Lepton Flavour Universality tests using semitauonic decays at LHCb
Introduction
The first BABAR measurement (2012)
Review of all other measurements until now
The new R(D*) measurement from LHCb

- First public release at FPCP2017 on June 5, 2017
- Published on Arxiv Aug 29, 2017 hep-ex 1708.08856

Prospects and conclusion
Lepton Flavour Universality
a key ingredient of the standard model

- In the SM, the charged and neutral current interactions must respect **Lepton Flavour Universality**
  - Equal couplings of the W and Z bosons to electrons, muons and taus
- For the Z boson, this has been checked at the 2 per mille accuracy at LEP
- For the W boson, the $\tau$ BR is $2.8 \sigma$ above $<e,\mu>$ which are equal to 2 per mille precision

\[
\frac{B(W \rightarrow \tau \nu_\tau)}{[B(W \rightarrow e\nu_e) + B(W \rightarrow \mu\nu_\mu)]/2}_{\text{LEP}} = 1.077 \pm 0.026,
\]

( an exemple of a theory paper regarding this effect :Arxiv : hep-ph/0607280 )

Can ATLAS (or CMS) measure this precisely?
Why semitauonic decays are interesting?
Very simple b->c W system

- Tree Level decays combine the advantages:
  - Very precise prediction from SM : $R(D^*)$ known better than to 2% precision, using
    $$R(D^*) = \frac{B \rightarrow D^*\tau\nu/B \rightarrow D^*\mu\nu}{B \rightarrow D^*\tau\nu/B \rightarrow D^*\mu\nu}$$
  - Abundant channel $BR(B^0 \rightarrow D^*\tau\nu)=1.24\%$, one of the largest individual BR
  - Sensitivity to new physics: (simplest realization) A charged Higgs will automatically couple more to the $\tau$. LFU violation can also occur through other mechanisms (leptoquarks,..)

- They offer several hadronisation implementations:
  - $D^*, D^0, D+, D_s, \Lambda_c, J/\psi$
  - Differing not only by various properties of the spectator particle but also its spin $0,1 (D^* \text{ and } J/\psi)$ and $1/2 (\Lambda_c!!)$

\[
\frac{d^3\sigma^{\text{SM}}(B \rightarrow D^{(*)}\ell^-\ell^+)}{dq^2} = \frac{G_F^2 |V_{cb}|^2 |p_{D^{(*)}}|^2 (1 - \frac{m_{\ell}^2}{q^2})^2}{96\pi^3 m_B^2} \times \left[ (|H_+|^2 + |H_-|^2 + |H_0|^2) \left( 1 + \frac{m_{\ell}^2}{2q^2} \right) + \frac{3m_{\ell}^2}{2q^2} |H_\ell|^2 \right].
\]  

\[\text{(3)}\]

ArXiv: HEP-1703-01766
New physics reach

- Charged Higgs, Leptoquarks are the usual suspects
- Sensitivity comparable or even higher at ATLAS and CMS in some models: many scenarios still open after taking into account the present direct exclusions domains
- If the WA average is correct, \( \frac{R(D^*)}{R(D^*)_{SM}} = 1.23 \): Large new physics effects!!
- Sensitivity not only on the yield but also in the internal characteristics of the event (\( q^2 \) and angular distributions)
- New physics can couple to Vcb transitions and not Vub!!
- Therefore, very important to get a high statistics sample as pure as possible
Search for LFU violation in $V_{ub}$ decays

- Note that in the long term the ‘$V_{ub}$’ analog $b \rightarrow uW$ is also quite interesting, since its coupling to new physics can be different from the $cW$ case
  - Rather difficult in practice B factories can search for $B \rightarrow \pi \tau \nu$
  - LHCb can look for $\Lambda_b \rightarrow p \tau \nu$ or $B^0 \rightarrow p \overline{p} \tau \nu$

- A similar reaction is the annihilation diagram

\[
\mathcal{B}(B^- \rightarrow \tau^- \overline{\nu}_\tau) = (1.06 \pm 0.19) \times 10^{-4}.
\]
\[
\mathcal{B}^{SM}(B^- \rightarrow \tau^- \overline{\nu}_\tau) = (0.75 \pm 0.10_{\text{0.05}}) \times 10^{-4}.
\]
R(D) and R(D*) as of March 2017

\[ \Delta \chi^2 = 1.0 \text{ contours} \]

- BaBar, PRL 109, 101802 (2012)
- Belle, PRD 92, 072014 (2015)
- LHCb, PRL 115, 111803 (2015)
- Belle, PRD 94, 072007 (2016)
- Belle, arXiv:1612.00529
- Average

SM Predictions

- \( R(D) = 0.300(8) \) HPQCD (2015)
- \( R(D) = 0.299(11) \) FNAL/MILC (2015)
- \( R(D*) = 0.252(3) \) S. Fajfer et al. (2012)

KEK seminar, October 24, 2017
R(D*) is predicted more precisely than R(D) (?)

- Different sensitivity to FF uncertainties

Standard Model predictions

\[ \frac{d\Gamma}{dq^2}[10^{-2} GeV^{-2}] \]

- \( f_0 = 0 \)
- \( B \to D\mu\nu \)
- \( B \to D\tau\nu \)

Current experimental data

HFAG average today \( R(D^*)_{exp} = 0.310 \pm 0.015 \pm 0.008 \)

Talk from A. Celis (LMU) GDR Intensity Frontier March 30, 2017
https://indico.in2p3.fr/event/14159
Recent trends(1): $R(D)$ better than $R(D^\ast)$

- **Regarding $R(D)$**  
  - “First, two calculations of the form factors of $B \rightarrow Dl\nu$ beyond zero-recoil have appeared in 2015. They represent the first unquenched calculations of these form factors performed at different $q^2$ values, which significantly reduces the uncertainty of the extrapolation from the $q^2$ region where most data are taken.
  - Second, a new, more precise Belle measurement has been published, which for the first time provides the $q^2$ differential distribution with complete statistical and systematic uncertainties and correlations. The combination of these steps forward allows for a competitive extraction of $|V_{cb}|$ and for a very precise determination of the $B \rightarrow D$ form factors.”

- $R(D) = 0.299 \pm 0.003$
Recent trends(2): $R(D)$ better than $R(D^*)$

- **Regarding $R(D^*)$**  P. Gambino, D. Bigi, S. Schacht
  arxiv 1707.09509 (July 29, 2017)
  - Change of CLN to BGL parametrization leads to $V_{cb}$ exclusive of $0.42(2) \times 10^{-3}$ in agreement with inclusive results
  - and to $R(D^*) = 0.260(10)$

- **F. Bernlocher et al.**
  - $R(D^*) = 0.257 (3)$  *Phys. Rev. D95* (2017) no. 11, 115008 (June 8, 2017)
    - “The tensions concerning the exclusive and inclusive determinations of $|V_{cb}|$ cannot be considered resolved.”
At the Y(4S), the strategy is a priori simple:
- Reconstruct a « tag » B to gain access to the other B center of mass frame and thus to the missing mass
- Select events with D*μ topology on the signal side
- Count events with μ much softer than for normal semileptonic decays
- The winning « trick »: much higher efficiency reconstruction of the « tag » B particle
Other $R(D^*)$ results up to now

- **3 new measurements by BELLE collaboration**
  - Hadronic tag as for BABAR-leptonic tau decay
    - PRD92, 072014 (2015)
  - Semileptonic Tag, more statistics but worse CM and missing mass resolution-leptonic tau decay
  - Hadronic tag – hadronic tau decay in $\pi/\pi^0$. Important to access tau polarization information. Real challenge to fight hadronic background
    - PRL118, 211801 (2017), arXiv1612.00529

- **1 new measurement from LHCb collaboration**
  - PRL115, 1183 (2015)
  - Muonic tau decay in a hadronic collider !!!!

KEK seminar, October 24 2017
LHCb muonic result (2015)

Fit Result

- Shown above: signal fit to “signal” data passing isolation selection
- Result $\frac{N_{B}}{N_{\mu}} = (4.32 \pm 0.37) \times 10^{-2}$, $R(D^{*}) = 0.336 \pm 0.027 \pm 0.030$
- $N(\bar{B}^{0} \rightarrow D^{*-} \mu^{-}\bar{\nu}_{\mu}) = 363,000 \pm 1600$
If WA is correct, $\frac{R(D^*)}{R(D^*)_{\text{SM}}} = 1.23$: Large new physics effects!!
The unusual features of the LHCb analysis
$D^*\tau_n;\tau\to 3\pi(\pi^0)$

- A semileptonic decay without (charged) lepton !!:  
  - ZERO background from normal semileptonic decays!!!!
- In this analysis, it is the background 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 $\tau$ vertex  
  - The complete event kinematics can be reconstructed with good precision
- No sensitivity to $\tau$ polarisation through $P_{3\pi}$ ($m_{a_1}^2 \approx 0.5*m_\tau^2$)
- Note: measure $R(D^{*-})$ and not $R(D^*)$ as B Factories

KEK seminar, October 24 2017
The initial very large background

- The $D^*\tau\nu$ decay, with $\tau$ going into 3 pions (it can also be $3\pi+\pi^0$) leads to a $D^*3\pi(+X)$ final state.
- Nothing is more common than a $D^*3\pi(+X)$ final state in a typical B decay:

$$\frac{BR(B^0\rightarrow D^*3\pi+X)}{BR(B^0\rightarrow D^*\tau\nu;\tau\rightarrow 3\pi)}_{SM} \sim 100$$

A very strong background suppression method is absolutely needed:

The DETACHED VERTEX METHOD
Vertex topology of the usual B decay

\[ B \rightarrow D^* \pi^+ \pi^- \pi^+ (+X) \]
Selection: detached vertex

\[ B^0 \rightarrow D^{*-} \tau^+ \nu_\tau \]

\[ \Delta z > 4\sigma_\Delta z \]
Selection: the detached vertex method
LHCb-PAPER-2017-017 arxiv 1708.08856

KEK seminar, October 24 2017
The second level of background

- After the 4σ cut in $\Delta z/\sigma_{\Delta z}$, the prompt background is suppressed by $\sim 3$ orders of magnitude!!!!!
- The second level of background consists of B decays where the $3\pi$ vertex is transported away from the $B^0$ vertex by a charm carrier: $D_s$, $D^+$ or $D^0$ (in that order of importance)
- This background is smaller:
  \[
  \frac{\text{BR}(B^0 \rightarrow D^* 'D'; 'D' \rightarrow 3\pi X)}{\text{BR}(B^0 \rightarrow D^* \tau \nu; \tau \rightarrow 3\pi)}_{\text{SM}} \sim 10
  \]
- ... and we can suppress it strongly
Analysis workflow

- Lo Trigger: LoTOS OR (LoHadron OR LoMuon)TIS
- HLT2: (Topo OR D*) AND Trigalltopo
- Stripping: B2toDstarTauNu stripping line (S21)
- Cleaning cuts (secondary vertex, one_combi, no_charm,...)
- Detached/normal topology for signal/normalization
- Charged isolation, tighter PID cut on the « negative » pion
- Fit of the reconstructed D_s sample using the exclusive 3\pi decay channel
- Low BDT sample (50% of the data sample): D_s decay model fit
- High BDT final fit with D_s decay model parameters
The inclusive $D_s$ decays in 3 pions

- The $W \rightarrow c\bar{s}$ decays can produce a single meson $D_s$, very often in an excited state $D_s^*$, $D_s^{**}$ or two particles $D^0 K^-$, $D^+ K^0$, and their excited counterparts.
- Although the exclusive $D_s \rightarrow 3\pi$ is small (1% BR), the $D_s$ is an amazingly rich source of $3\pi + X$ final states (~25%!).
- We classify hadronic $D_s$ decays into 3 pions in 4 categories:
  - $\eta \pi X (\eta \pi, \eta \rho)$
  - $\eta' \pi X (\eta' \pi, \eta' \rho)$
  - $(\phi/\omega) \pi X (\phi/\omega \pi, \phi/\omega \rho)$
  - $M_{3\pi}$, where $M$ can be $\nu, K^0, \eta, \eta', \omega, \phi$
- We do not have precise BR for all of these (some well measured, some poorly, some not at all).
- The inclusive BR of $D_s$ into 3 pions that could constraint all of these is not known either.

We extract these informations from LHCb data in a $D_s$ enriched region (BDT<-0.075) (~90% $D_s$).
The anti-$D_s$ BDT: $3\pi$ dynamics, partial reconstruction and isolation

\begin{align*}
\text{Min}(\text{mass}(\pi^+\pi^-)) & \quad \text{Max}(\text{mass}(\pi^+\pi^-)) \\
E(\nu) & \quad \text{mass}(D^{*+}\pi^-\pi^+\pi^-)
\end{align*}

Neutral Isolation

LHCb-PAPER-2017-017, arxiv 1708.08856
Background Partial reconstruction

Partial reconstruction

For $B^0 \to D^{*-}D_s^+$: $|\vec{p}_B|\hat{u}_B = |\vec{p}_{D_s^+}|\hat{u}_{D_s} + |\vec{p}_{D^*}|$

After some vectorial algebra $\to$ get magnitude of $B^0$ and $D_s^+$ momenta

First approximation $\to \hat{u}_{D_s}$ is the $3\pi$ direction

Apply a correction to $B^0$ vertex due to the presence of neutral particles in $D_s^+$ decay $\to$ parametrization of this correction as function of $3\pi$ mass on $D^{*-}D_s^+$ MC $\to$ get $B^0$ and $D_s^+$ momenta at a next-level of approximation

Reconstruction of $D_s^+$ mass, with nominal $B^0$ and $D^{*-}$ masses values

Entries: 1187
Mean: 2017
RMS: 486.5
• Good separation obtained

• Allows to select an high purity sample at high efficiency

• Charged Isolation and PID cuts are also required to select candidates
The $D_s$ decay model fit at low BDT

LHCb-PAPER-2017-017, arxiv 1708.08856
The importance of the « D_s-o-meter »

- The minimum $\pi^+\pi^-$ mass contains critical information about the rate of $\eta$ and $\eta'$ decays
- At low mass, only $\eta$ and $\eta'$ (red, green) contributions are peaking
  
  $\eta \rightarrow \pi^+\pi^- \pi^0$ and $\eta' \rightarrow \eta \pi^+\pi^-$

- At the $\rho$ mass where the signal lives, only $\eta'$ contributes ($\eta' \rightarrow \rho \gamma$)
- Using the low BDT region, one constraints the $D_s$ decay model to be used at high BDT
Charged Isolation and PID

- LHCb software can attach a track passing nearby a vertex: very useful to tag $D^0$ decays in $K_3\pi$
- Necessity to reject also 5 prong $D_s$ decays which are frequent when there is the combined presence of an $\eta$ and $\eta'$ presence in the decay chain.
- Very efficient for $D^0$ decays which is often accompanied by 2 charged kaons, less for the $D^+$
- To keep the background low, we request only events with 1 combination
- Important to reject $K^- \pi^+\pi^+$ events where the « negative » Kaon is taken as a pion
- Can be of course used a good control sample for $D^+$ meson
- The presence of $\pi\pi$ l events where the lepton from a semileptonic $D_s$ decays is taken as pion
The inclusive \( D^0 \) and \( D^+ \) decays in 3 pions

The situation is simpler in \( D^+ \) and \( D^0 \) decays whose main \( 3\pi \) decay mode is thru the \( K3\pi \) decay

- For the \( D^0 \), the inclusive 4 prongs BR constrains strongly the rate of \( 3\pi \) events
- Unfortunately, this constraint does not exist for the \( D^+ \) mesons, \( K3\pi\pi^0 \) is poorly known, the inclusive BR is not measured

- We let the \( D^+ \) component float in the fit

(Note: For all these \( D \) decays, contacts have been established with BES-3 collaboration to measure these numbers in the near future)
The control channels $D_s$, $D^0$, and $D^+$

LHCb-PAPER-2017-017, arxiv 1708.08856
Run 1, 3 fb$^{-1}$

KEK seminar, October 24 2017
Importance of the normalization channel

$B^0 \rightarrow D^*3\pi$

- Normalization mode as similar as possible to the signal to cancel production yield, BR uncertainties and systematics linked to trigger, PID, first selection cuts

Run 1, 3 fb$^{-1}$
17k events

LHCb-PAPER-2017-017, arxiv 1708.08856
BABAR measurement of $\text{BR}(B^0 \rightarrow D^{*}3\pi)$
(Phys.Rev. D94 (2016), 091101)

- In PDG 2014 $\text{BR}(B^0 \rightarrow D^{*}3\pi)$ known only to 11% precision 😞
- New BABAR analysis with full available statistics

$\text{BR}(B^0 \rightarrow D^{*}3\pi)= 0.726\pm0.011\pm0.031)$%

WA =($0.721\pm0.029)$%

PDG 2017

There is also an LHCb result of $D^{*3}\pi/D^{*}\pi$ not included in the PDG

Dominated by systematics errors
Good precision of 4.0 % now with the new WA !!

BELLE : Could you remeasure this very precisely as well !!!
D*D_s + X events with reconstructed D_s in 3\pi

- Clear separation obtained of the D_s, D_s^* and D_s^{**} components
- Ratios \sim 1:2:2 (only 20% of D_s come directly from B)

LHCb-PAPER-2017-017, arxiv 1708.08856
$X_b \rightarrow D^* D^0 X$ control sample

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

- A correction to the $q^2$ distribution is applied to the simulation to match the data.
The 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).

<table>
<thead>
<tr>
<th>Model components</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau \rightarrow \pi^+ \pi^+ \pi^- \nu_\tau$</td>
<td>Ratio constrained using known BR and efficiencies.</td>
</tr>
<tr>
<td>$\tau \rightarrow \pi^+ \pi^+ \pi^0 \nu_\tau$</td>
<td></td>
</tr>
<tr>
<td>$X_b \rightarrow D^{*+} \tau^-$</td>
<td>Ratio to signal fixed to 0.11 ± 0.04 from theory.</td>
</tr>
<tr>
<td>$B^0 \rightarrow D^+ D_s^+$</td>
<td>Relative yields constrained from $X_b \rightarrow D^{*+}D_s^+X$ control sample.</td>
</tr>
<tr>
<td>$B^0 \rightarrow D^+ D_s^{*+}$</td>
<td></td>
</tr>
<tr>
<td>$B^0 \rightarrow D^+ D_{s0}^{*+}$</td>
<td></td>
</tr>
<tr>
<td>$B^0 \rightarrow D^+ D_{s1}^+$</td>
<td></td>
</tr>
<tr>
<td>$B_s^0 \rightarrow D^+ D_s^{*+}$</td>
<td></td>
</tr>
<tr>
<td>$B \rightarrow D^{*+}D_s^+X$</td>
<td></td>
</tr>
<tr>
<td>$X_b \rightarrow D^+ D^- X$</td>
<td>Yields constrained from control samples.</td>
</tr>
<tr>
<td>$X_b \rightarrow D^+ D^0 X$</td>
<td></td>
</tr>
<tr>
<td>$X_b \rightarrow D^+ \pi^+ \pi^- X$</td>
<td></td>
</tr>
</tbody>
</table>
The 3 fit projections (\(q^2\), lifetime and BDT)

This shows the overall quality of the fit.
The 3D template binned likelihood fit results are presented for the lifetime and $q^2$ in four BDT bins.

- The increase in signal (red) purity as function of BDT is very clearly seen, as well as the decrease of the $D_s$ component (orange).
- The dominant background at high BDT becomes the $D^+$ component (blue), with its distinctive long lifetime.
- The overall $\chi^2$ per dof is 1.15.
Systematic uncertainties table

<table>
<thead>
<tr>
<th>Contribution</th>
<th>Value %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated sample size</td>
<td>4.7</td>
</tr>
<tr>
<td>Signal modeling</td>
<td>1.8</td>
</tr>
<tr>
<td>$D^{<strong>\tau\nu}$ and $D^{</strong>*\tau\nu}$ feed-downs</td>
<td>2.7</td>
</tr>
<tr>
<td>$D^+_s \rightarrow 3\pi X$ decay model</td>
<td>2.5</td>
</tr>
<tr>
<td>$B \rightarrow D^{-}D^{+}_s X$, $B \rightarrow D^{-}D^+ X$, $B \rightarrow D^{-}D^0 X$ backgrounds</td>
<td>3.9</td>
</tr>
<tr>
<td>Combinatorial background</td>
<td>0.7</td>
</tr>
<tr>
<td>$B \rightarrow D^{*}3\pi X$ background</td>
<td>2.8</td>
</tr>
<tr>
<td>Empty bins in templates</td>
<td>1.3</td>
</tr>
<tr>
<td>Efficiency ratio</td>
<td>3.9</td>
</tr>
<tr>
<td>Total internal uncertainty</td>
<td>8.9</td>
</tr>
</tbody>
</table>

$\mathcal{B}(B^0 \rightarrow D^{*}3\pi)$ and $\mathcal{B}(B^0 \rightarrow D^{*}\mu\nu\mu)$ | 4.5     |
A post fit projection of variables not used in the fit mass: $D^*\pi^+\pi^-\pi^+$ and $\min(\pi^+\pi^-)$
Post-fit projection of $D^{*-}\pi^+\pi^-\pi^+$ mass for 4 BDT bins
\[ BR(B^\circ \rightarrow D^* \tau \nu)/BR(B^\circ \rightarrow D^* 3\pi) = 1.93 \pm 0.13\text{(stat)} \pm 0.17\text{(syst)} \]

\[ BR(B^\circ \rightarrow D^{*+} \tau \nu) = (1.39 \pm 0.09\text{(stat)} \pm 0.12\text{(syst)} \pm 0.06\text{(ext)})\% \]

Using for \( BR(B^\circ \rightarrow D^* 3\pi) \) the new PDG 2017 WA of 0.721 \pm 0.029 to be compared with the PDG(2017) (1.67 \pm 0.13 \%)%

New (naive) average \( BR(B^\circ \rightarrow D^* \tau \nu) = (1.56 \pm 0.10)\% \)

\[ R(D^*) = 0.285 \pm 0.019\text{(stat)} \pm 0.025\text{(syst)} \pm 0.013\text{(ext)} \]

Using the HFLAV \( BR(B^\circ \rightarrow D^{*\mu \nu}) = (4.88 \pm 0.10)\% \)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Method</th>
<th>( N\text{ evts} B \rightarrow D^* \tau \nu )</th>
<th>( N\text{ evts} B^\circ \rightarrow D^{*+} \tau \nu )</th>
</tr>
</thead>
<tbody>
<tr>
<td>BABAR</td>
<td>Leptonic hadronic tag</td>
<td>888 \pm 63</td>
<td>245 \pm 27</td>
</tr>
<tr>
<td>BELLE</td>
<td>Leptonic hadronic tag</td>
<td>503 \pm 65</td>
<td>0.4 \times 503 = 200</td>
</tr>
<tr>
<td>BELLE</td>
<td>Single pi hadronic tag</td>
<td>88 \pm 11</td>
<td>88 \pm 11</td>
</tr>
<tr>
<td>LHCb</td>
<td>3\pi Hadronic</td>
<td>1273 \pm 95</td>
<td>1273 \pm 95</td>
</tr>
</tbody>
</table>
D** cross check

- $B^0 \rightarrow D^{**} \tau \nu$ and $B^+ \rightarrow D^{**0} \tau \nu$ constitute potential feeddown 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 $D^{**3\pi}$ BDT distribution and to deduce a $D^{**}\tau \nu$ upper limit with the following assumption.
  - $D^{**0}\tau \nu = D^{**}(2420)^0\tau \nu$ (no sign of $D^{**}(2460)^0$
  - $D^{**+}\tau \nu = D^{**0}\tau \nu$
- This upper limit is consistent with the theoretical prediction
- Subtraction in the signal of $0.11 \pm 0.04$ due to $D^{**}\tau \nu$ events leading to an error of 2.3%

All detached vertices

Detached vertex for BDT $> 0.1$
This analysis:

\[ R(D^*) = 0.285 \pm 0.019 \text{(stat)} \pm 0.029 \text{(syst)} \]

Reminder muonic \( R(D^*) = 0.336 \pm 0.027 \pm 0.030 \)

- 2.1 \( \sigma \) above SM, 0.6 \( \sigma \) above WA

Preliminary LHCb average

\[ 0.306 \pm 0.016 \pm 0.022 \]

- 2.1 \( \sigma \) above SM, 0.1 \( \sigma \) above WA

This results pulls down WA a bit but increases slightly the discrepancy wrt SM!!

New WA

\[ R(D^*) = 0.304 \pm 0.013 \text{(stat)} \pm 0.07 \text{(syst)} \]
The new FPCP average

Combined significance: 4.1 σ away from SM

Δχ² = 1.0 contours

- SM Predictions
- R(D)=0.300(8) HPQCD (2015)
- R(D)=0.299(11) FNAL/MILC (2015)
- R(D*)=0.252(3) S. Fajfer et al. (2012)
Prospects

For the hadronic $R(D^*)$ LHCb measurement, the inclusion of Run2 data will allow to multiply the statistics by a factor 3 (4 with 2017 data)

- Higher $bb$ cross section, better trigger
- If WA is correct, the discrepancy with SM could increase significantly

Several $Rs$ will be measured in the coming year: $R(\Lambda_c)$, $R(J/\psi)$, ...

The details of the internal event structure will be scrutinized

Other $R(D^*)$ measurements from BABAR and BELLE still possible
The semitauonic program

1. Vertical extension of R(D*)
   - R(D*) measurement with Run2 data
   - Extraction of internal quantities, most notably $q^2$, search for NP effects using our high stats high purity sample
   - Measure $R(D^{**\circ}(2420)$ per se and to constraint D** feed-down

2. Horizontal extension of R(D*)
   - $R(\Lambda_c)$
   - $R(J/\psi R(D^+), R(D^\circ)$
   - $R(D_s)$
   - $V_{ub}$
Precision Goals for Run1+Run2 data

- Run2 = 2015+2016 (already available) + 2017
- $D^*D_s (\text{Run2})/D^*D_s (\text{Run1}) \sim 3$
- Statistical precision $\sim 4\%-3\%$
- Internal systematic precision $\sim 5\%$ (need more data from BES) *(Collaboration in preparation)*
- External systematic precision $\sim 3\%$ (need more data from BELLE-1)
The semitauonic workshop

- To be held in Orsay Nov 13-15 2017

Open sessions:
- Monday Nov 13 (afternoon)
- Tuesday Nov 14 (all day)
How BELLE-1 data could help !!

- **BR(B^0 \rightarrow D^*3\pi)**
  - Not as simple as it appears:
    - a_1(1260), \rho\pi, f_2(1270), 3\pi nr, D^{**} states
    - An effective a_1(1260) region could be the best thing to use

- **Study of B \rightarrow D^*(*)D_s(*)(*)**
  - “Straightforward” recoil study (performed by BABAR in 2006)
    - BR(B \rightarrow D^*D_s), high q^2 templates

- **R(D^{**})** as new measurement of its own and as a control of D^{**} feeddown

- **B^+(D^*\pi) D_s(\ast)** a channel forgotten up to now by B-factories which can provide a very good measurement of the D^{**} spectrum

- **D_s \rightarrow 3\pi X, D^+ \rightarrow 3\pi X**

- And of course all improvements in D^*lv decays are very useful for theorist to further improve R(D) and R(D^{**}) predictions
**D* and Ds recoil study from BABAR**

Study of $B \rightarrow D(*) D(*) \ (s(J))$ Decays and Measurement of $D^- s$ and $DsJ(2460)$ Branching Fractions  *Phys.Rev. D74 (2006) 031103*

- Only 205 fb$^{-1}$
- Does not cover the higher mass regions for $D_s^{**}$ and $D^{**}$
Conclusions

- The analysis to measure the ratio $\text{BR}(B^o \rightarrow D^{*}\tau\nu)/\text{BR}(B^o \rightarrow D^{*}3\pi)$ using the 3 $\pi$ hadronic decay of the $\tau$ lepton has been performed at LHCb (Preliminary)
  
  $$R(D^*)=0.285\pm0.019(\text{stat})\pm0.025(\text{syst})\pm0.013(\text{ext})$$

- New preliminary LHCb average of $R(D^*)=0.306\pm0.026$

- This analysis was made possible due to the unique LHCb capabilities for separating secondary and tertiary vertices with unprecedented precision

- The $R(D^*)$ result, the first one to use $3\pi$ final state, is one of the best single measurements, having the smallest statistical error.

- It is compatible both with the SM prediction and with the present WA. However, it slightly increases the discrepancy of the WA wrt to the SM

- This method *paves the way* for the measurements of
  - $R(D^*)$ using the full Run2 data with a goal of 3% statistical precision
  - All other $R(X)$, with $R(\Lambda_c)$ and $R(J/\psi)$ currently underway
  - The detailed internal characteristics of the events due to the unique possibility to isolate a **high statistics high purity sample** of $D^{*}\tau\nu$ events

KEK seminar, October 24 2017
The 2012 BABAR results

<table>
<thead>
<tr>
<th>Decay</th>
<th>$N_{stg}$</th>
<th>$N_{norm}$</th>
<th>$\varepsilon_{stg}/\varepsilon_{norm}$</th>
<th>$R(D^{(*)})$</th>
<th>$B(B \rightarrow D^{(*)}\tau\nu)$ (%)</th>
<th>$\Sigma_{stat}$</th>
<th>$\Sigma_{tot}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^- \rightarrow D^0 \tau^- \bar{\nu}_\tau$</td>
<td>314 ± 60</td>
<td>1995 ± 55</td>
<td>0.367 ± 0.011</td>
<td>0.429 ± 0.082 ± 0.052</td>
<td>0.99 ± 0.19 ± 0.13</td>
<td>5.5</td>
<td>4.7</td>
</tr>
<tr>
<td>$B^- \rightarrow D^{*0} \tau^- \bar{\nu}_\tau$</td>
<td>639 ± 62</td>
<td>8766 ± 104</td>
<td>0.227 ± 0.004</td>
<td>0.322 ± 0.032 ± 0.022</td>
<td>1.71 ± 0.17 ± 0.13</td>
<td>11.3</td>
<td>9.4</td>
</tr>
<tr>
<td>$B^0 \rightarrow D^+ \tau^- \bar{\nu}_\tau$</td>
<td>177 ± 31</td>
<td>986 ± 35</td>
<td>0.384 ± 0.014</td>
<td>0.469 ± 0.084 ± 0.053</td>
<td>1.01 ± 0.18 ± 0.12</td>
<td>6.1</td>
<td>5.2</td>
</tr>
<tr>
<td>$B^0 \rightarrow D^{*+} \tau^- \bar{\nu}_\tau$</td>
<td>245 ± 27</td>
<td>3186 ± 61</td>
<td>0.217 ± 0.005</td>
<td>0.355 ± 0.039 ± 0.021</td>
<td>1.74 ± 0.19 ± 0.12</td>
<td>11.6</td>
<td>10.4</td>
</tr>
<tr>
<td>$\bar{B} \rightarrow D^- \tau^- \bar{\nu}_\tau$</td>
<td>489 ± 63</td>
<td>2981 ± 65</td>
<td>0.372 ± 0.010</td>
<td>0.440 ± 0.058 ± 0.042</td>
<td>1.02 ± 0.13 ± 0.11</td>
<td>8.4</td>
<td>6.8</td>
</tr>
<tr>
<td>$\bar{B} \rightarrow D^{*-} \tau^- \bar{\nu}_\tau$</td>
<td>888 ± 63</td>
<td>11953 ± 122</td>
<td>0.224 ± 0.004</td>
<td>0.332 ± 0.024 ± 0.018</td>
<td>1.76 ± 0.13 ± 0.12</td>
<td>16.4</td>
<td>13.2</td>
</tr>
</tbody>
</table>

$N(B^\rightarrow D^{*+}\tau\nu) = 245 \pm 27$ events

$BR(B^\rightarrow D^{*+}\tau\nu) = (1.76 \pm 0.19 \pm 0.12 \%)$
The sources of the different efficiencies between signal and normalization have been studied in great detail. The major contribution come from the softer D*(slow pion) and $3\pi p$ and $p_T$ spectrum for the signal induced by the presence of two extra neutrinos.