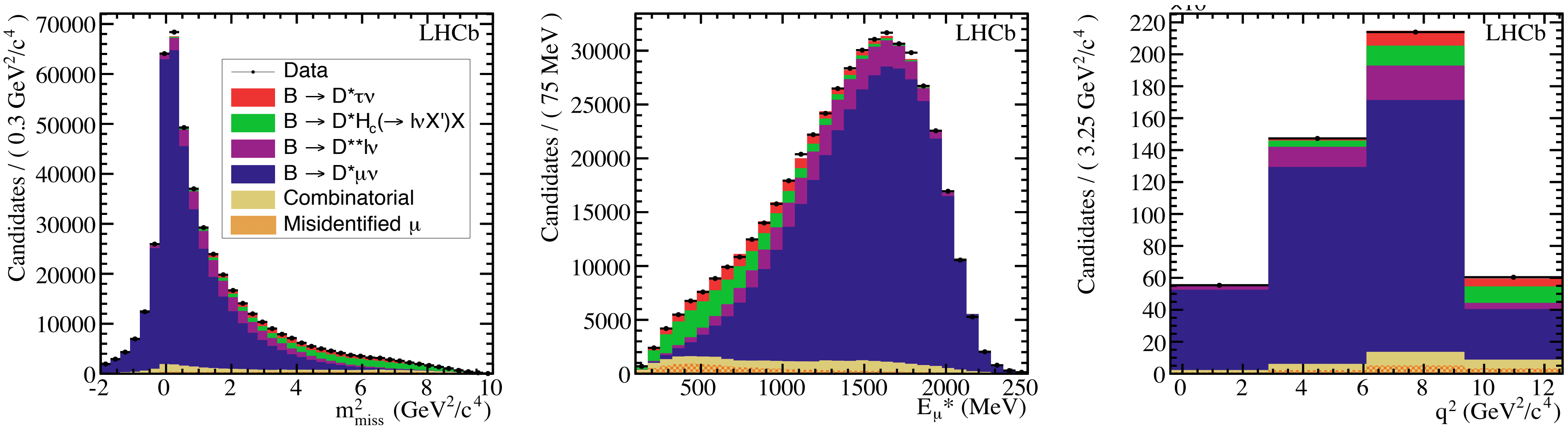
[LHCb-PAPER-2015-025]

LHCb muonic R(D*)

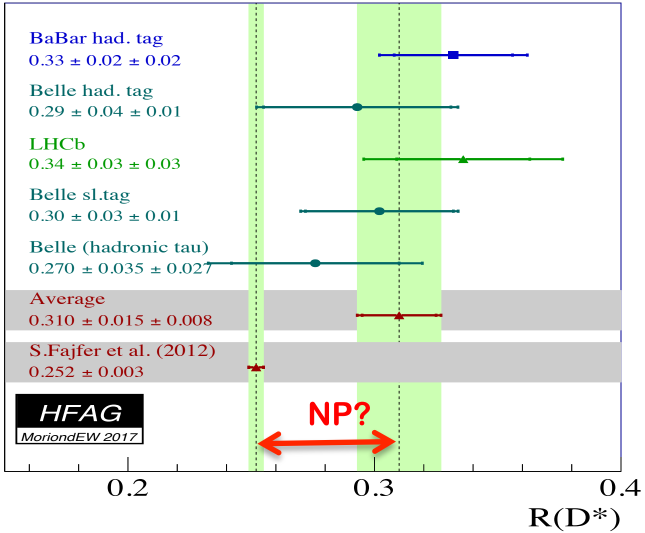
[Phys. Rev. Lett. 115, 111803 (2015)]

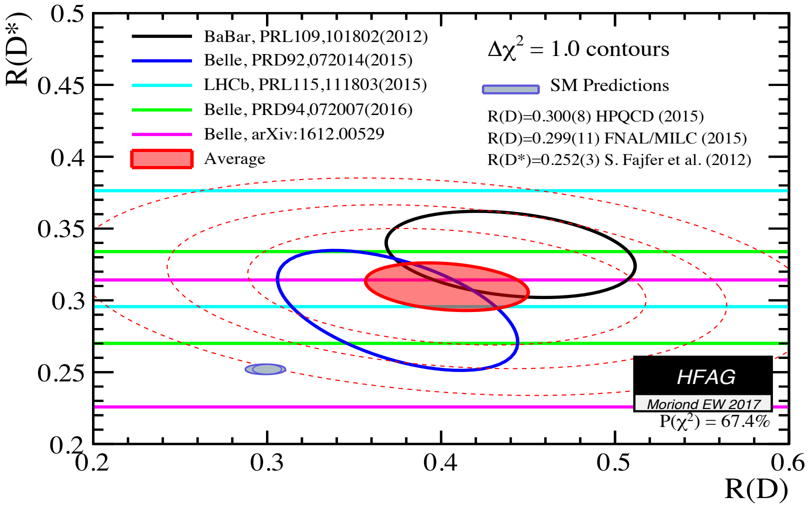
- R(D*): fit parameter obtained from a 3-dimensional template fit to m^2_{miss}, $E_\mu{}^*$ and q^2:
  - R(D*) = 0.336 +- 0.027 +- 0.030
- Result is 2.1σ above SM.

$m^2_{miss} = (p_B - p_{D^*} - p_\mu)^2 = m^2_{3\nu}$
$E_\mu{}^*$: muon energy in B rest frame.
$q^2 = (p_B - p_{D^*})^2 = m^2_{W^*}$



R(D(*)) status





- **R(D*) in tension with SM at 3.4σ level.**
- **R(D) and R(D*) combination in tension with SM at the level of 3.9σ.**

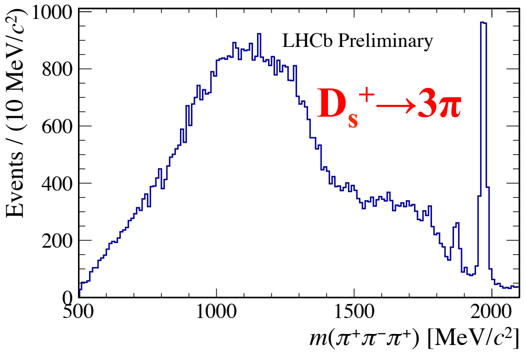
Measuring R(D*) using 3-prong $\tau^- \to \pi^- \pi^+ \pi^- (\pi^0) \nu$ decays

LHCb-PAPER-2017-017, in preparation

Features of this analysis

- τ lepton reconstructed using the $\tau^- \rightarrow \pi^-\pi^+\pi^-(\pi^0)\nu_\tau$ decay mode.
- A semileptonic decay without charged leptons in final state (pions and kaons).
- Zero background from normal semileptonic decays ($B^0 \rightarrow D^{*-}\mu^+\nu_\mu X$).
- In this analysis, it is the background ($B \rightarrow D^{*-}DX$) that leads to nice mass peaks and not the signal. This provides key handle to control the various backgrounds.
- Only 1 neutrino emitted at the τ vertex ($\tau^- \rightarrow \pi^-\pi^+\pi^-(\pi^0)\nu_\tau$ vs $\tau \rightarrow \mu\nu_\mu\nu_\tau$). Fit variables can be reconstructed with reasonable precision.

τ decay mode	BR (%) [PDG-2017]
$\tau \rightarrow \mu\nu_\mu\nu_\tau$	17.39 ± 0.04
$\tau \rightarrow e\nu_\mu\nu_\tau$	17.82 ± 0.04
$\tau^- \rightarrow \pi^-\pi^+\pi^-\nu_\tau$	9.31 ± 0.05
$\tau^- \rightarrow \pi^-\pi^+\pi^-\pi^0\nu_\tau$	4.62 ± 0.05
$\tau^- \rightarrow \pi^-\nu_\tau$	10.82 ± 0.05
$\tau^- \rightarrow \rho^-\nu_\tau$	25.49 ± 0.09



Method for measuring R(D*)

- What we measure:

$$K_{had}(D^*) = \frac{BR(B^0 \to D^{*-}\tau^+\nu_\tau)}{BR(B^0 \to D^{*-}\pi^+\pi^-\pi^+)} = \frac{N(B^0 \to D^{*-}\tau^+\nu_\tau)}{N(B^0 \to D^{*+}\pi^-\pi^+\pi^-)} \times \frac{1}{BR(\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\bar{\nu}_\tau)} \times \frac{\varepsilon(B^0 \to D^{*+}\pi^-\pi^+\pi^-)}{\varepsilon(B^0 \to D^{*-}\tau^+\nu_\tau)}$$

- Signal and normalization share same visible final state ($D^{*-}\pi^+\pi^-\pi^+$).

- Most of the systematic uncertainties cancel in the ratio (PID, trigger …).

- R(D*) obtained from:

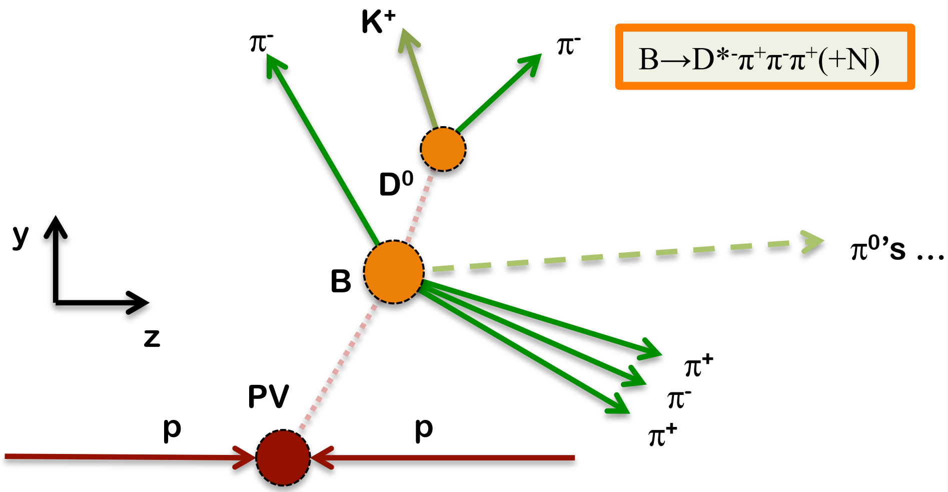
$$R(D^*) = K_{had}(D^*) \times \frac{BR(B^0 \to D^{*-}\pi^+\pi^-\pi^+)}{BR(B^0 \to D^{*-}\mu^+\nu_\mu)}$$

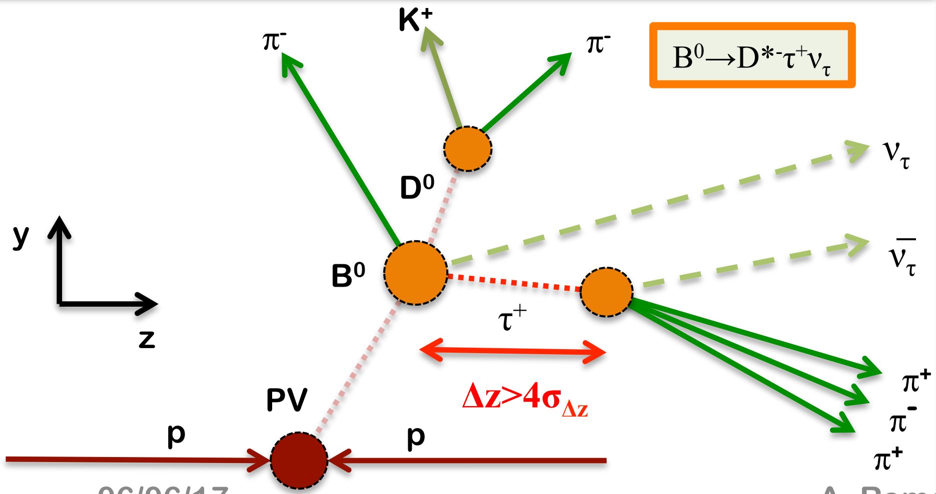
[~4% precision]

[~2% precision]

[PDG 2016]

- $N(B^0 \to D^{*-}\pi^+\pi^-\pi^+)$ from an un-binned likelihood fit to $m(D^{*-}\pi^+\pi^-\pi^+)$.
- $N(B^0 \to D^{*-}\tau^+\nu_\tau)$ from a 3-dimensional template fit.

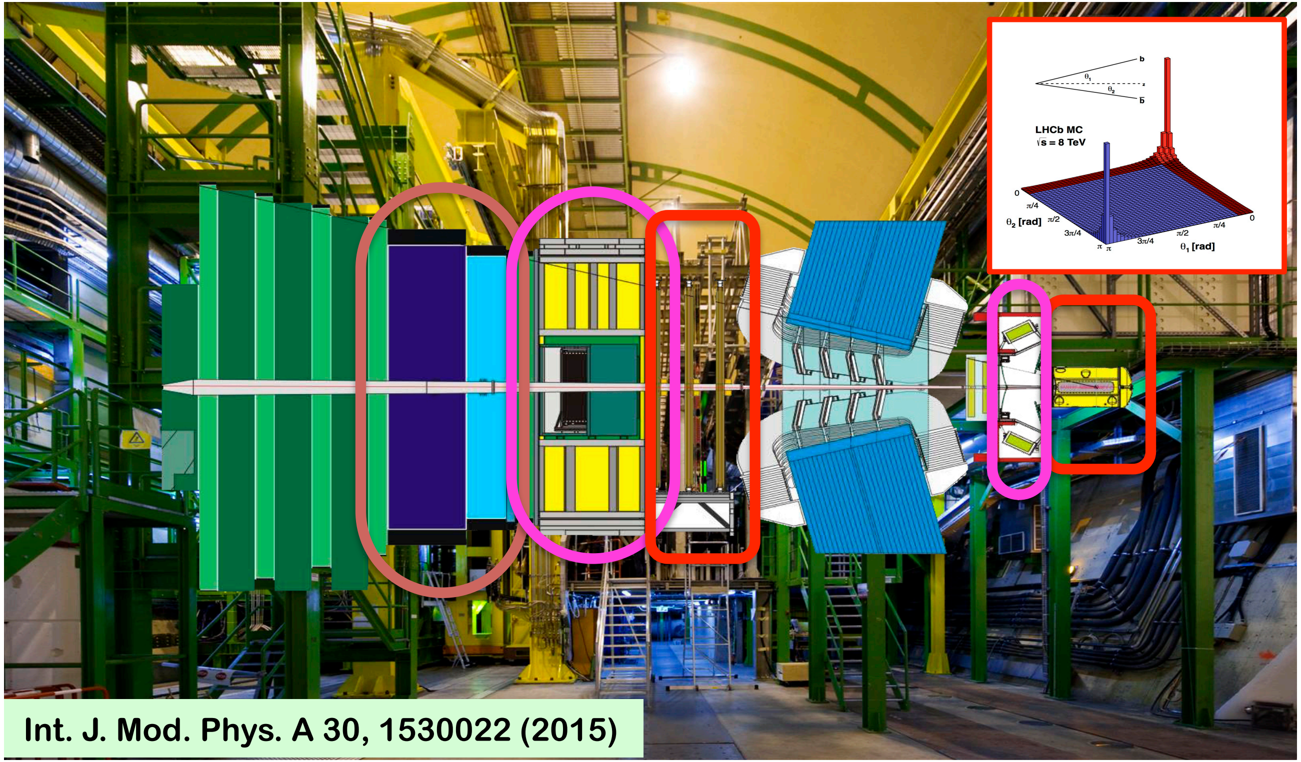




Displaced vertex

- The most abundant background is due to ("prompt") $X_b \rightarrow D^{*-}\pi^+\pi^-\pi^+ + N$ (neutrals) where the 3 pions come from the X_b vertex (BR ≈100 times higher than signal).
- Suppressed by requiring minimum distance between X_b and τ vertices ($>4\sigma_{\Delta z}$).
- This background suppressed by 3 orders of magnitude. 35% efficient on signal.
- Possible due to the excellent LHCb vertex resolution.

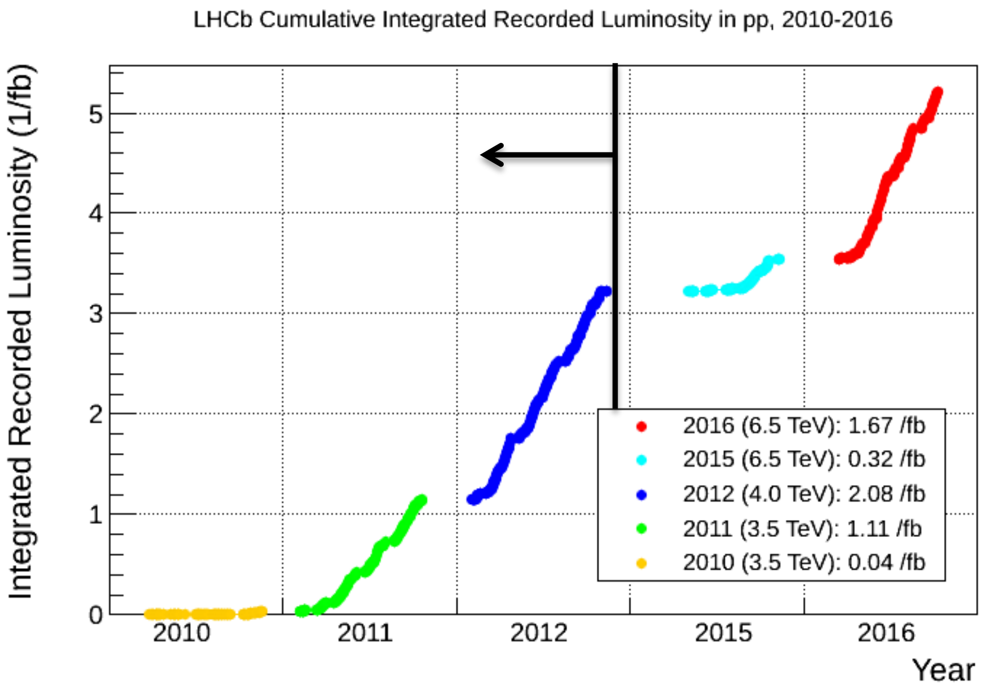
The LHCb detector



Int. J. Mod. Phys. A 30, 1530022 (2015)

- **Excellent vertex resolution:** $20\mu m$ **resolution on impact parameter.**
- **Excellent particle identification.**
- **Calorimeter systems: in this analysis used to suppress events with missing neutral energy:** π^0, K^0, γ.

Dataset

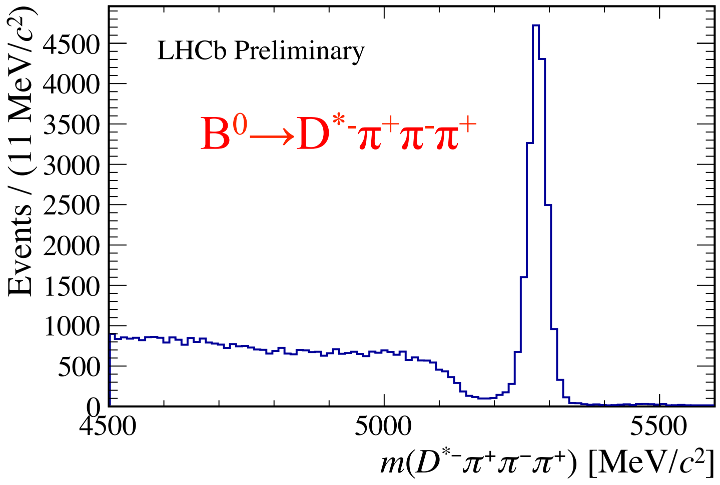


- >90% data taking efficiency with >99% of collected data good for analysis.
- Luminosity collected:
  - $1fb^{-1}$ at 7 TeV
  - $2fb^{-1}$ at 8 TeV

The normalization mode

- **Normalization channel as similar as possible to the signal (same visible final state) →** $B^0 \to D^{*-}\pi^+\pi^-\pi^+$.
- **This cancels production yield and systematics linked to trigger, PID and selection.**
- **In PDG 2014, BR(**$B^0 \to D^{*-}\pi^+\pi^-\pi^+$**) known with 11% precision.**
- **New BaBar measurement 4.3% precision.**
  [Phys. Rev. D94 (2016) 091101]
- **In this analysis ~17000 events (1% precision).**

LHCb-PAPER-2017-017



Selection: displaced vertex

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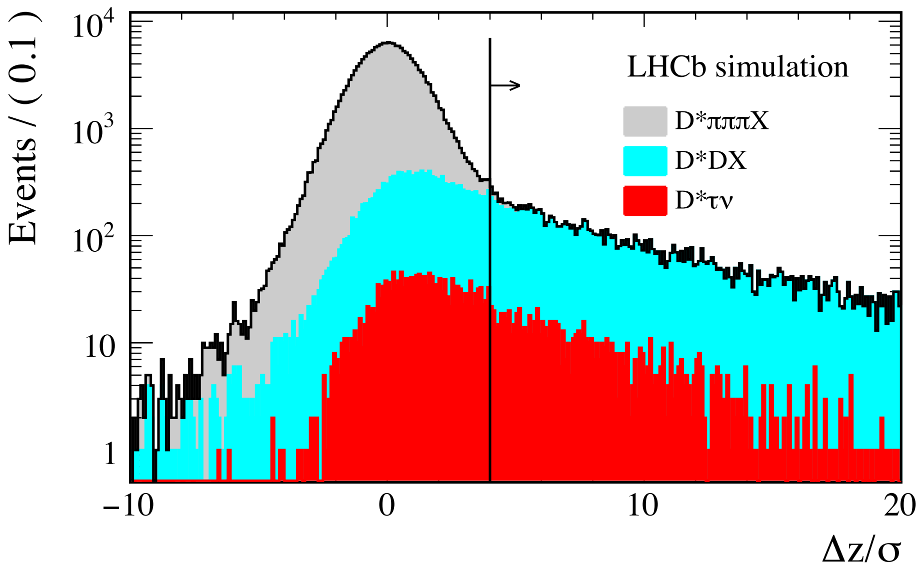


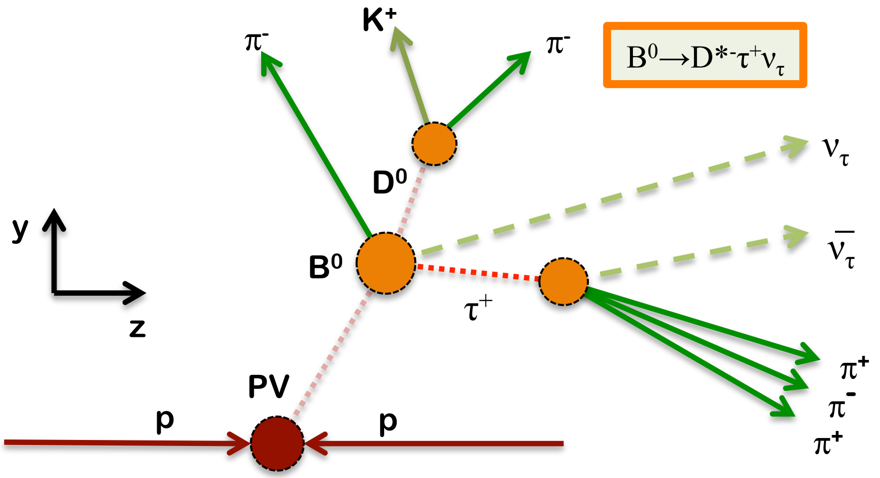
- The **4$\sigma_{\Delta z}$** vertex cut suppresses $X_b \to D^{*-}\pi^+\pi^-\pi^+X$ events by 3 orders of magnitude.

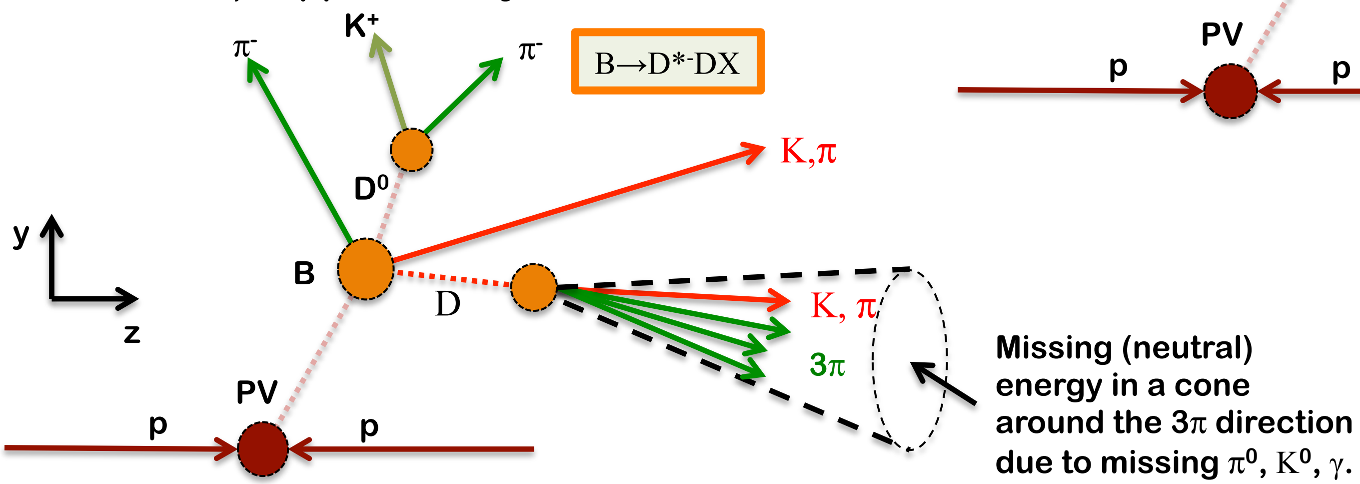
- Remaining **background** due to doubly charmed decays $X_b \to D^{*-}D_s^+X$, $X_b \to D^{*-}D^+X$, $X_b \to D^{*-}D^0X$, i.e. mediated by particles with **non-negligible lifetime.**

  - $X_b \to D^{*-}D_s^+X$: ~**10** x **signal**
  - $X_b \to D^{*-}D^+X$: ~**1** x **signal**
  - $X_b \to D^{*-}D^0X$: ~**0.2** x **signal**

Isolation

- Signal candidates are required to be well isolated.
- Events with extra charged particles pointing to the B and/or τ vertices are vetoed.
- Events with neutral energy (signal in calorimeters) suppressed by a BDT.



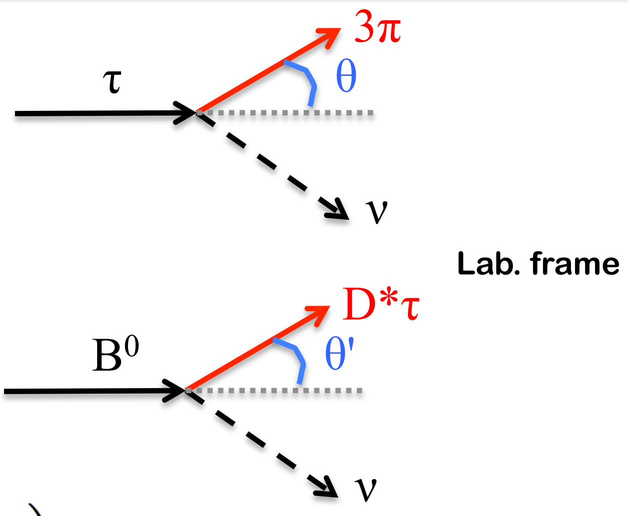


Signal reconstruction

- **4-fold ambiguity:**

$$|\vec{p}_\tau| = \frac{(m_{3\pi}^2 + m_\tau^2)|\vec{p}_{3\pi}|\cos\theta \pm E_{3\pi}\sqrt{(m_\tau^2 - m_{3\pi}^2)^2 - 4m_\tau^2|\vec{p}_{3\pi}|^2\sin^2\theta}}{2(E_{3\pi}^2 - |\vec{p}_{3\pi}|^2\cos^2\theta)}$$

$$|\vec{p}_{B^0}| = \frac{(m_{D*\tau}^2 + m_{B^0}^2)|\vec{p}_{D*\tau}|\cos\theta' \pm E_{D*\tau}\sqrt{(m_{B^0}^2 - m_{D*\tau}^2)^2 - 4m_{B^0}^2|\vec{p}_{D*\tau}|^2\sin^2\theta'}}{2(E_{D*\tau}^2 - |\vec{p}_{D*\tau}|^2\cos^2\theta')}$$



- **Can be approximated by doing:**

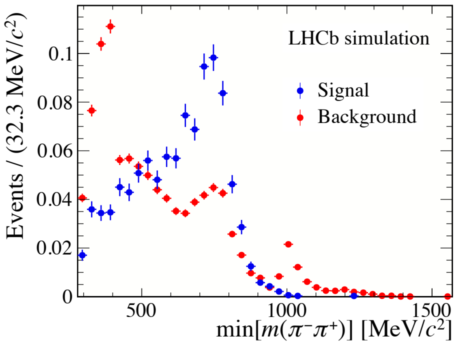
$$\theta_{max} = \arcsin\left(\frac{m_\tau^2 - m_{3\pi}^2}{2m_\tau|\vec{p}_{3\pi}|}\right) \qquad \theta'_{max} = \arcsin\left(\frac{m_{B^0}^2 - m_{D*\tau}^2}{2m_{B^0}|\vec{p}_{D*\tau}|}\right)$$

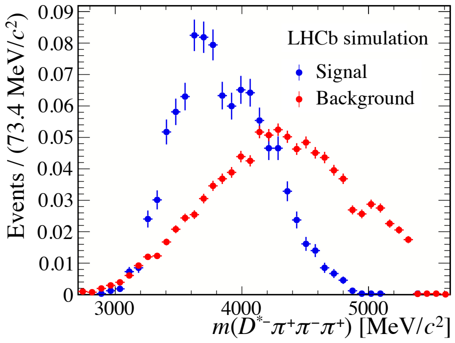
- **Possible to reconstruct rest frame variables such as tau decay time and q^2.**

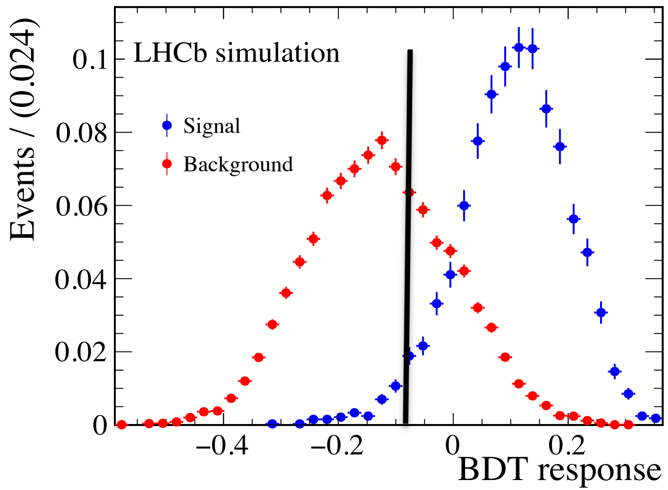
- **These variables have negligible biases, and sufficient resolution to preserve good discrimination between signal and background.**

Rejecting $X_b \to D^{*-} D_s^+ X$ events using a BDT

- **BDT trained to suppress main background: $X_b \to D^{*-} D_s^+ X$ events.**
- **Training: background MC vs signal MC. Input variables:**
  - **3π dynamics.**
  - **$D^*3\pi$ dynamics.**
  - **Neutrals isolation variables.**
- **BDT is used as a variable in the fit to extract signal yield.**
- **Tightening BDT cut, ~50% purity can be achieved. Important for (future) angular analysis.**







LHCb-PAPER-2017-017

The $D_s \to 3\pi X$ decay model: low-BDT fit

- D_s decay modes with 3 pions + neutrals not very well measured.
- Exclusive $D_s \to 3\pi$ is only 1/15 of the inclusive $D_s \to 3\pi X$.
- $D_s \to 3\pi X$ decay model obtained from data.
- Low BDT region (not used for signal extraction) is used to measure the $D_s \to 3\pi X$ composition.
- Simultaneous fit to: $\min[m(\pi^+\pi^-)]$
  $\max[m(\pi^+\pi^-)]$
  $m(\pi^+\pi^+)$
  $m(3\pi)$

The $D_s \to 3\pi X$ decay model: low-BDT fit

Fit components:

- D_s decays with at least 1 pion from η or η': $\eta^{(\prime)}\pi^+$, $\eta^{(\prime)}\rho^+$.
- D_s decays with at least 1 pion from an intermediate state (IS) other than η or η': ω or ϕ.
- D_s decays where none of the 3 pions come from a IS: $K^0 3\pi$, $\eta 3\pi$, $\eta' 3\pi$, $\omega 3\pi$, $\phi 3\pi$, non-resonant.

Fit results used to describe the $D_s \to 3\pi X$ model at high BDT.

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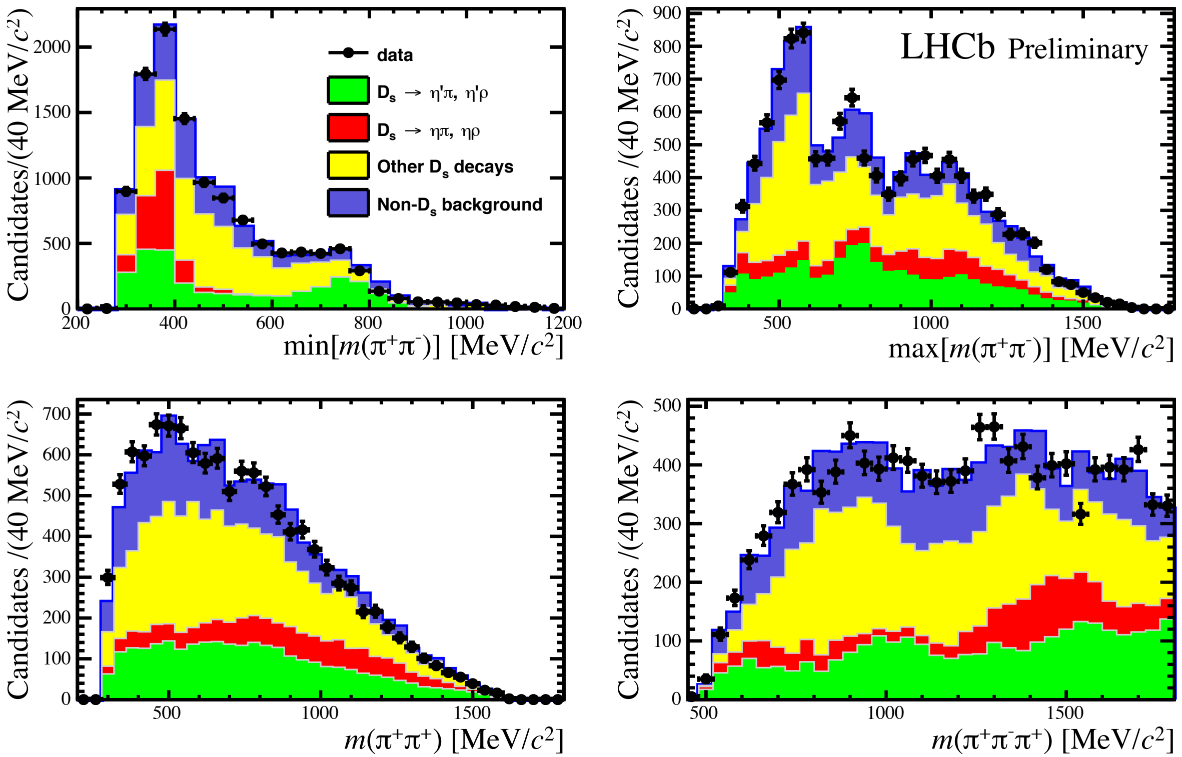
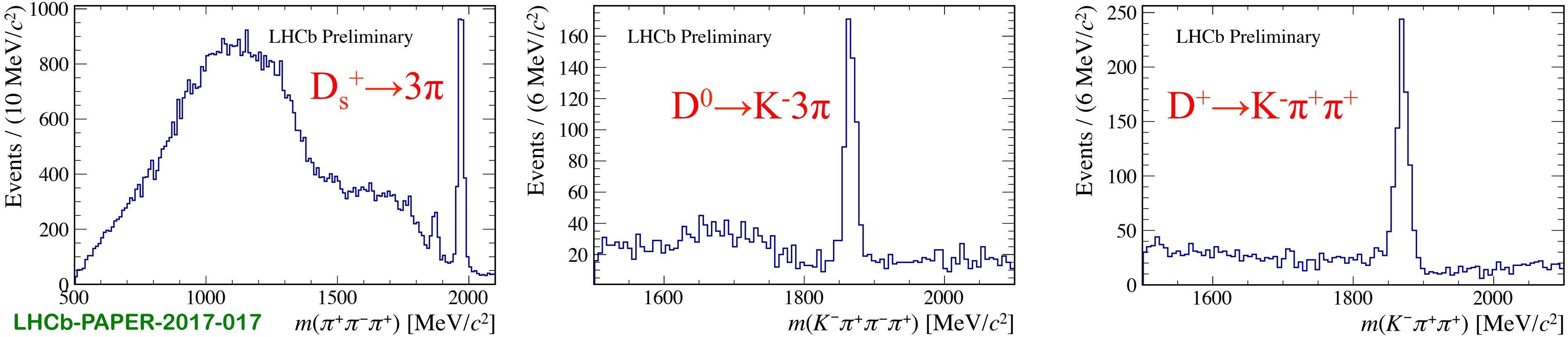


Control samples



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- **Different control samples are used to study background components:**
  - $D_s^+ \to \pi^+\pi^-\pi^+$: **control sample for** $X_b \to D^* D_s X$.
  - $D^0 \to K^-\pi^+\pi^-\pi^+$ **(kaon recovered by isolation tools) : control sample for** $X_b \to D^* D^0 X$.
  - $D^+ \to K^-\pi^+\pi^+$ **(mis-ID kaon/pion) : control sample for** $X_b \to D^* D^+ X$.
- **Simulation corrected to match these data.**

$X_b \to D^*D_sX$ control sample

- A pure $X_b \to D^*D_sX$ control sample obtained by selecting exclusive $D_s \to 3\pi$ decays.
- Allows to know the different $X_b \to D^*D_sX$ contributions from a fit to $m(D^*D_s)$:
  - $B^0 \to D^*D_s$, $B^0 \to D^*D_s^*$, $B^0 \to D^*D_{s0}^*$, $B^0 \to D^*D_{s1}'$, $B_s^0 \to D^*D_sX$, $B \to D^{**}D_sX$
- Uncertainties in the fit parameters propagated to final analysis.

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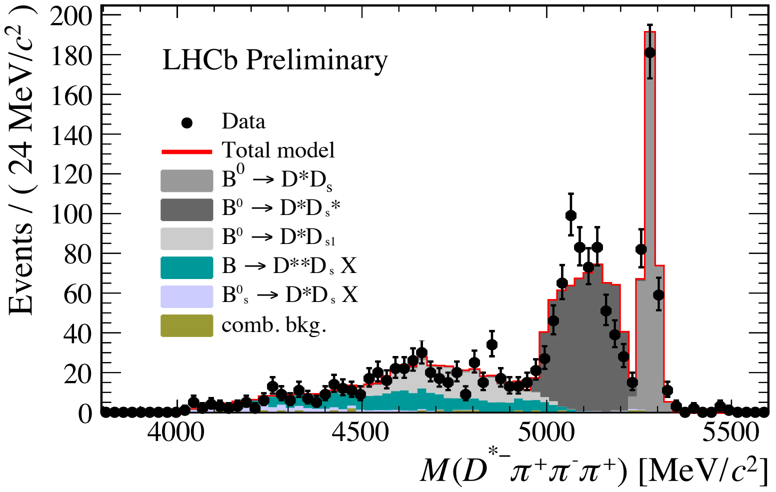

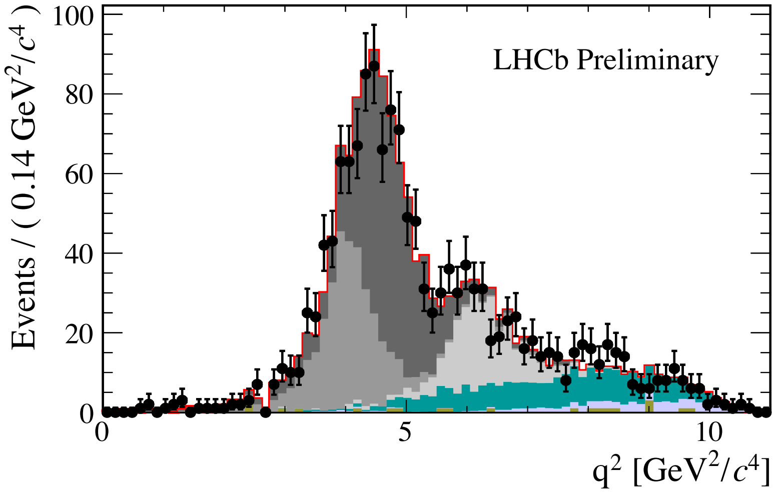

$X_b \rightarrow D^*D^0X$ control sample

- $X_b \rightarrow D^*D^0X$ **decays can be isolated by selecting exclusive** $D^0 \rightarrow K^-3\pi$ **decays (kaon recovered using isolation tools).**

- **A correction to the q^2 distribution is applied to the simulation to match the data.**

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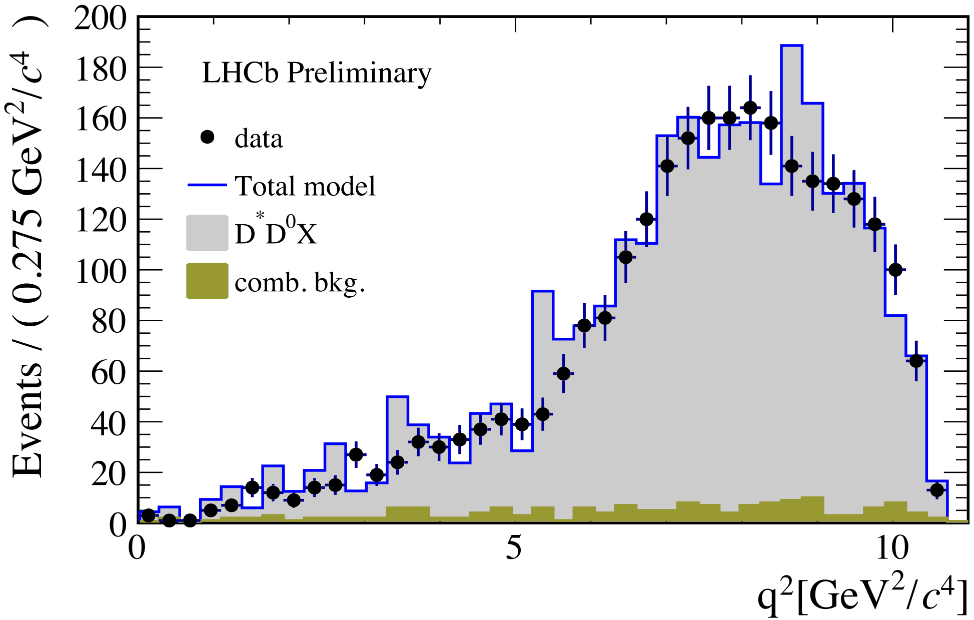


Signal extraction: fit model

- 3D extended maximum likelihood fit to data.
- Fit components described by templates obtained from simulation (and corrected from control samples):
  - q^2 (8 bins).
  - 3π decay time (8 bins): important to separate D^+ component (large lifetime).
  - BDT (4 bins).

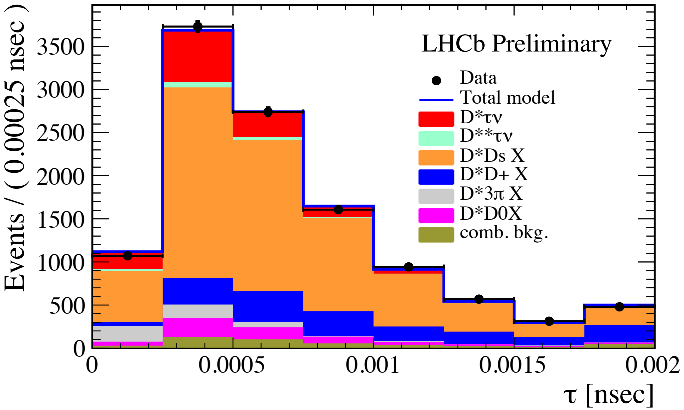
Model components	
$\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$	Ratio constrained using known BR and efficiencies.
$\tau^- \to \pi^-\pi^+\pi^-\pi^0\nu_\tau$	
$X_b \to D^{**}\tau\nu$	Ratio to signal fixed to 0.11 ± 0.04 from theory.
$B^0 \to D^{*-}D_s^+$	Relative yields constrained from $X_b \to D^* D_s^+ X$ control sample.
$B^0 \to D^{*-}D_s^{*+}$	
$B^0 \to D^{*-}D_{s0}^{*+}$	
$B^0 \to D^{*-}D_{s1}'$	
$B_s^0 \to D^{*-}D_s^+X$	
$B \to D^{**}D_s^+X$	
$X_b \to D^{*-}D^+X$	
$X_b \to D^{*-}D^0X$	Yields constrained from control samples.
$X_b \to D^{*-}\pi^+\pi^-\pi^+X$	
Comb. Bkg.	

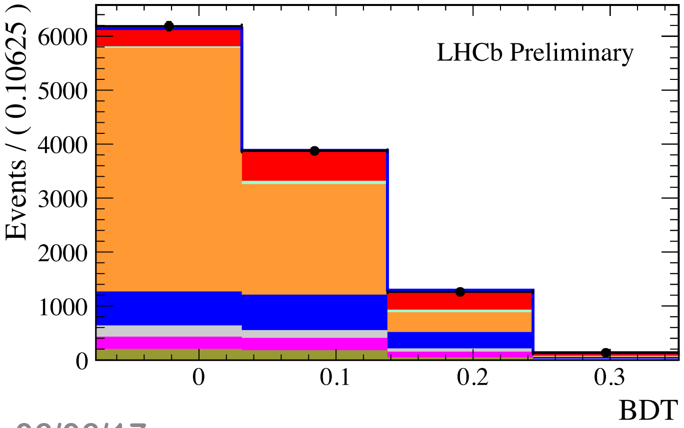
Fit results

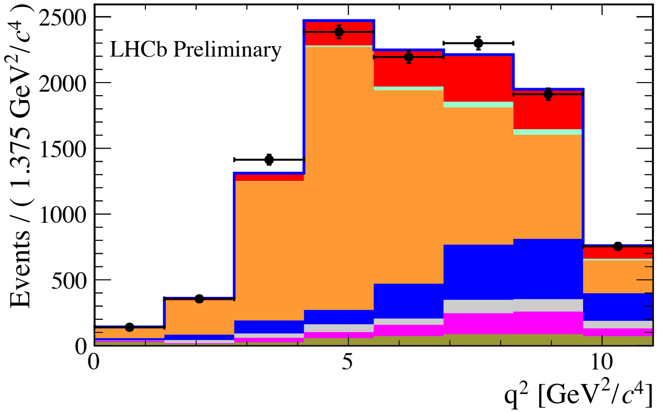
- **Signal yield: 1300 events.**
- **Leads to** $K_{had}(D^*) = 1.93 \pm 0.13(stat) \pm 0.17(syst)$
- **Using measured** $BR(B^0 \to D^*3\pi) = (7.26 \pm 0.11 \pm 0.31) \times 10^{-3}$:

  [Phys. Rev. D94 (2016) 091101]

$BR(B^0 \to D^*\tau\nu) = (1.40 \pm 0.09(stat) \pm 0.12(syst) \pm 0.06(ext))\%$







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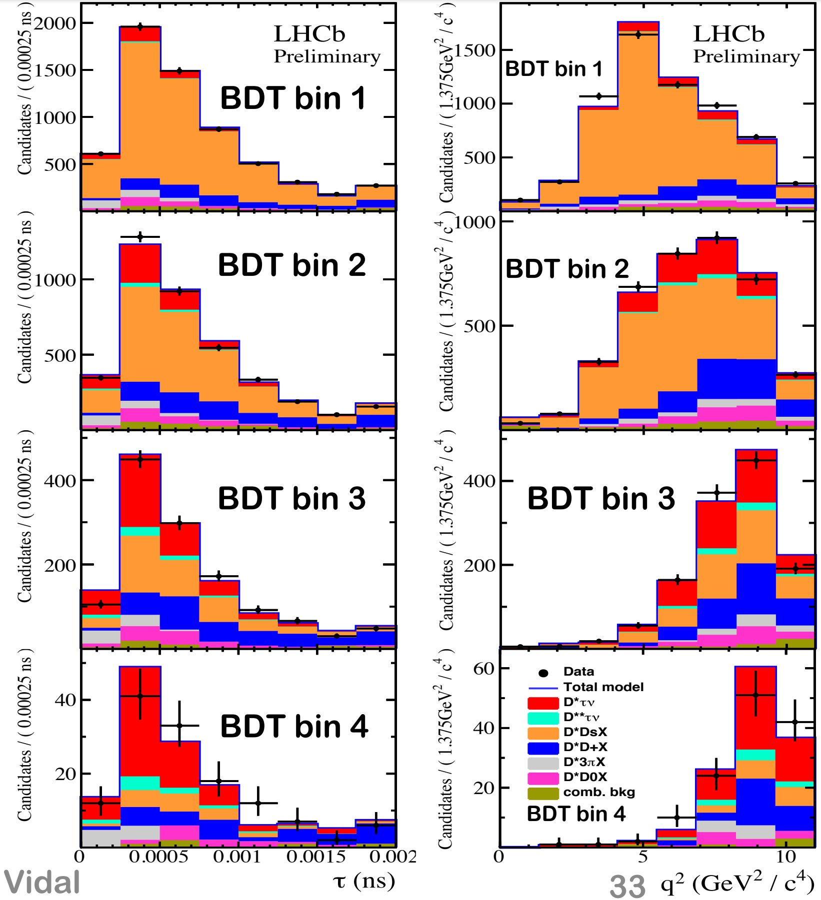
Fit projections in BDT bins

- **Important to check the quality of the model as a function of the BDT output.**
- **Good agreement in BDT bins.**
- **High signal purity at high BDT.**



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Fit projections on m(D*$\pi\pi\pi$) and min[m($\pi^+\pi^-$)]

- **Important variables in BDT training.**

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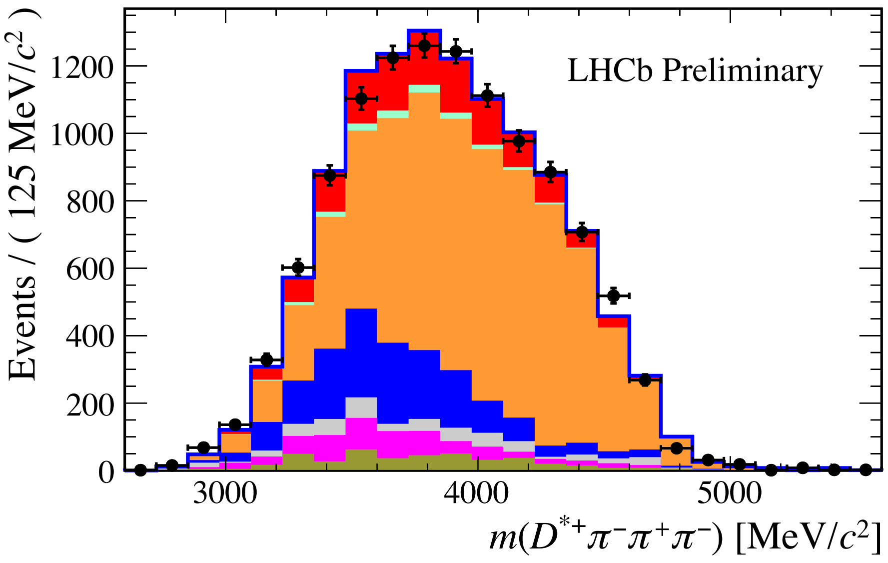
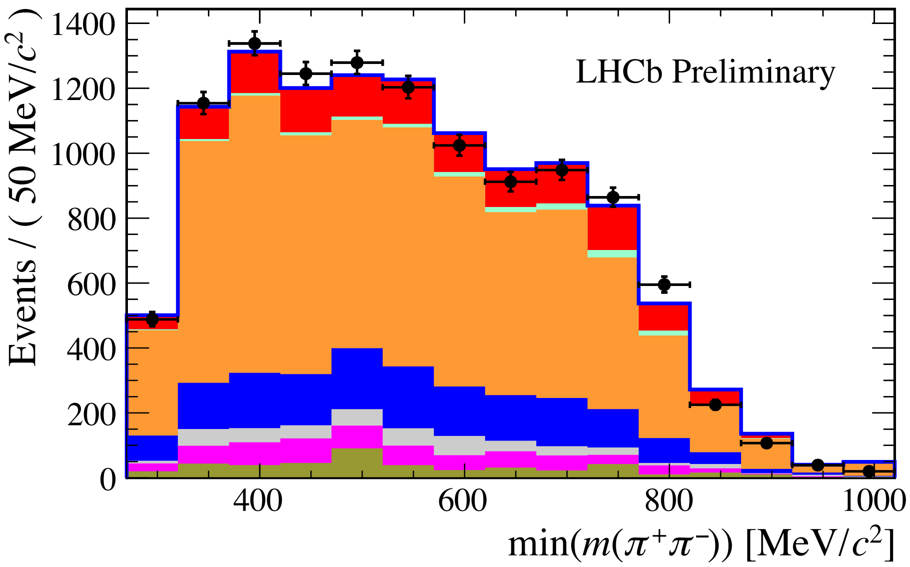
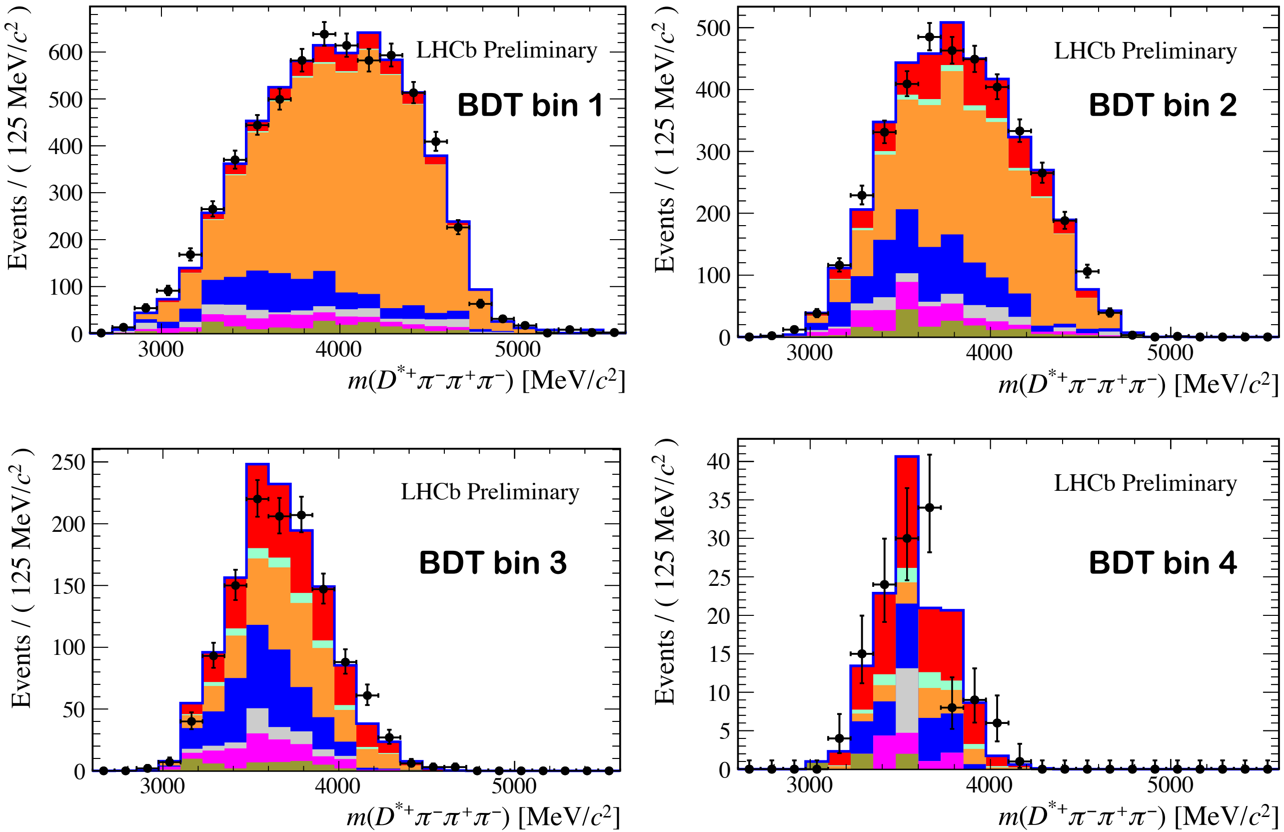




- **Good agreement with data.**

Fit projections in BDT bins



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- **Important check: m(D*3π) vs BDT bin.**
- **Good agreement.**

Systematic uncertainties and cross-checks

Additional cross-checks: splitting samples

- We have split the data in:

  1. Different trigger configurations:
     - Event triggered by our candidate (trigger on signal, TOS).
     - Event triggered by other tracks in the event (not-TOS).

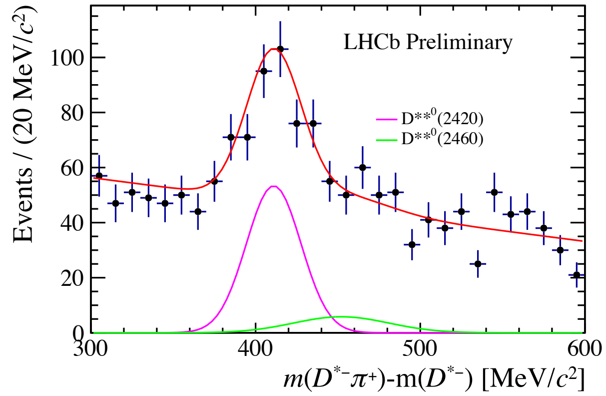
  2. Different year (beam energy).

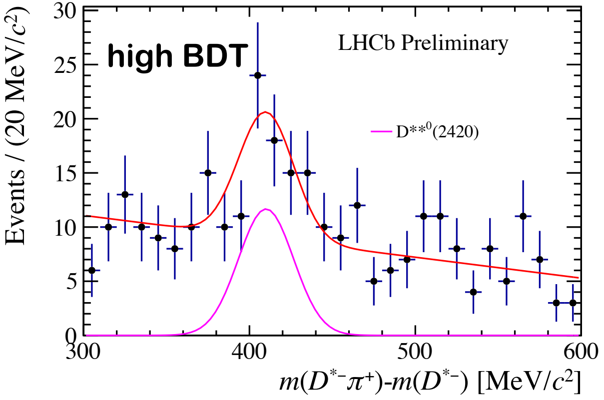
- Both decompositions correspond to 2/3-1/3 of both data samples. Bias corrections are needed to take into account the lack of MC statistics in the 1/3 samples.

- Found consistent results in all sub-samples.

Additional cross-checks: $X_b \to D^{**}\tau\nu$

- $B^0 \to D^{**}\tau\nu$ and $B^+ \to D^{**0}\tau\nu$ constitute potential feed-down to the signal.
- $D^{**}(2420)^0$ is reconstructed using its decay to $D^{*+}\pi^-$ as a cross-check.
- The observation of the $D^{**}(2420)^0$ peak allows to compute the D^{**} BDT distribution and to deduce a $D^{**}\tau\nu$ upper limit. This upper limit is consistent with the theory.
- Ratio of $D^{**}\tau\nu$ yield with respect to signal yield of 0.11 ± 0.04 from theory leads to a systematic uncertainty of 2.3%.





Summary of systematic uncertainties

Source	$\delta R(D^{*-})/R(D^{*-})[\%]$
Simulated sample size	4.7
Signal decay model	1.8
$D^{**}\tau\nu$ and $D_s^{**}\tau\nu$ feeddowns	2.7
$D_s^+ \to 3\pi X$ decay model	2.5
$B \to D^{*-}D_s^+X$, $B \to D^{*-}D^+X$, $B \to D^{*-}D^0X$ backgrounds	3.9
Combinatorial background	0.7
$B \to D^*3\pi X$ background	2.8
Empty bins in templates	1.3
Efficiency ratio	3.9
Total internal uncertainty	8.9
$\mathcal{B}(B^0 \to D^*3\pi)$ and $\mathcal{B}(B^0 \to D^*\mu\nu_\mu)$	4.8

- **Effect of MC statistics studied by performing toys studies.**
- **Templates fluctuated according to Poisson statistics.**
- **Small bias of 3% used to correct the signal yield.**

Summary of systematic uncertainties

Source	$\delta R(D^{*-})/R(D^{*-})[\%]$
Simulated sample size	4.7
Signal decay model	1.8
$D^{**}\tau\nu$ and $D_s^{**}\tau\nu$ feeddowns	2.7
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Empty bins in templates	1.3
Efficiency ratio	3.9
Total internal uncertainty	8.9
$\mathcal{B}(B^0 \to D^*3\pi)$ and $\mathcal{B}(B^0 \to D^*\mu\nu_\mu)$	4.8

- **$D_s \to 3\pi X$ decay model, obtained from a fit to low-BDT events, is varied using toys.**
- **Future BESIII measurements on inclusive $D_{(s)} \to 3\pi X$ decays can help to reduce this error.**

Summary of systematic uncertainties

Source	$\delta R(D^{*-})/R(D^{*-})[\%]$
Simulated sample size	4.7
Signal decay model	1.8
$D^{**}\tau\nu$ and $D_s^{**}\tau\nu$ feeddowns	2.7
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Empty bins in templates	1.3
Efficiency ratio	3.9
Total internal uncertainty	8.9
$\mathcal{B}(B^0 \to D^* 3\pi)$ and $\mathcal{B}(B^0 \to D^* \mu\nu_\mu)$	4.8

- **Templates shape allowed to vary using "histogram interpolation" technique.**
- **Allows to change templates shape depending on external variables.**
- **Same method applied for the combinatorial background.**

Summary of systematic uncertainties

Source	$\delta R(D^{*-})/R(D^{*-})$[%]
Simulated sample size	4.7
Signal decay model	1.8
$D^{**}\tau\nu$ and $D_s^{**}\tau\nu$ feeddowns	2.7
$D_s^+ \to 3\pi X$ decay model	2.5
$B \to D^{*-}D_s^+X$, $B \to D^{*-}D^+X$, $B \to D^{*-}D^0X$ backgrounds	3.9
Combinatorial background	0.7
$B \to D^*3\pi X$ background	2.8
Empty bins in templates	1.3
Efficiency ratio	3.9
Total internal uncertainty	8.9
$\mathcal{B}(B^0 \to D^*3\pi)$ and $\mathcal{B}(B^0 \to D^*\mu\nu_\mu)$	4.8

- **Total systematic uncertainty 8.9%.**
- **Additional external uncertainty due to precision in BR($B^0 \to D^{*-}\pi^+\pi^-\pi^+$) and BR($B^0 \to D^*\mu\nu$).**

World average

- Using BR($B^0 \to D^* \mu\nu$) = (4.93 ± 0.11)% [PDG-2016] we measure:

  R(D*) = 0.285 ± 0.019(stat) ± 0.025(syst) ± 0.014(ext)

- In combination with the muonic LHCb measurement:

  R(D*) = 0.336 ± 0.027 ± 0.030,

  the LHCb average is:

  - $R_{LHCb}(D^*)$ = 0.306 ± 0.016 ± 0.022
  - 2.1σ above the SM.

- Naïve new WA:
  - R(D*) = 0.305 ± 0.015
  - 3.4σ above the SM.

- Naïve R(D)/R(D*) combination at 4.1σ from SM.

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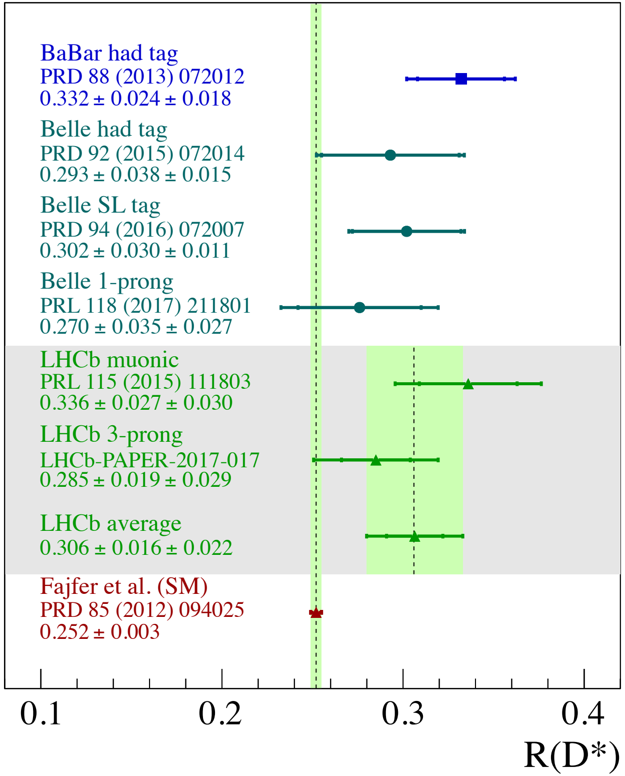


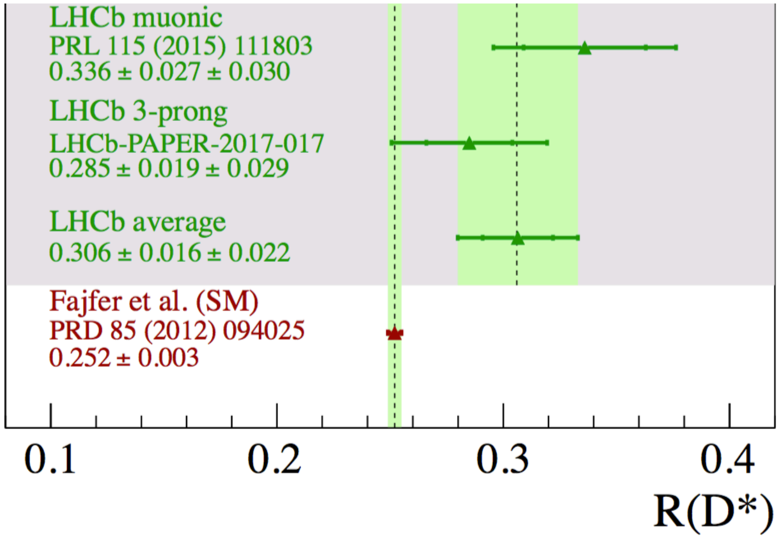
Prospects

- For R(D*), Run-2 will ~quadruple the dataset, the statistical uncertainty can decrease by a factor of ≈2.
- The internal systematic uncertainty can also decrease by a factor of ≈2.
- Other measurements on going (including run-2 data) using:

Decay	Observable
$B^0 \to D^{*-}\tau^+\nu_\tau$	$R(D^{*-})$
$B^0 \to D^-\tau^+\nu_\tau$	$R(D^-)$
$B^+ \to D^0\tau^+\nu_\tau$	$R(D^0)$
$B_s^0 \to D_s^{(*)}\tau^+\nu_\tau$	$R(D_s^{(*)})$
$B_c^+ \to J/\psi\tau^+\nu_\tau$	$R(J/\psi)$
$\Lambda_b \to \Lambda_c^{(*)-}\tau^+\nu_\tau$	$R(\Lambda_c^{(*)})$

Conclusions

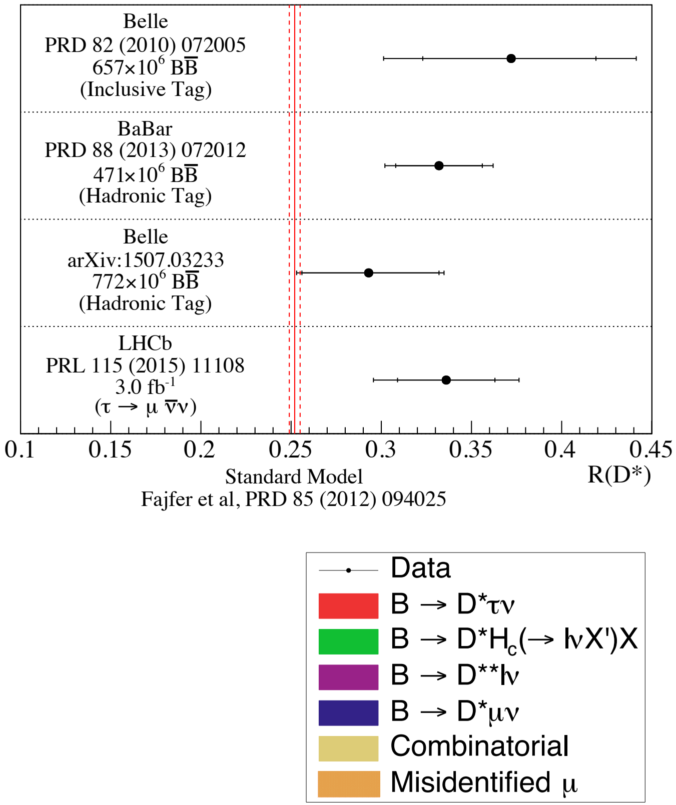
- We have measured the ratio $K_{had}(D^*)=BR(B^0\to D^{*-}\tau\nu)/BR(B^0\to D^{*-}3\pi)$ using the $3\pi(\pi^0)$ hadronic decay of the τ lepton.
- The result regarding R(D*) is compatible with all other measurements and with the SM, having the smallest statistical error.
- This analysis was made possible due to the unique **LHCb** capabilities for separating secondary and tertiary vertices with **excellent resolution**.

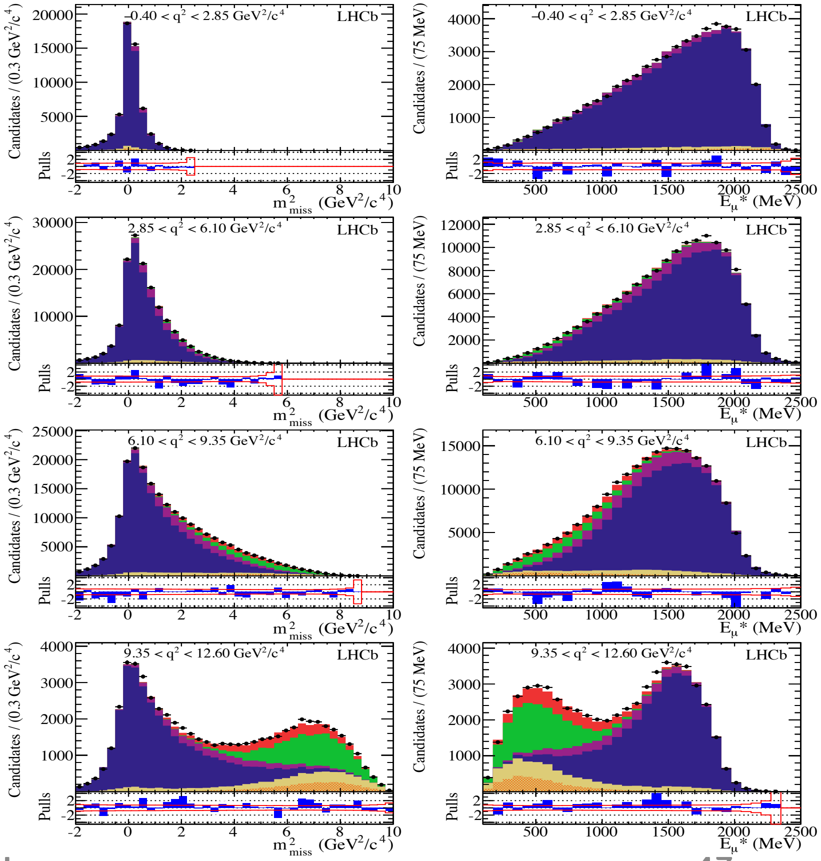


BACKUP

LHCb muonic R(D*)

[Phys. Rev. Lett. 115, 111803 (2015)]





BDT variables

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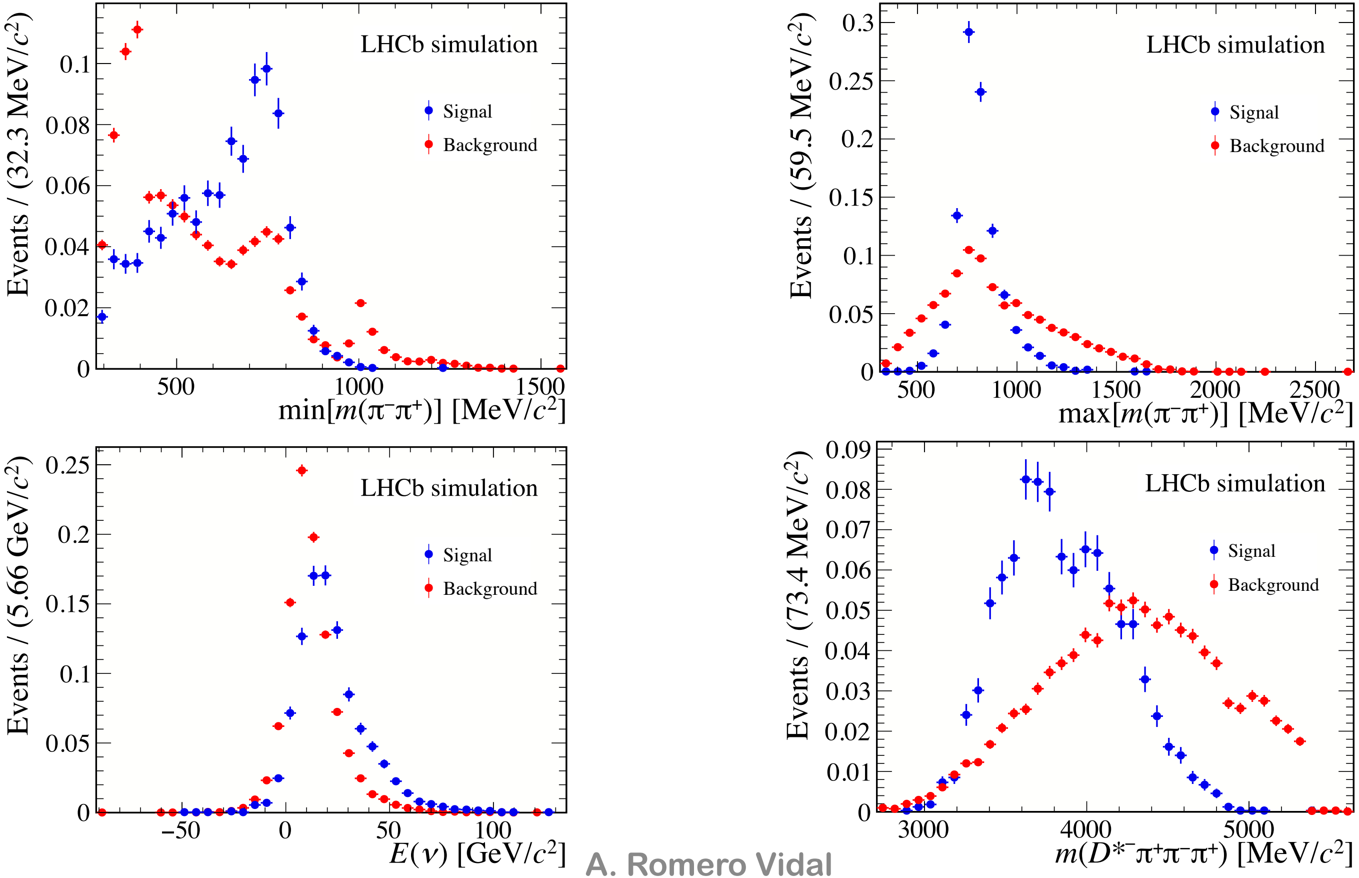

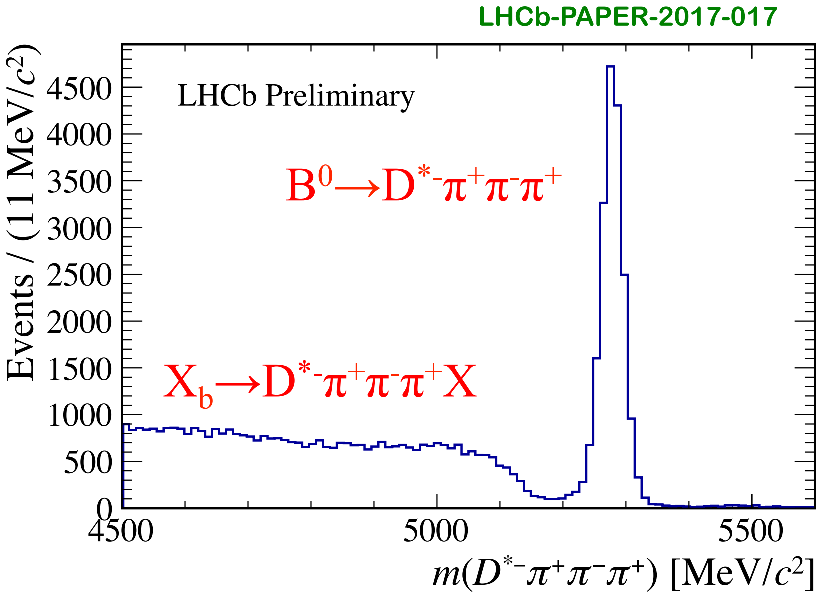
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LHCb Preliminary
$B^0 \to D^{*-}\pi^+\pi^-\pi^+$
$X_b \to D^{*-}\pi^+\pi^-\pi^+X$
Events / (11 MeV/c^2)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
4500
5000
5500
$m(D^{*-}\pi^+\pi^-\pi^+)$ [MeV/c^2]