Lepton Flavour Universality tests using semitauonic decays at LHCb

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Talk outline

- Introduction
- The first BABAR measurement (2012)
- Review of all other mesurements until now
- The new R(D*) measurement from LHCb
  - **First public release at FPCP2017 on June 5, 2017**
  - **Published on Arxiv Aug 29, 2017 hepx-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 τ BR is 2.8 σ above <e,μ> which are equal to 2 per mille precision

$$\left.\frac{\mathcal{B}(W \to \tau\nu_\tau)}{[\mathcal{B}(W \to e\nu_e) + \mathcal{B}(W \to \mu\nu_\mu)]/2}\right|_{\mathrm{LEP}} = 1.077 \pm 0.026,$$

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

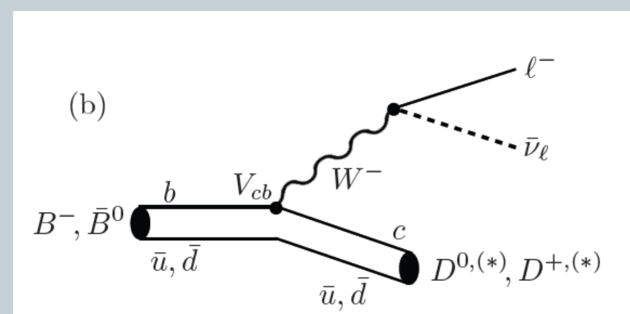
Can ATLAS (or CMS) measure this precisely ?

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*) =(B➔D*τν/B➔D*μν)
  - Abundant channel BR(B°➔D*τν)=1,24%, one of the largest individual BR
  - Sensitivity to new physics : (simplest realization) A charged Higgs will automatically couple more to the τ . LFU violation can also occur through other mechanisms (leptoquarks,..)
- They offer several hadronisation implementations:
  - D*,D°,D+,Ds,Λ_c,J/ψ
  - Differing not only by various properties of the spectator particle but also its spin 0,1(D* and J/ψ) and ½ (Λ_c!!)

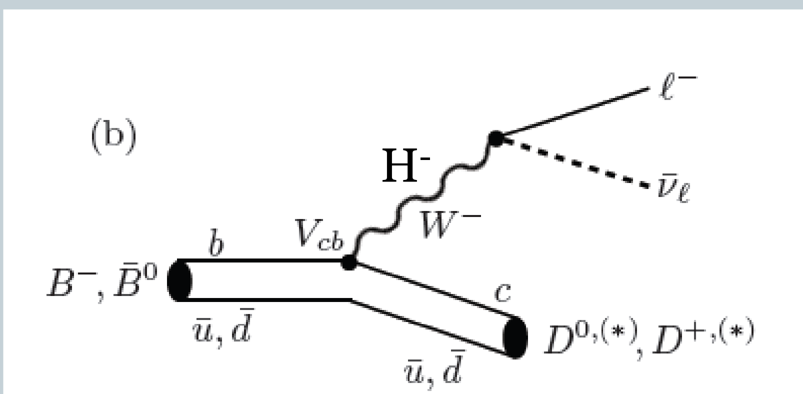
$$\frac{d\Gamma^{SM}(\bar{B}\to D^{(*)}\ell^-\bar{\nu}_\ell)}{dq^2} = \underbrace{\frac{G_F^2\,|V_{cb}|^2\,|p^*_{D^{(*)}}|\,q^2}{96\pi^3 m_B^2}\left(1-\frac{m_\ell^2}{q^2}\right)^2}_{\text{universal and phase space factors}} \tag{3}$$
$$\times \underbrace{\left[\left(|H_+|^2+|H_-|^2+|H_0|^2\right)\left(1+\frac{m_\ell^2}{2q^2}\right)+\frac{3m_\ell^2}{2q^2}|H_s|^2\right]}_{\text{hadronic effects}} .$$

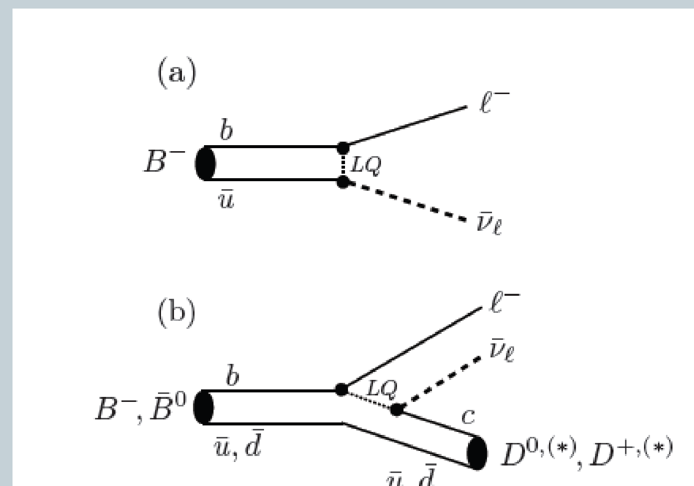


ArXiv: HEP-1703-01766

New physics reach

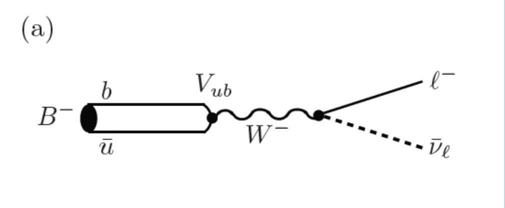
- Charged Higgs, Leptoquarks are the usual suspects
- Sensitivity comparable or even higher at ATLAS and CMS in some models : many scenarios still open after taking into account the present direct exclusions domains
- If the WA average is correct,, , **$R(D^*)/R(D^*)_{SM}$=1.23: Large new physics effects !!**
- Sensitivity not only on the yield but also in the internal characterics 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

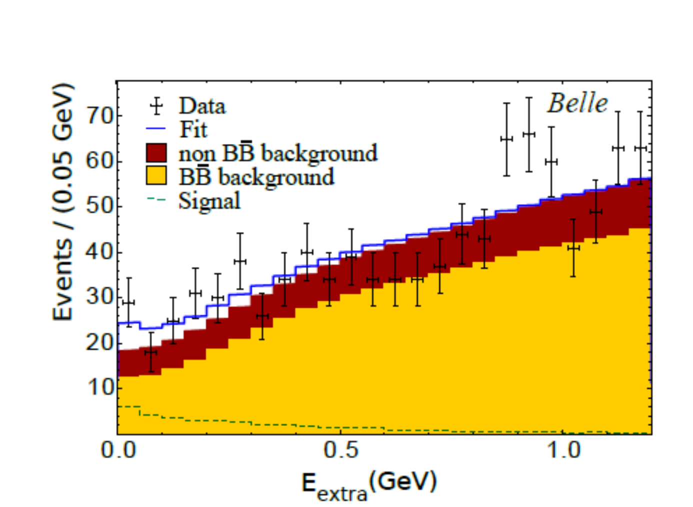




Search for LFU violation in V_{ub} decays

- Note that in the long term the 'Vub' analog b->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➔$\pi\tau\nu$
  - LHCb can look for Λ_b➔$p\tau\nu$ or B°➔$p\bar{p}\tau\nu$
- A similar reaction is the annihilation diagram

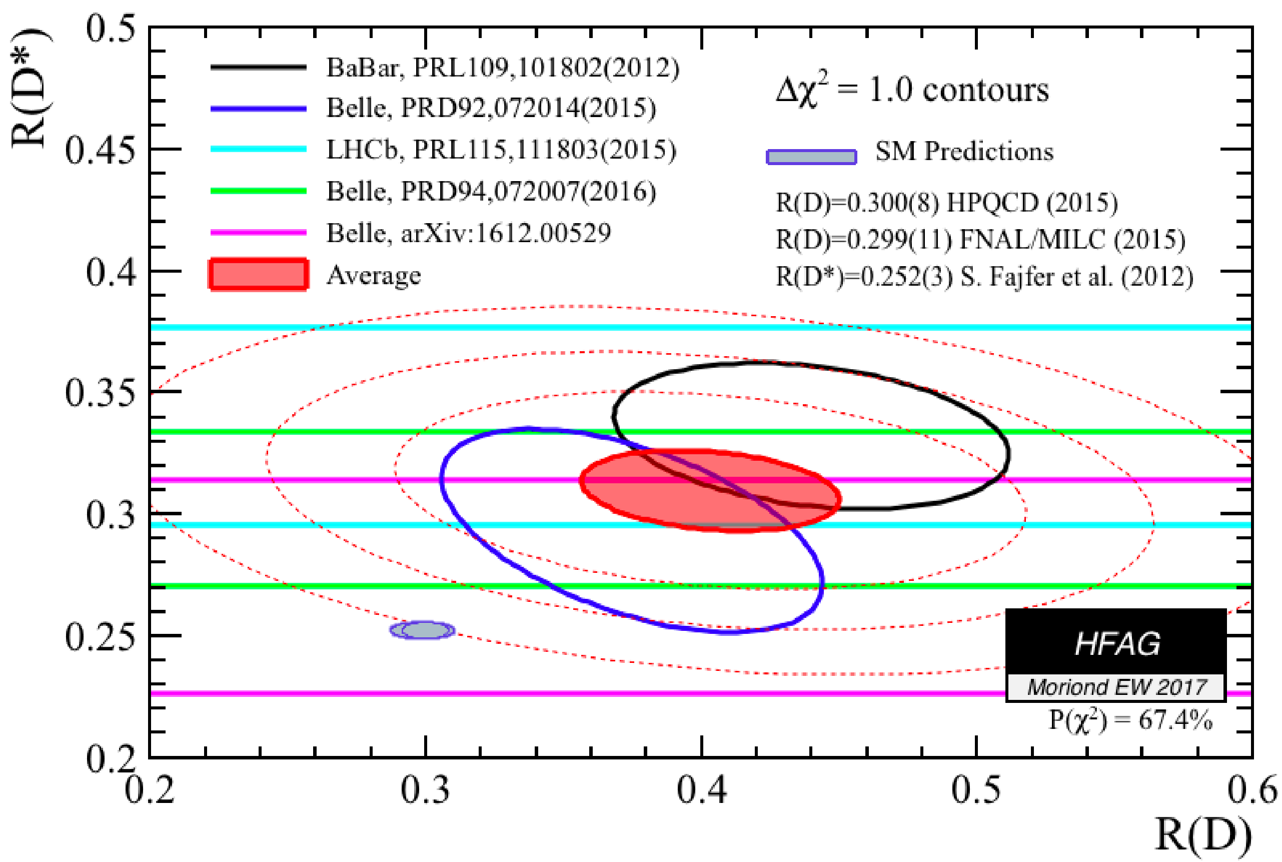




$$\mathscr{B}(B^- \to \tau^- \overline{\nu}_\tau) = (1.06 \pm 0.19) \times 10^{-4}.$$

$$\mathscr{B}^{SM}(B^- \to \tau^- \overline{\nu}_\tau) = (0.75 \pm^{0.10}_{0.05}) \times 10^{-4}.$$

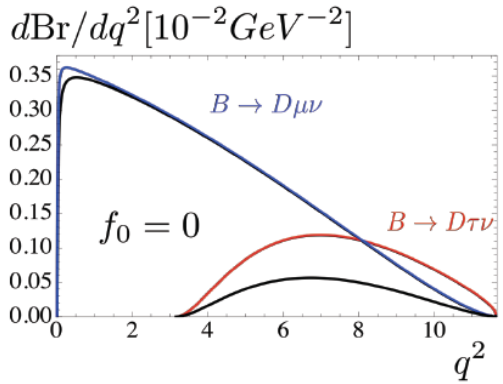
R(D) and R(D*) as of March 2017



R(D*) is predicted more precisely than R(D) (?)

- Different sensistivity to FF uncertainties

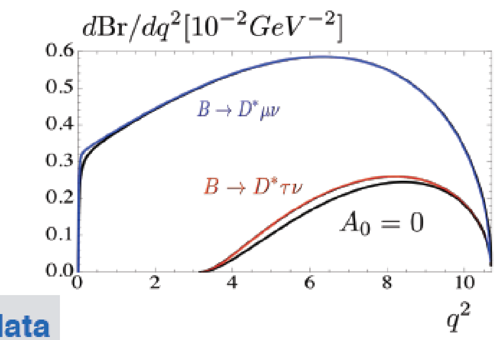
Standard Model predictions



$$R(D^*) = 0.252 \pm 0.003$$

Fajfer, Kamenik, Nisandzic (2012)

scalar form factor has a small impact



Current experimental data

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

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*)

- Regarding R(D) P. Gambino and D. Bigi, Phys. Rev. D 94, 094008 (2016)
  - "First, two calculations of the form factors of B→Dlν beyond zero-recoil have appeared in 2015 . They represent the first unquenched calculations of these form factors performed at different q2 values, which significantly reduces the uncertainty of the extrapolation from the q2 region where most data are taken.
  - Second, a new, more precise Belle measurement has been published , which for the first time provides the q2 differential distribution with complete statistical and systematic uncertainties and correlations. The combination of these steps forward allows for a competitive extraction of |Vcb| and for a very precise determination of the B→D form factors."
- R(D)=0.299 (3)

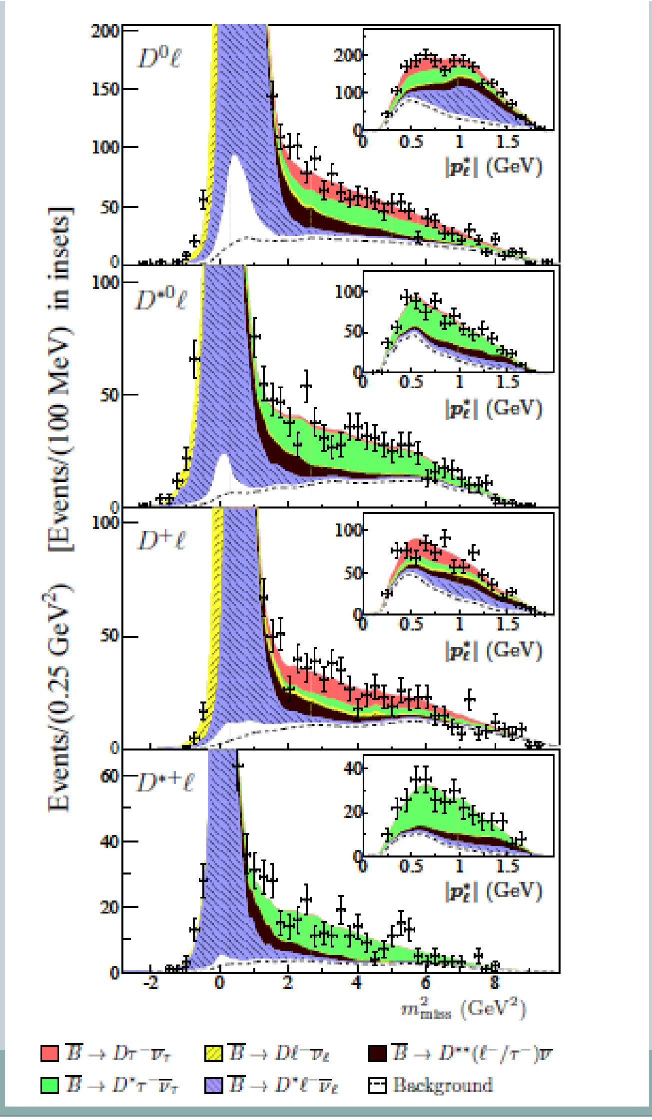
Recent trends(2): R(D) better than R(D*)

- Regarding R(D*) P. Gambino, D. Bigi, S.Schacht arxiv 1707.09509 (July 29,2917)
  - Change of CLN to BGL parametrization leads to Vcb exclusive of 0.42(2) 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)**
  - Tensions and correlations in $|V_{cb}|$ determinations arXiv:1708.07134
    - "The tensions concerning the exclusive and inclusive determinations of $|V_{cb}|$ cannot be considered resolved."

The first BABAR 2012 result
PRL109, 101802(2012)

- 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
    - PRD94, 072007 (2015)
  - Hadronic tag –hadronic tau decay in $\pi/\pi\pi^0$. Important to access tau polarization information. Real challenge to fight hadronic background
    - PRL118,211801 (2017), arXiv1612. 00529
- 1 new mesurement from LHCb collaboration
    - PRL115, 1183(2015)
  - Muonic tau decay in a hadronic collider !!!!

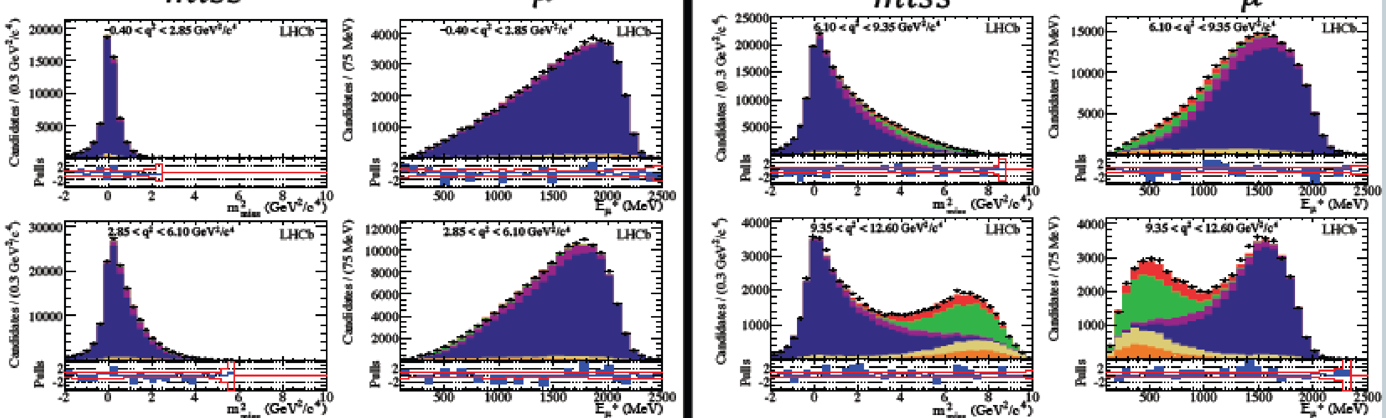
LHCb muonic result (2015)

PRL 115 111803 (2015)

Fit Result

Low q^2 | High q^2

m^2_{miss} | E^*_μ | m^2_{miss} | E^*_μ

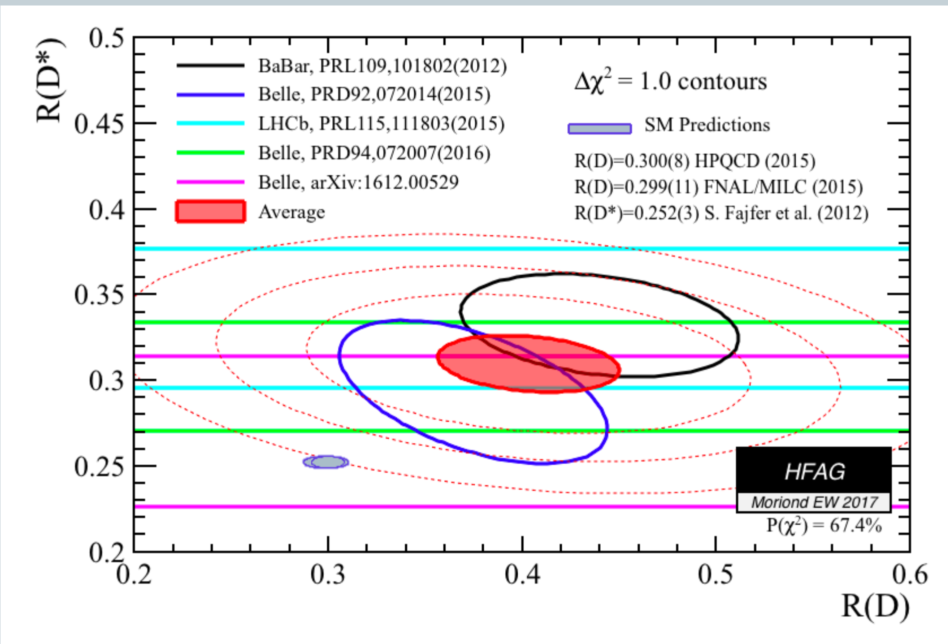


- Shown above: signal fit to "signal" data passing isolation selection
- Result $\frac{N_\tau}{N_\mu} = (4.32 \pm 0.37)\times 10^{-2}$, $R(D^*) = 0.336 \pm 0.027 \pm 0.030$
- $N(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu) = 363{,}000 \pm 1600$

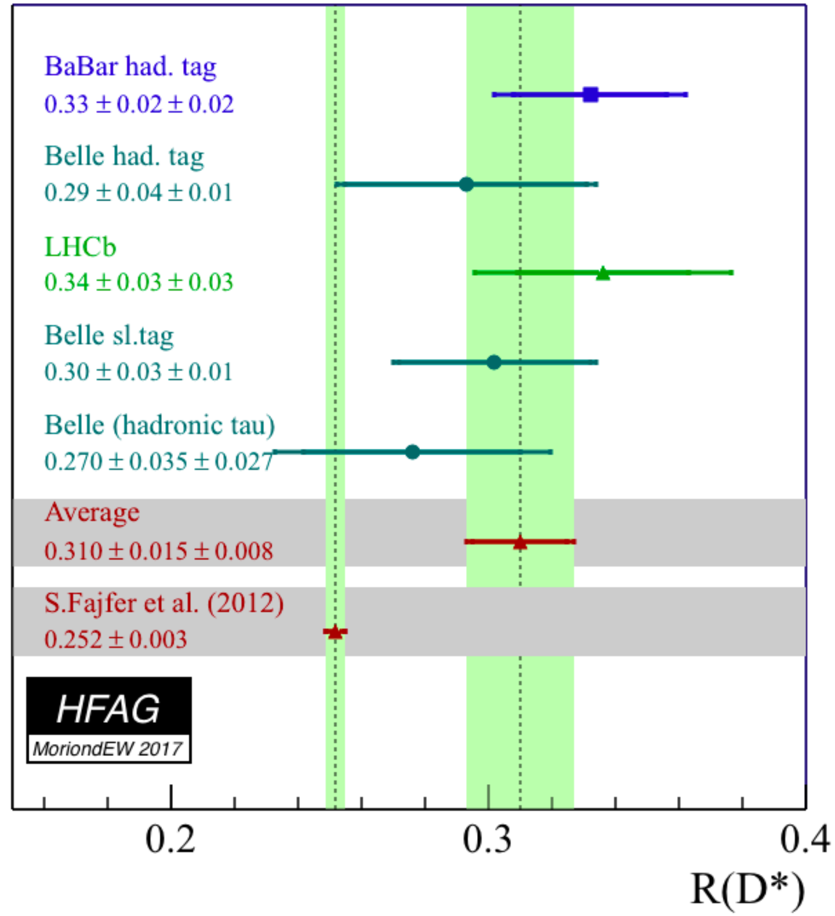
Data
$B \to D^*\tau\nu$
$B \to D^*H_c(\to l\nu X')X$
$B \to D^{**}l\nu$
$B \to D^*\mu\nu$
Combinatoric
Misidentified μ

R(D*) status in Spring 2017

R(D*) is predicted very precisely in the SM
R(D*) WA is 3.3 σ away from SM



http://www.slac.stanford.edu/xorg/hfag/semi/index.html



Combined R(D) and R(D*) is 4 σ away from SM

If WA is correct, $R(D^*)/R(D^*)_{SM}$=1.23: Large new physics effects !!

The unusual features of the LHCb analysis $D^{*}\tau\nu$; $\tau \rightarrow 3\pi(\pi^{\circ})$

- 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 τ vertex
  - The complete event kinematics can be reconstructed with good precision
- No sensitivity to τ 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

The initial very large background

- The $D^*\tau\nu$ decay, with τ 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 :

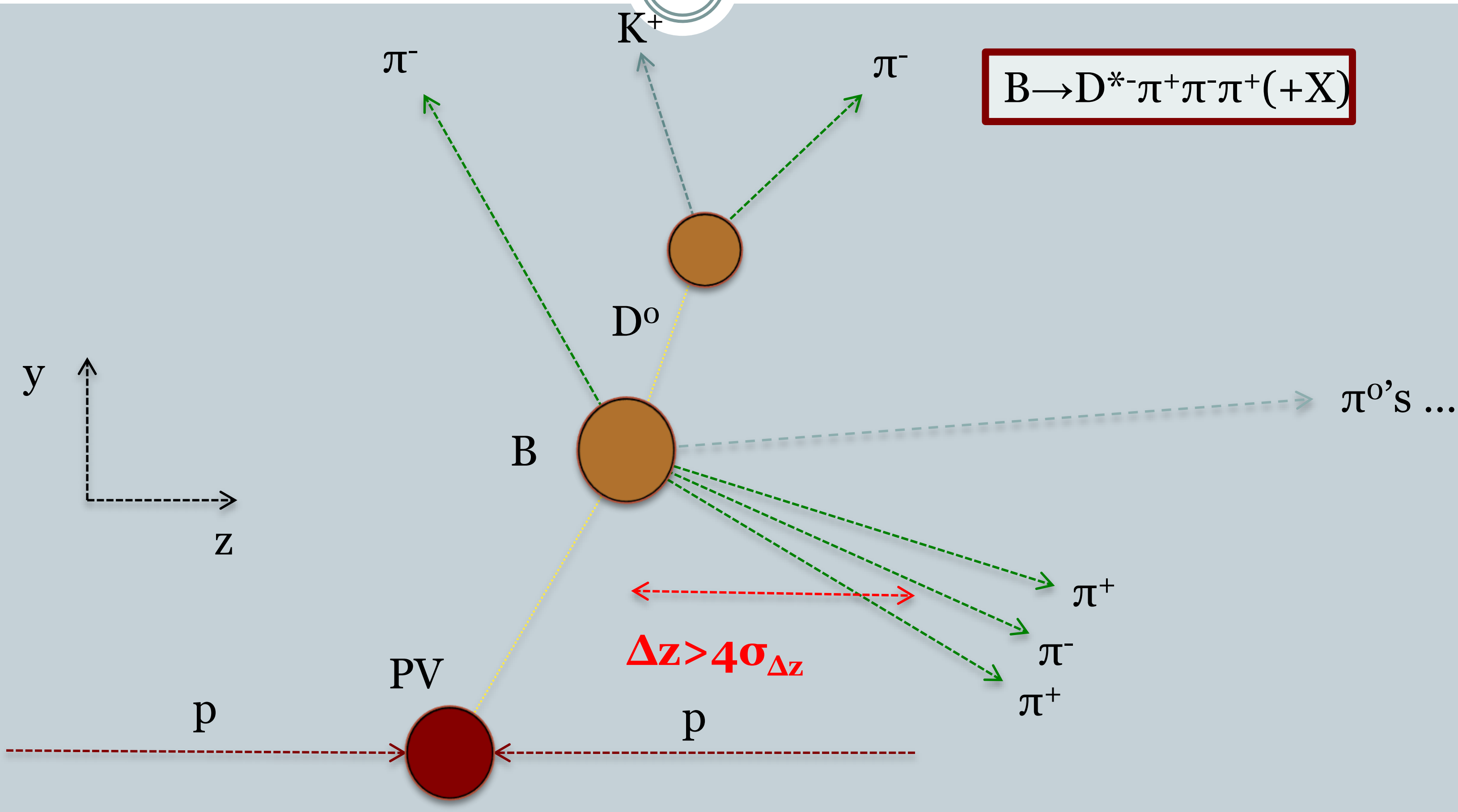
$$BR(B^o \to D^* 3\pi + X)/BR(B^o \to D^*\tau\nu; \tau \to 3\pi)_{SM} \sim 100$$

A very strong background suppression method is absolutely needed :

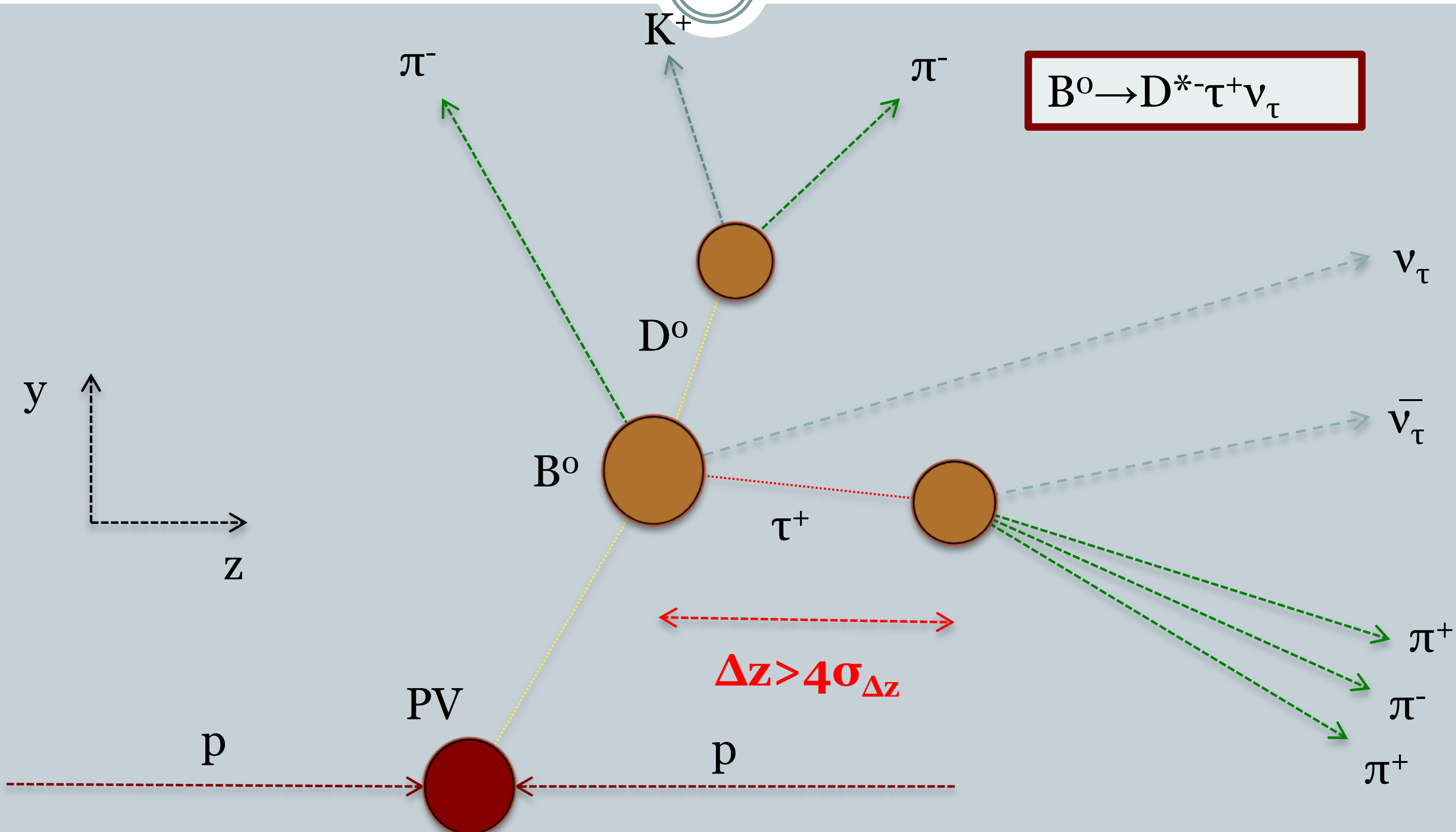
The DETACHED VERTEX METHOD

Vertex topology of the usual B decay

$B \to D^{*-}\pi^+\pi^-\pi^+(+X)$

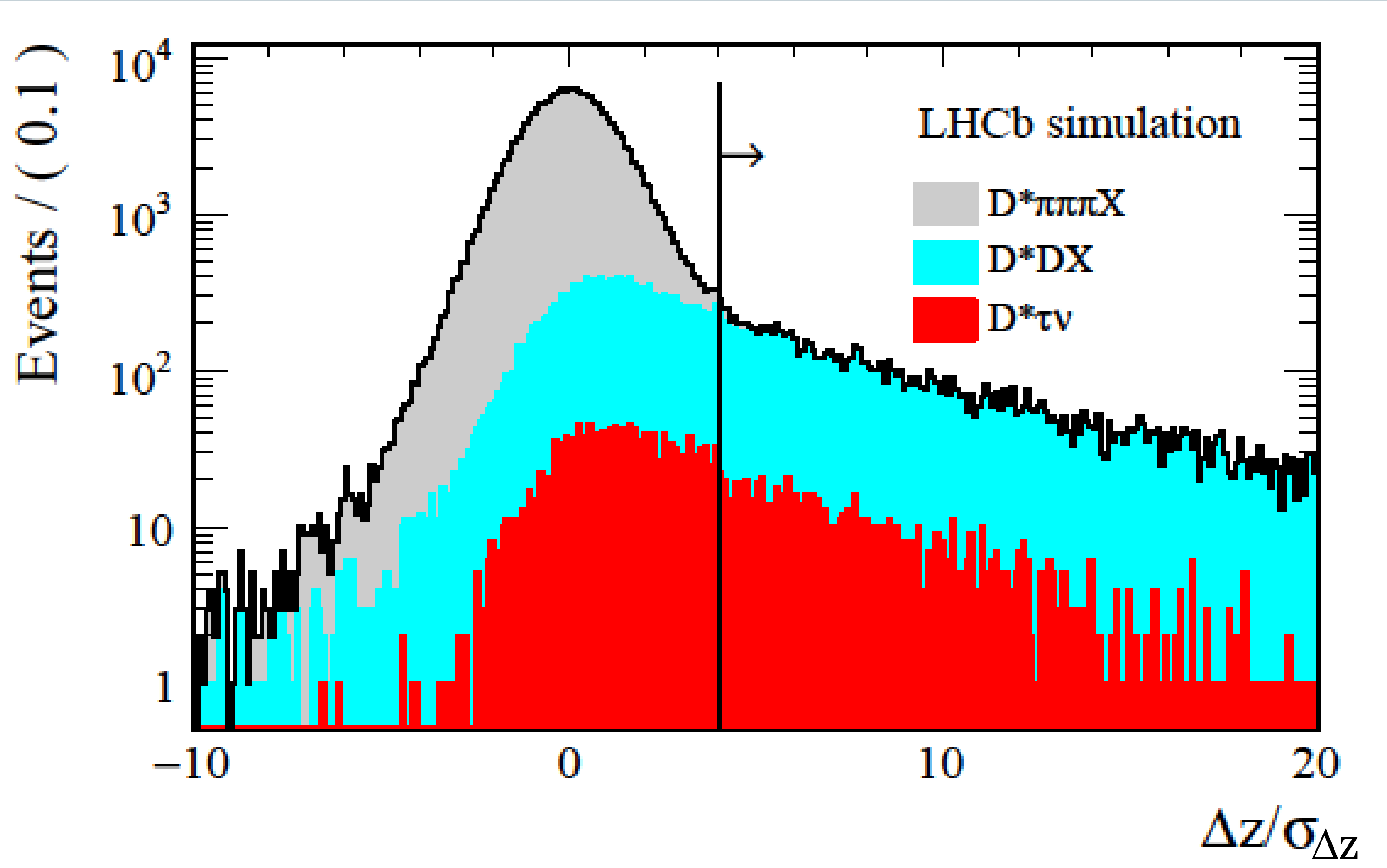


Selection: detached vertex



Selection: the detached vertex method

LHCb-PAPER-2017-017 arxiv 1708.08856



The second level of background

- After the 4σ cut in $\Delta z/\sigma_{\Delta z}$, the prompt background is suppressed by ~3 orders of magnitude!!!!!
- The second level of background consists of B decays where the 3π vertex is transported away from the B^o vertex by a charm carrier: D_s, D^+ or D^o (in that order of importance)
- This background is smaller :

$BR(B^o \to D^*\ 'D';\ 'D' \to 3\pi X)/\ BR(B^o \to D^* \tau\nu; \tau \to 3\pi)_{SM} \sim 10$

- … and we can suppress it strongly

Analysis workflow

- L0 Trigger : L0TOS OR (L0Hadron OR L0Muon)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 3π 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

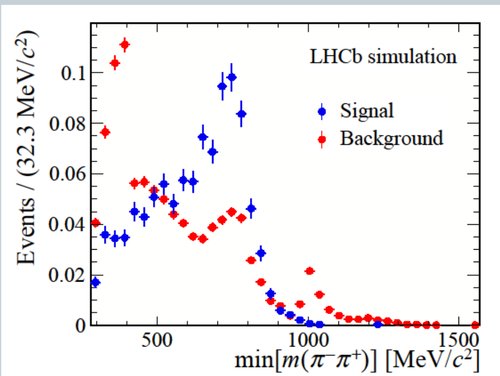
The inclusive D_s decays in 3 pions

- The $W \rightarrow c\bar{s}$ decays can produce a single meson $\mathbf{D_s}$, very often in an excited state D_s^*, D_s^{**} or two particles D^0K^-, 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 3π +X final states (~25%!)
- We classify hadronic D_s decays into 3 pions in 4 categories
  - $\eta\pi X$ ($\eta\pi$,$\eta\rho$)
  - $\eta'\pi X$($\eta'\pi$,$\eta'\rho$)
  - (ϕ/ω) πX (ϕ/ω π, ϕ/ω ρ)
  - $M3\pi$, where M can be ν,K^0,η,η',ω,ϕ
- We do not have precise BR for all of these (some well measured, some poorly, some not at all)
- The inclusive BR of Ds into 3 pions that could constraint all of these is not known either

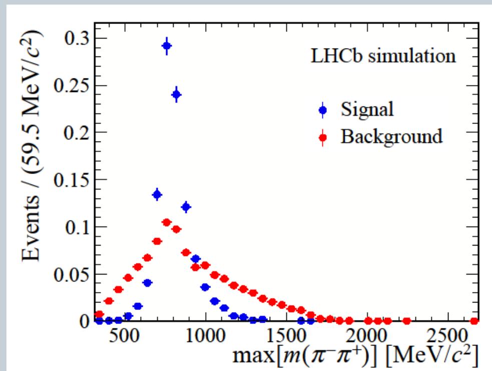
➔ **We extract these informations from LHCb data in a D_s enriched region (BDT<-0.075) (~90% D_s)**

The anti-D_s BDT : 3π dynamics, partial reconstruction and isolation

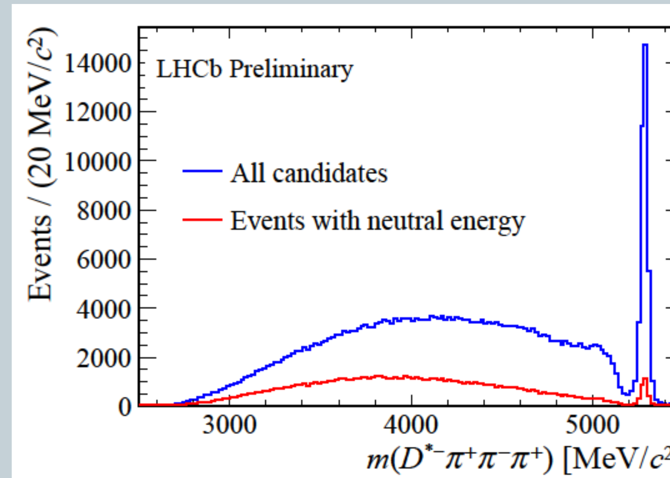
Min(mass($\pi^+\pi^-$))



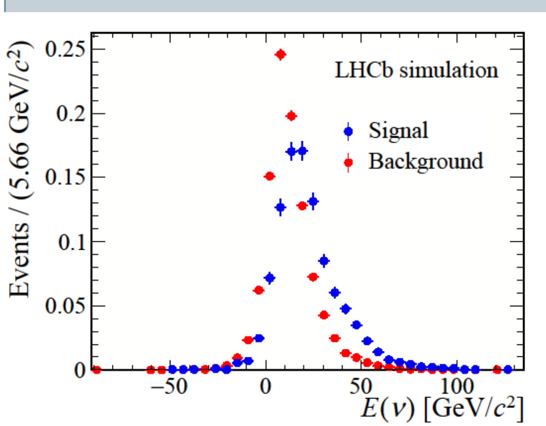
Max(mass($\pi^+\pi^-$))



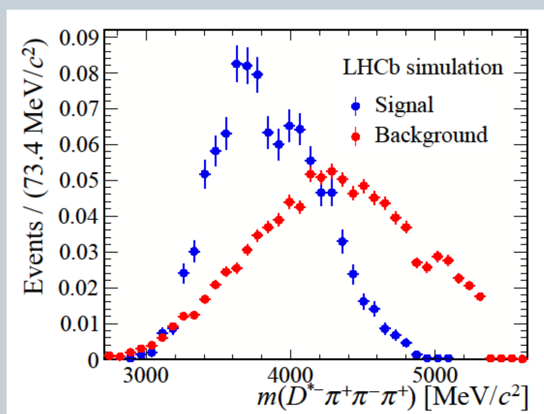
Neutral Isolation



E(ν)



mass($D^{*+}\pi^-\pi^+\pi^-$)



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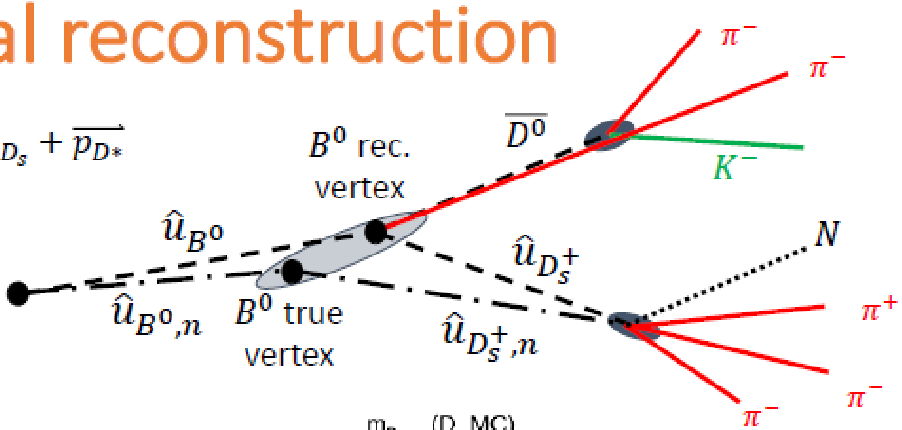
Background Partial reconstruction

Partial reconstruction

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

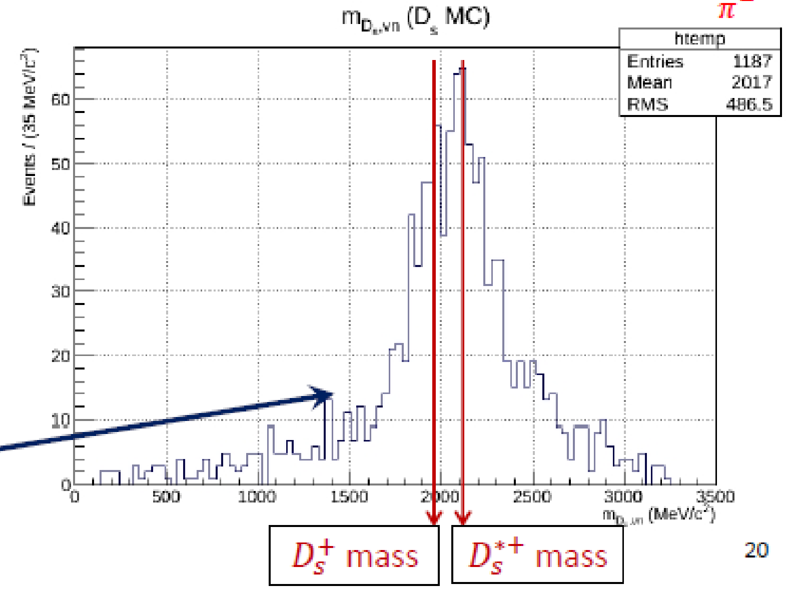
After some vectorial algebra → get magnitude of B^0 and D_s^+ momenta



First approximation → $\hat{u}_{D_s}$ is the 3π direction

Apply a **correction** to B⁰ vertex due to the presence of neutral particles in D_s^+ decay → **parametrization** of this correction as function of 3π mass on $D^{*-}D_s^+$ MC → get B^0 and D_s^+ momenta at a **next-level of approximation**

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



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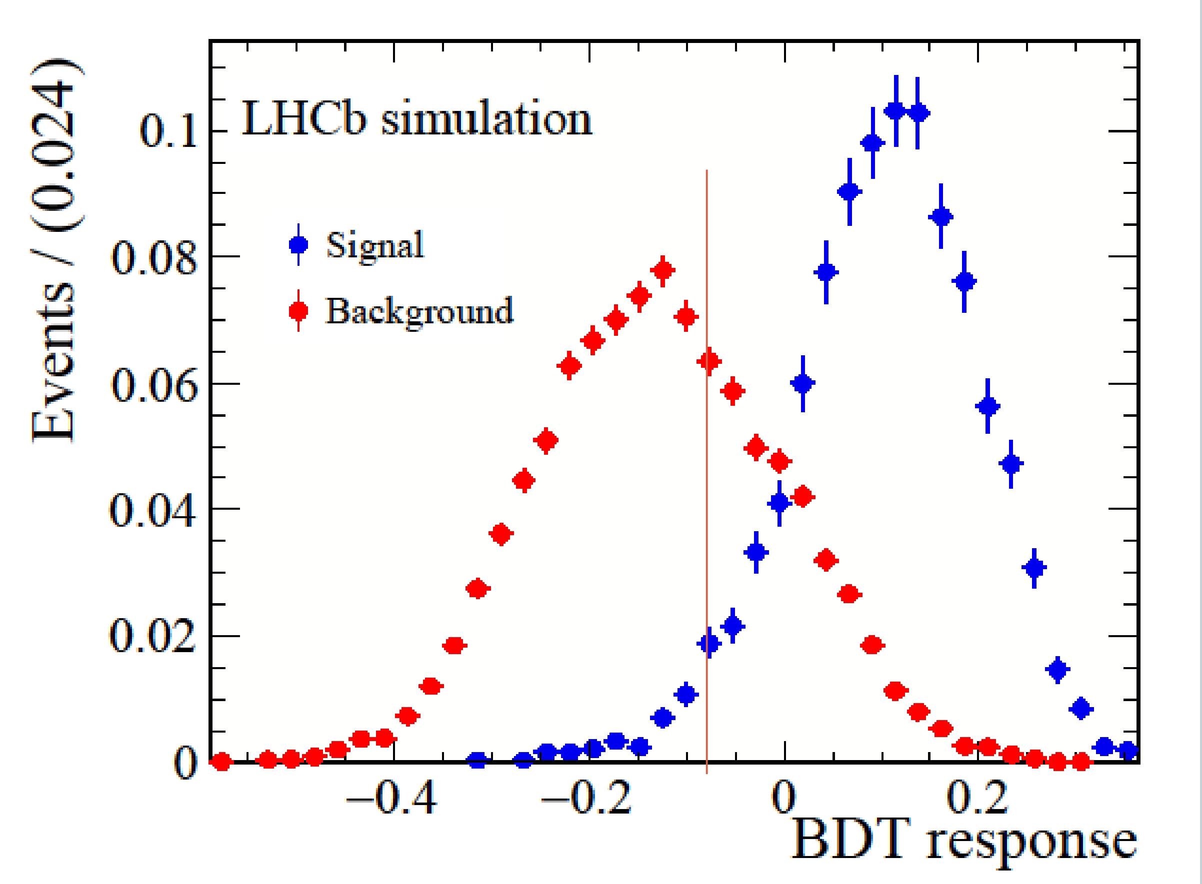
BDT results

- Good separation obtained
- Allows to select an high purity sample at high efficiency
- Charged Isolation and PID cuts are also required to select candidates



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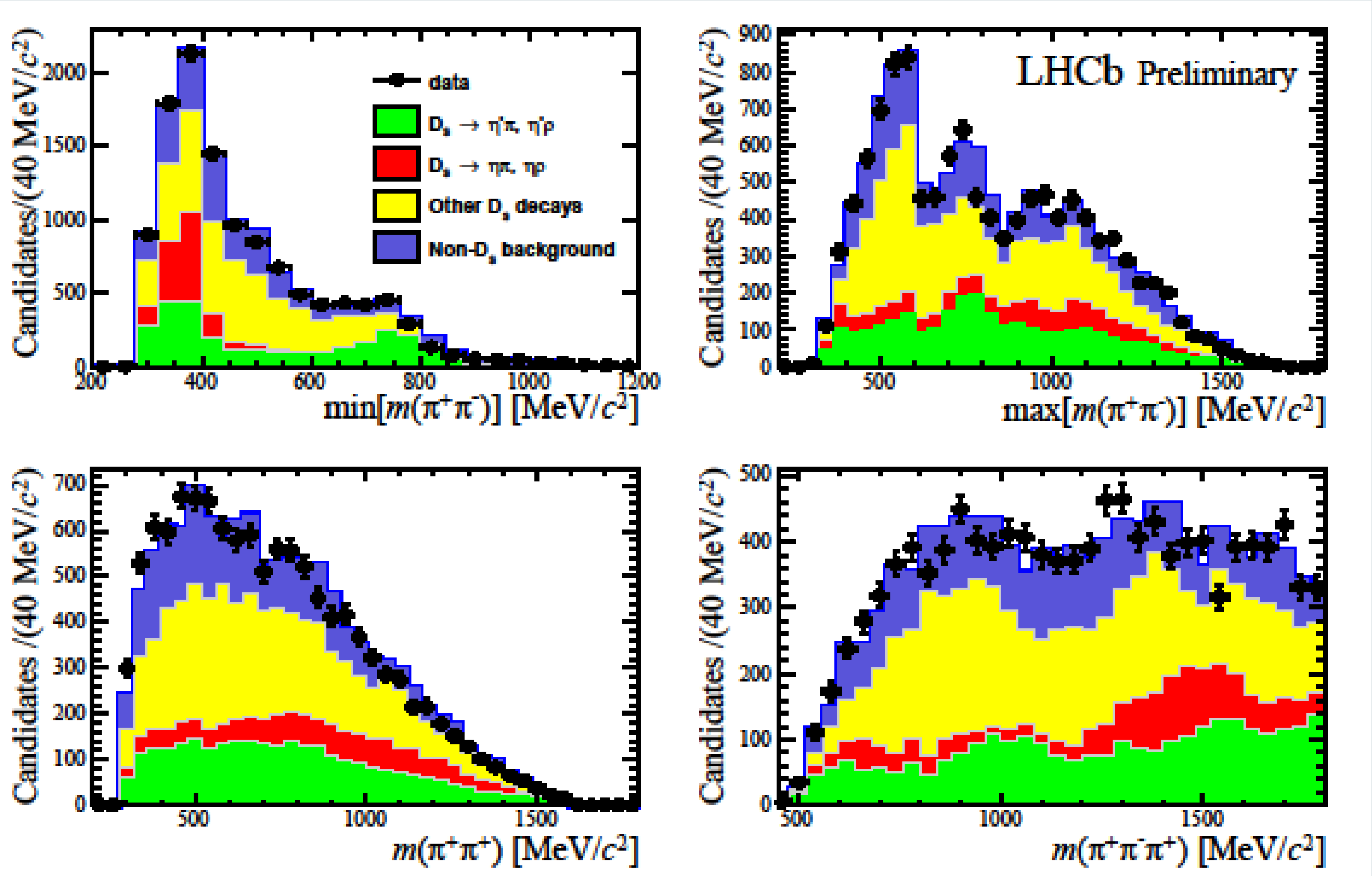
The D_s decay model fit at low BDT



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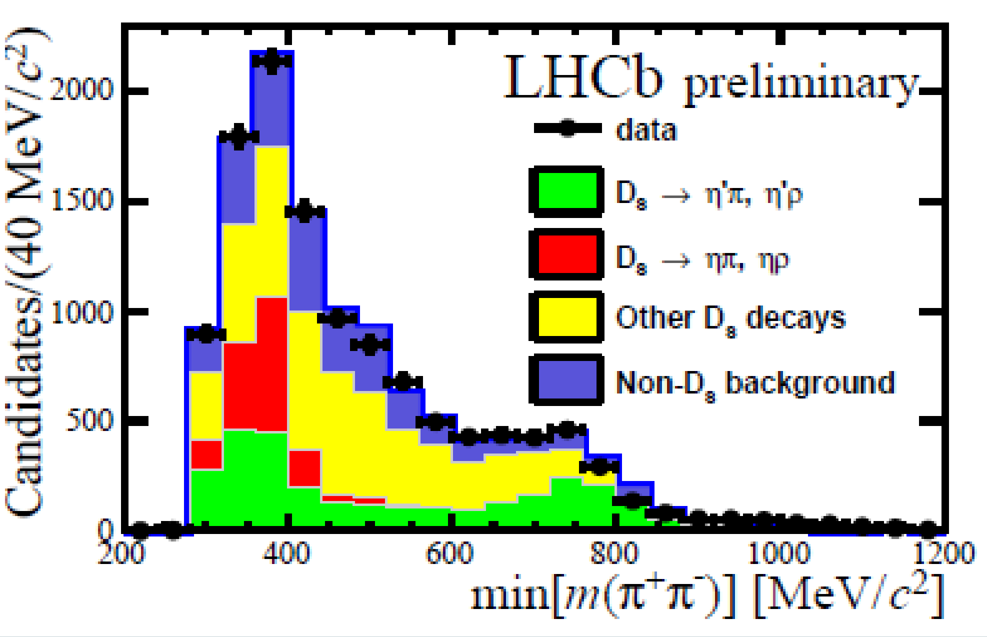
The importance of the « D_s-o-meter »

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

$\eta \rightarrow \pi^+\pi^- \pi^0$ and $\eta' \rightarrow \eta \pi^+\pi^-$

- At the ρ mass where the signal lives, only η' 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° decays in K3π
- Necessity to reject also 5 prong D_s decays which are frequent when there is the combined presence of an η and η' presence in the decay chain.
- Very efficient for D° 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 ππ l events where the lepton from a semileptonic D_s decays is taken as pion

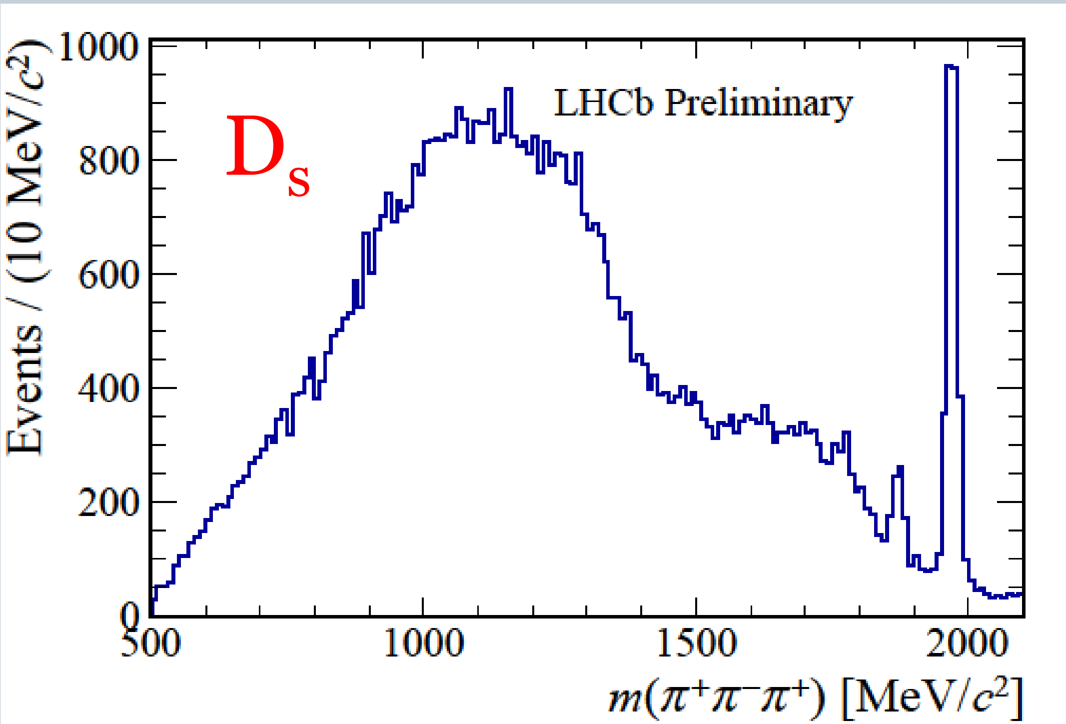
The inclusive D° and D$^+$ decays in 3 pions

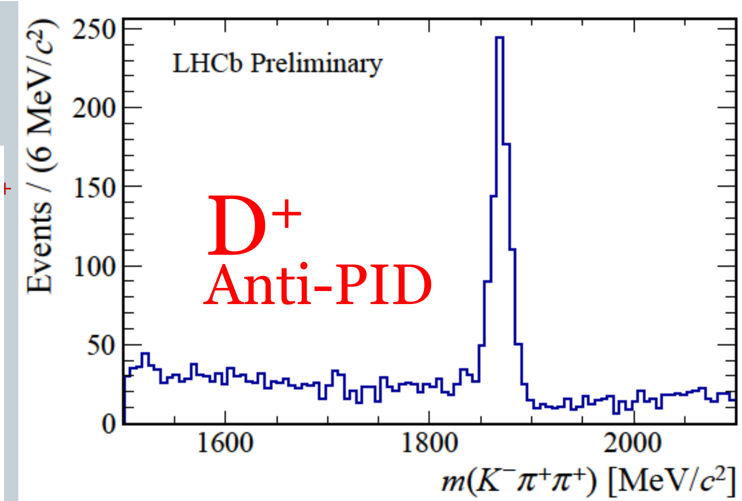
The situation is simpler in D$^+$ and D° decays whose main 3π decay mode is thru the K3π decay

- For the D°, the inclusive 4 prongs BR constrains strongly the rate of 3π events
- Unfortunately, this constraint does not exist for the D$^+$ mesons, K3ππ° is poorly known, the inclusive BR is not measured

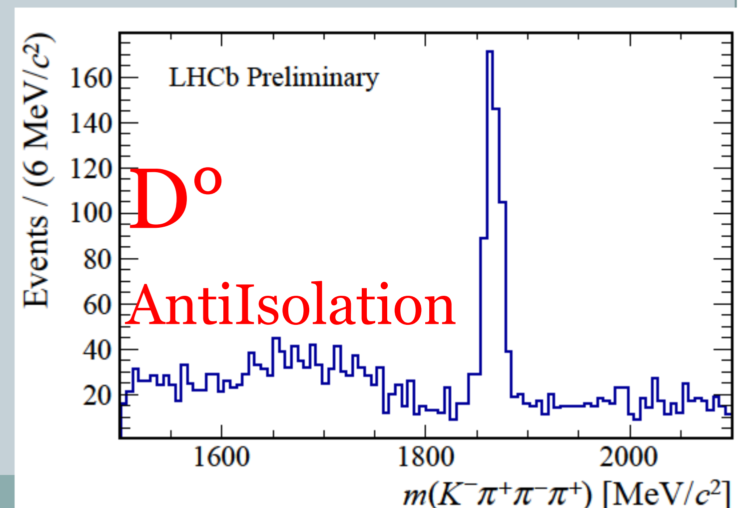
- ⟹ **We let the D$^+$ component float in the fit**
- **(Note : For all these D decays, contacts have been established with BES-3 collaboration to measure these numbers in the near future)**

The control channels D_s, D^o, and D^+





peak : Anti-Isolation



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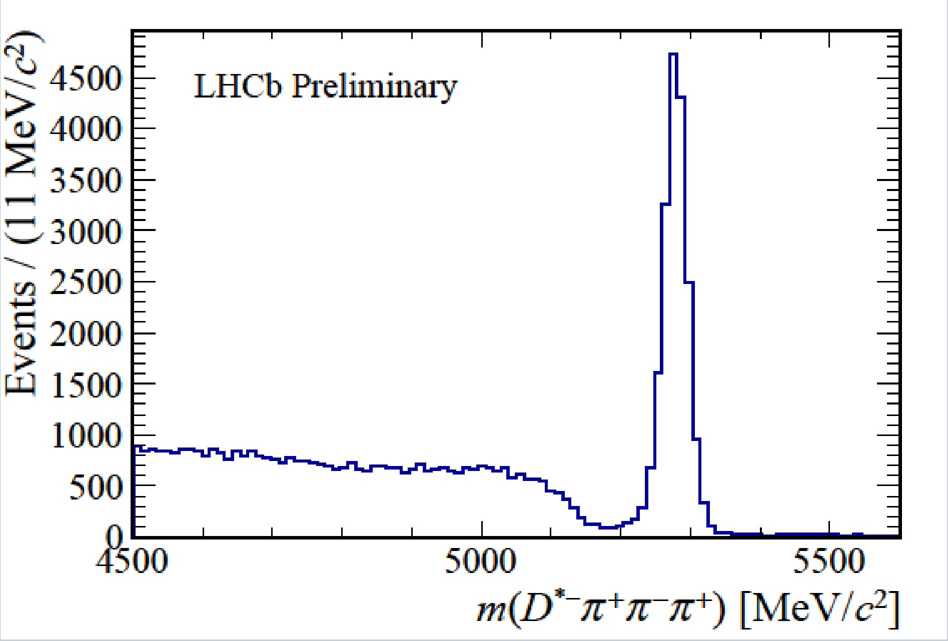
Run 1, 3 fb^{-1}

Importance of the normalization channel $B^o \rightarrow D^* 3\pi$

- 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



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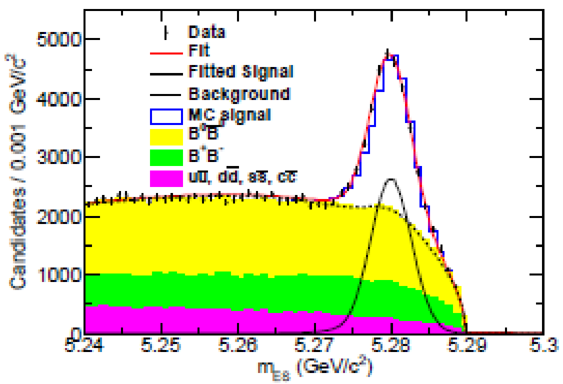
BABAR measurement of BR(B°→D*3π)

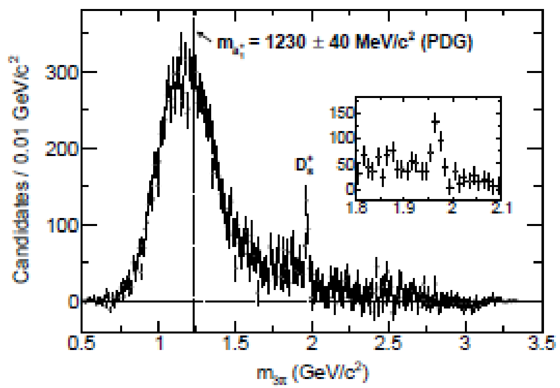
(Phys.Rev. D94 (2016), 091101)

- In PDG 2014 BR(B°→D*3π) known only to 11% precision ☹
- New BABAR analysis with full available statistics

BR(B°→D*3π)=
0,726±0.011±0.031)%

WA =(0,721±0.029)%
PDG 2017





There is also an LHCb result of D*3π/D*π not included in the PDG
Phys. Rev. D87,092001 (2013)

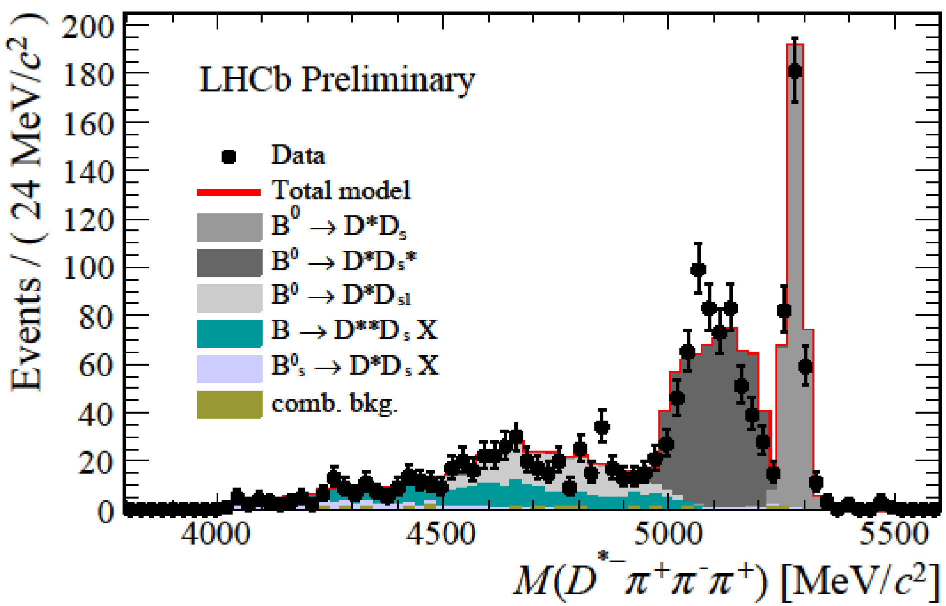
Dominated by systematics errors
Good precision of 4.0 % now with the new WA !!

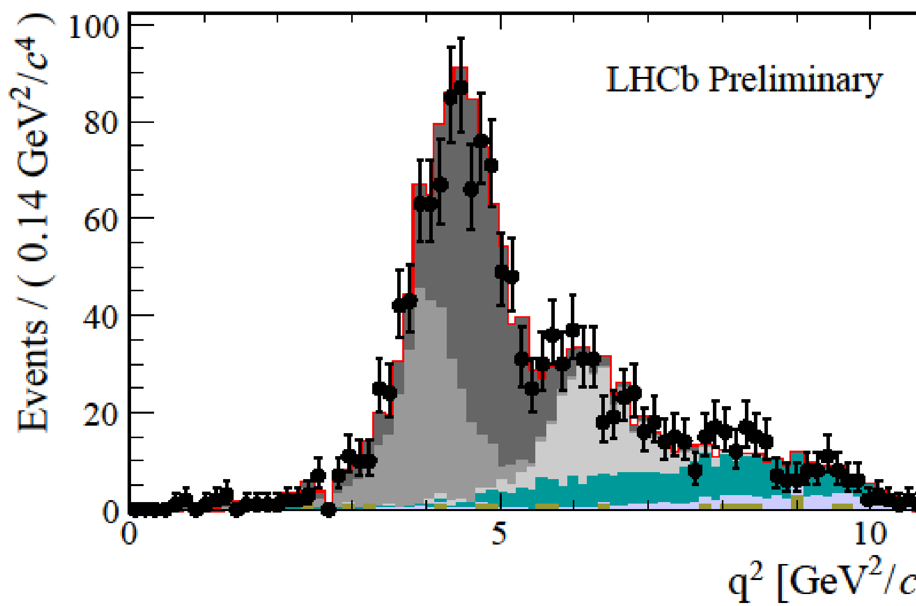
BELLE : Could you remeasure this very precisely as well !!!

Source	Uncertainty (%)
Fit algorithm and peaking backgrounds	2.4
Track-finding	2.0
$\pi^+\pi^-\pi^+$ invariant-mass modeling	1.7
D^{*-} and $\overline{D}^0$ decay branching fractions	1.3
$\Upsilon(4S) \to B^0\overline{B}^0$ decay branching fraction	1.2
K^+ identification	1.1
Signal efficiency MC statistics	0.9
Sideband subtraction	0.7
$B\overline{B}$ counting	0.6
Total	4.3

D^*D_s+X events with reconstructed D_s in 3π

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



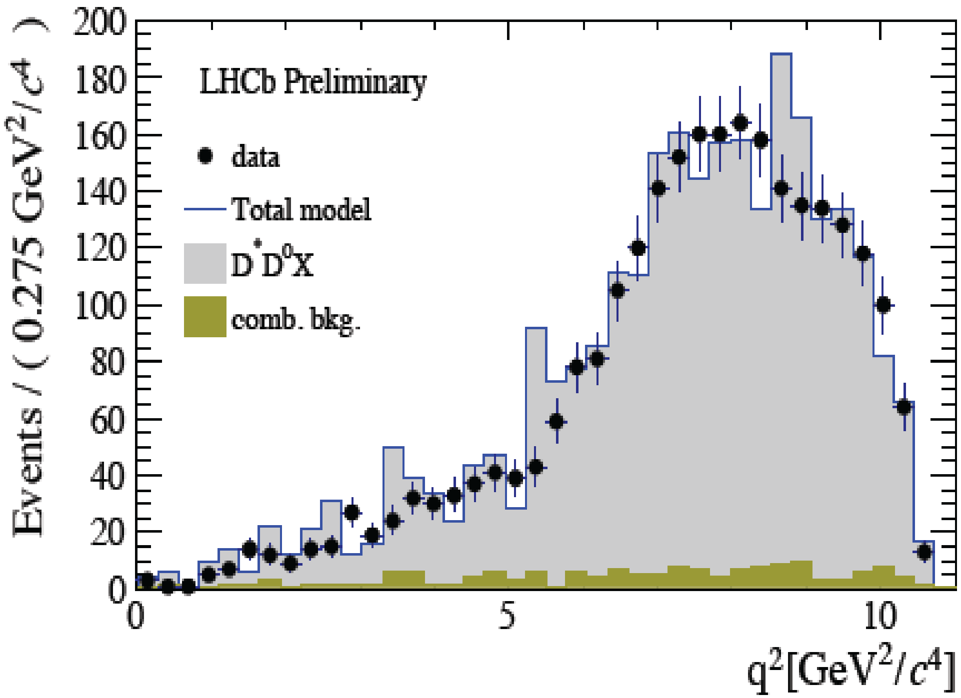


LHCb-PAPER-2017-017, arxiv 1708.08856

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

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

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

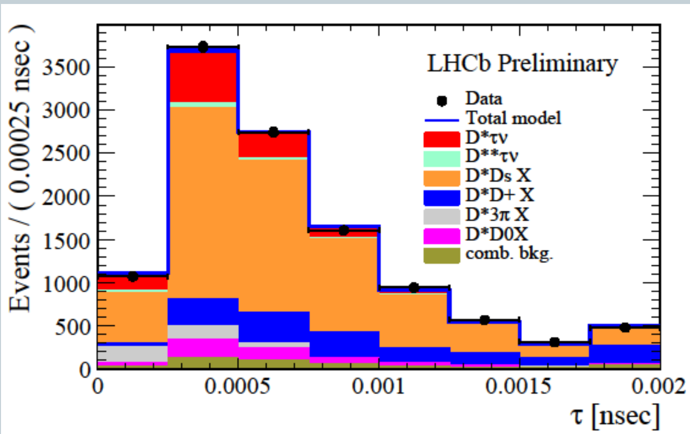


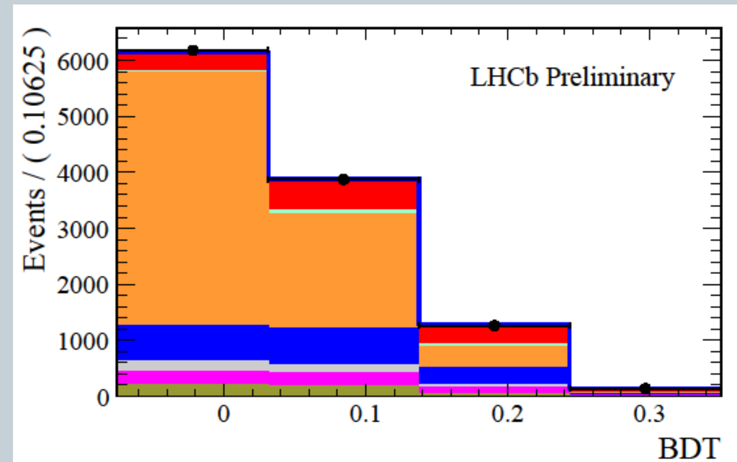
The fit model

- 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).

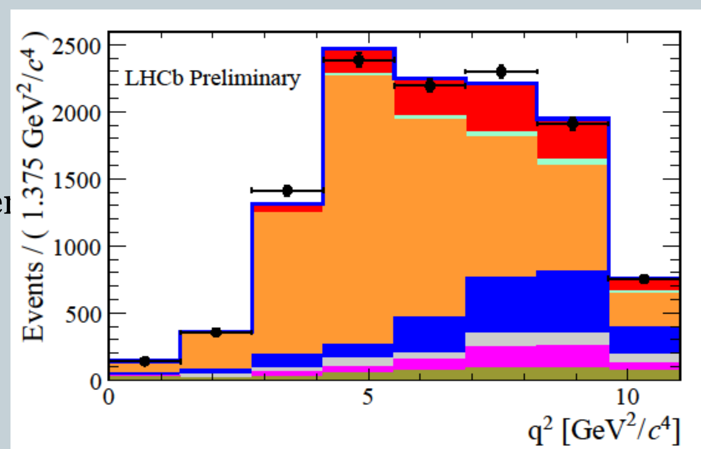
Model components	
$\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$	Ratio constrained using known BR and efficiencies.
$\tau^- \to \pi^-\pi^+\pi^-\pi^0\nu_\tau$	
$X_b \to D^{**}\tau\nu$	Ratio to signal fixed to 0.11 ± 0.04 from theory.
$B^0 \to D^{*-}D_s^+$	Relative yields constrained from $X_b \to D^* D_s^+ X$ control 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.
$X_b \to D^{*-}\pi^+\pi^-\pi^+X$	

The 3 fit projections
(q^2, lifetime and BDT)

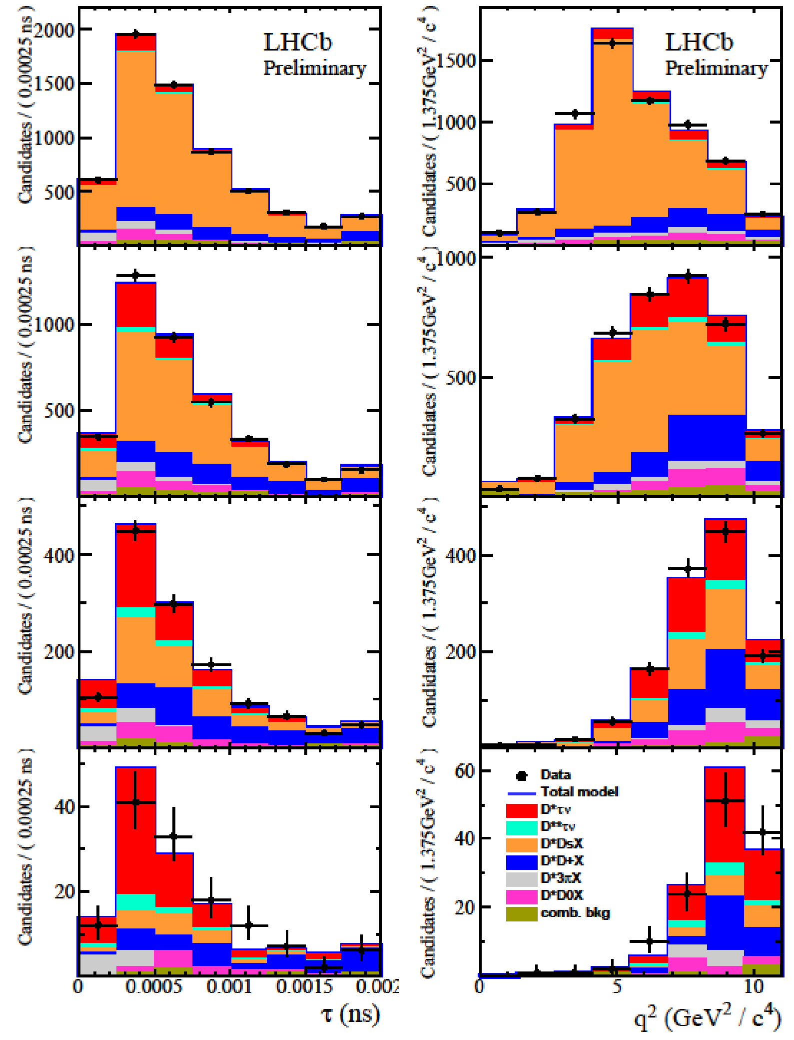




This shows the over
quality of the fit



Fit results
LHCb-PAPER-2017-017, arxiv 1708.08856

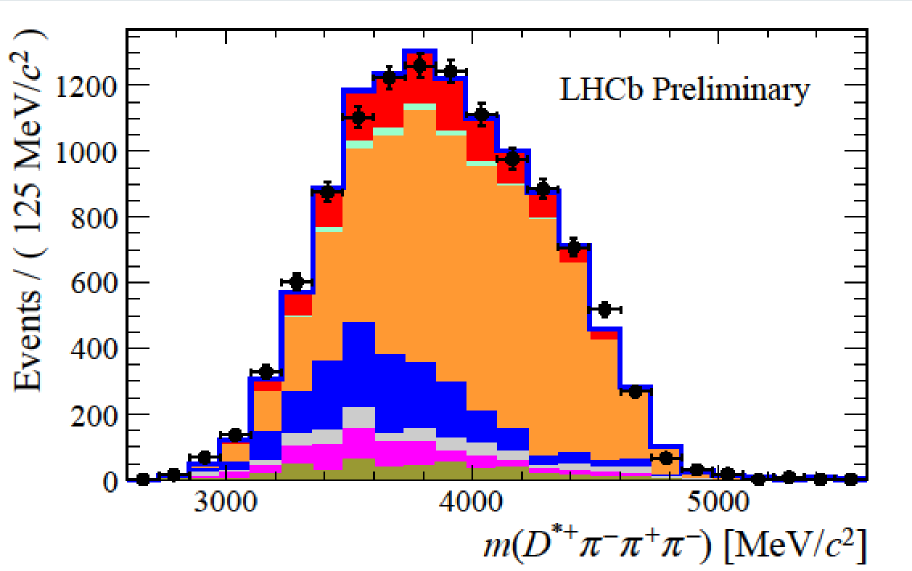


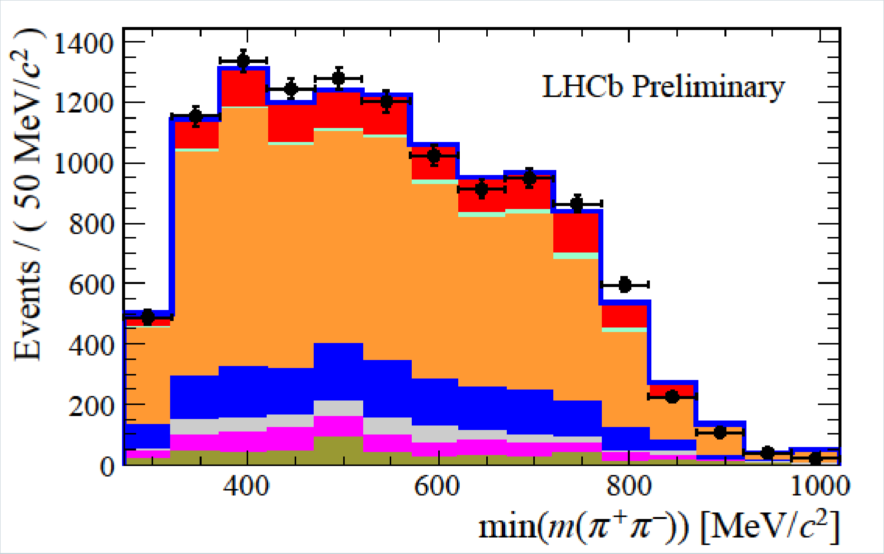
- The 3D template binned likelihood fit results are presented for the lifetime and q^2 in four BDT bins.
- The increase in signal (red) purity as function of BDT is very clearly seen, as well as the decrease of the D_s component (orange)
- The dominant background at high BDT becomes the D^+ component (blue) , with its distinctive long lifetime.
- The overall χ^2 per dof is 1.15

Systematic uncertainties table

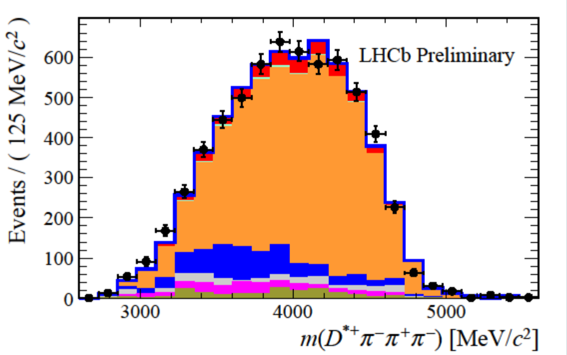
Contribution	Value %
Simulated sample size	4.7
Signal modeling	1.8
$D^{**}\tau\nu$ and $D_s^{**}\tau\nu$ feed-downs	2.7
$D_s^+ \to 3\pi X$ decay model	2.5
$B \to D^{*-}D_s^+X$, $B \to D^{*-}D^+X$, $B \to D^{*-}D^0X$ backgrounds	3.9
Combinatorial background	0.7
$B \to D^*3\pi X$ background	2.8
Empty bins in templates	1.3
Efficiency ratio	3.9
Total internal uncertainty	8.9
$\mathcal{B}(B^0 \to D^*3\pi)$ and $\mathcal{B}(B^0 \to D^*\mu\nu_\mu)$	4.5

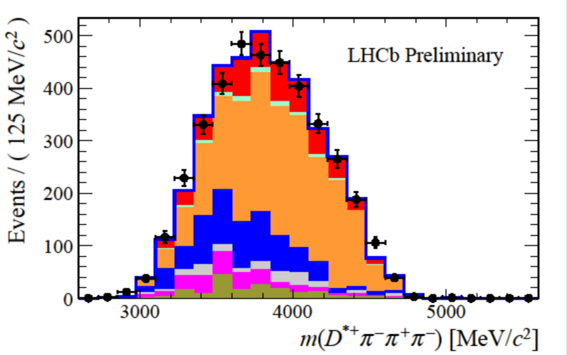
A post fit projection of variables not used in the fit mass: $D^{*-}\pi^+\pi^-\pi^+$ and $\min(\pi^+\pi^-)$

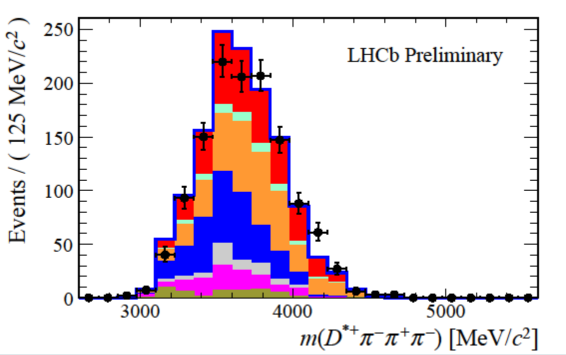


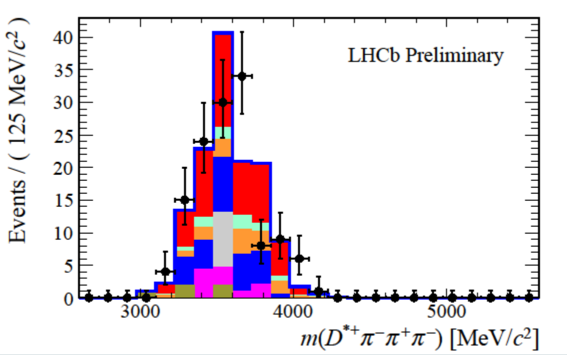


Post-fit projection of $D^{*-}\pi^+\pi^-\pi^+$ mass for 4 BDT bins









LHCb Results

LHCb-PAPER-2017-017, arxiv 1708.08856

BR(B° → D*τν)/BR(B° → D*3π)=1.93±0.13(stat) ±0.17(syst)

BR(B° → D*⁺τν)=(1.39±0.09(stat) ±0.12(syst)±0.06(ext))%

Using for **BR(B° → D*3π)** the new PDG 2017 WA of 0,721±0.029

to be compared with the PDG(2017) (1.67±0.13) %

New (naive) average **BR(B° → D*τν) =(1.56±0,10)%**

R(D*)=0.285±0.019(stat) ±0.025(syst) ±0.013(ext)

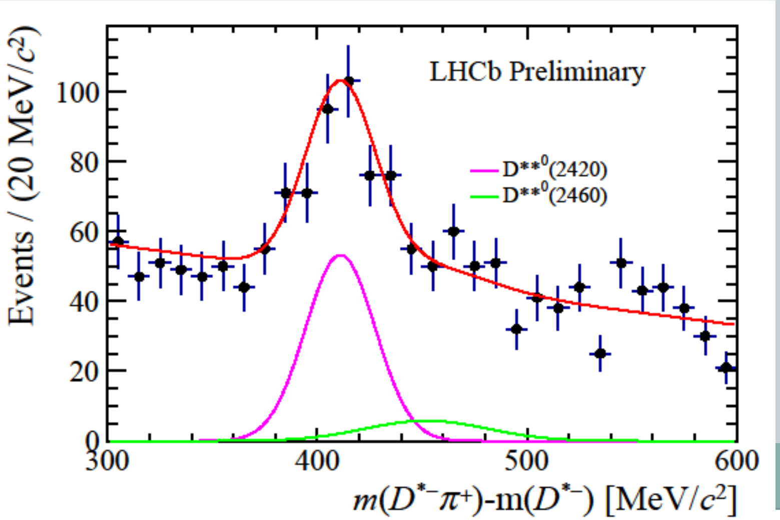
Using the HFLAV BR(B° → D*μν)=(4,88±0,10)%

Experiment	Method	N evts B → D*τν	N evts B° → D*⁺τ⁻ν
BABAR	Leptonic hadronic tag	888±63	245±27
BELLE	Leptonic hadronic tag	503±65	0,4x503=200
BELLE	Single pi hadronic tag	88 ±11	88 ±11
LHCb	3π Hadronic	1273±95	1273±95

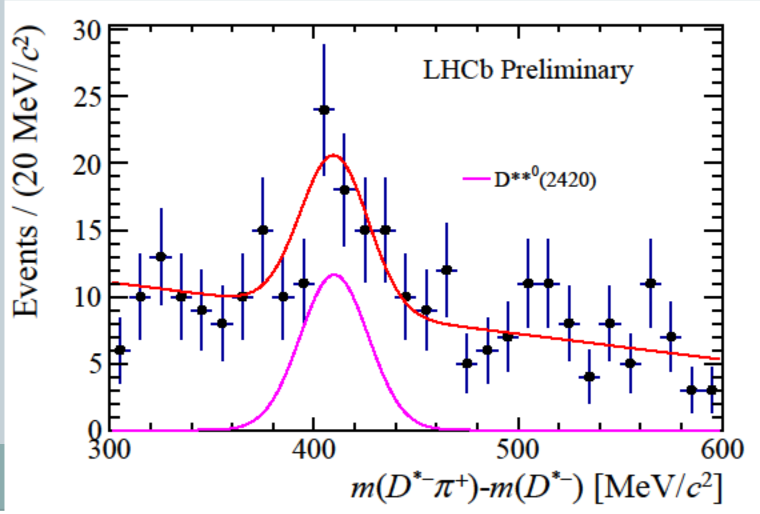
D** cross check

- $B^o \to D^{**}\tau\nu$ and $B^+ \to D^{**o}\tau\nu$ constitute potential feeddown to the signal
- $D^{**}(2420)^o$ is reconstructed using its decay to $D^{*+}\pi^-$ **as a cross check**
- The observation of the $D^{**}(2420)^o$ peak allows to compute the $D^{**}3\pi$ BDT distribution and to deduce a $D^{**}\tau\nu$ upper limit with the following assumption.
  - $D^{**o}\tau\nu = D^{**}(2420)^o\tau\nu$ (no sign of $D^{**}(2460)^o$
  - $D^{**+}\tau\nu = D^{**o}\tau\nu$
- This upper limit is consistent with the theoretical prediction
- Subtraction in the signal of 0.11±0.04 due to $D^{**}\tau\nu$ events leading to an error of 2.3%

All detached vertices



Detached vertice for BDT>.0.1



LHCb average and comparison with WA

LHCb-PAPER-2017-017, arxiv 1708.08856

- This analysis :

R(D*)=0.285±0.019(stat)±0.029(syst)

- Reminder muonic R(D*)=

  0.336 ±0.027 ±0.030

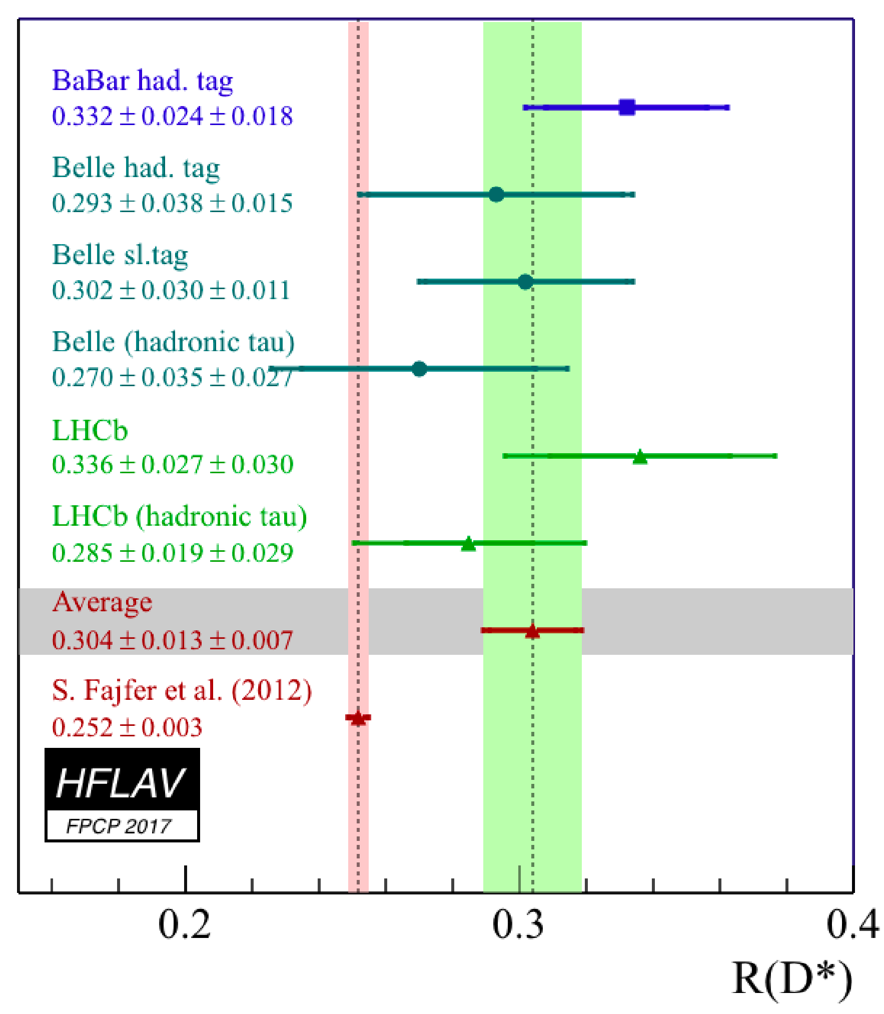
  - 2.1 σ above SM, 0.6 σ above WA

- Preliminary LHCb average

  0.306 ±0.016 ±0.022

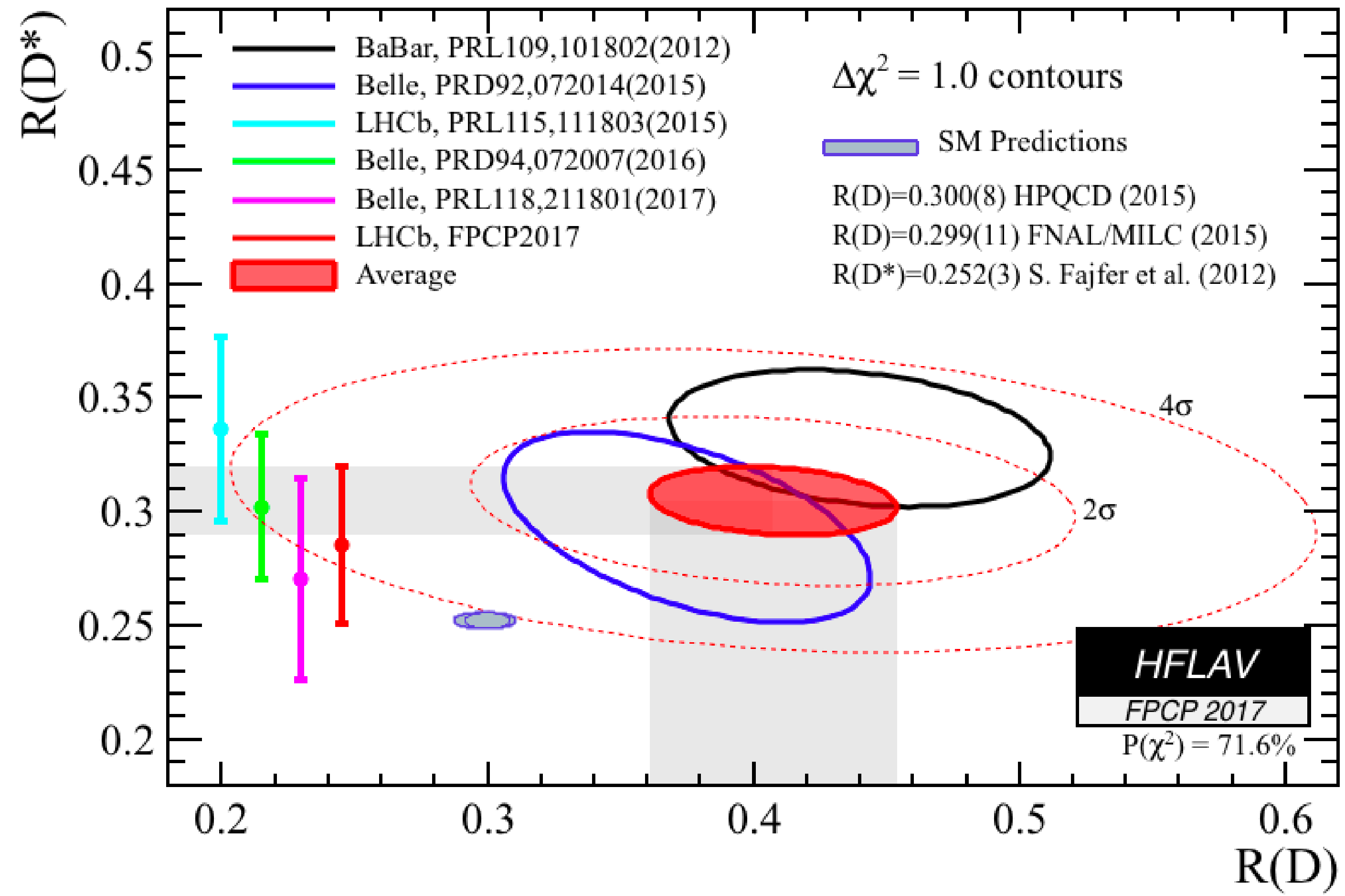
  - 2.1 σ above SM, 0.1 σ above WA

- This results pulls down WA a bit but increases slightly the discrepancy wrt SM!!
- New WA
  R(D*)=0.304±0.013(stat)±0.07(syst)



The new FPCP average

Combined signifance: 4.1 σ away from SM



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 significanlty
- 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**°(2420) per se and to constraint D** feed-down
2. Horizontal extension of R(D*)
   - $R(\Lambda_c)$
   - $R(J/\psi R(D^+),R(D^o)$
   - $R(D_s)$
   - V_{ub}

Precision Goals for Run1+Run2 data

- Run2 =2015+2016 (already available) + 2017
- D^*D_s (Run2)/D*Ds(Run1)~3
- Statistical precision ~4%-3%
- Internal systematic precision ~5% (need more data from BES) (Collaboration in preparation)
- External systematic precision ~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($B^o \rightarrow D^*3\pi$)
  - Not as simple as it appears:
    - a_1(1260), $\rho\pi$, f_2 (1270), 3π 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
- $B^+ \rightarrow (D^*\pi)\ D_s^{(*)}$ a channel forgotten up to now by B-factories

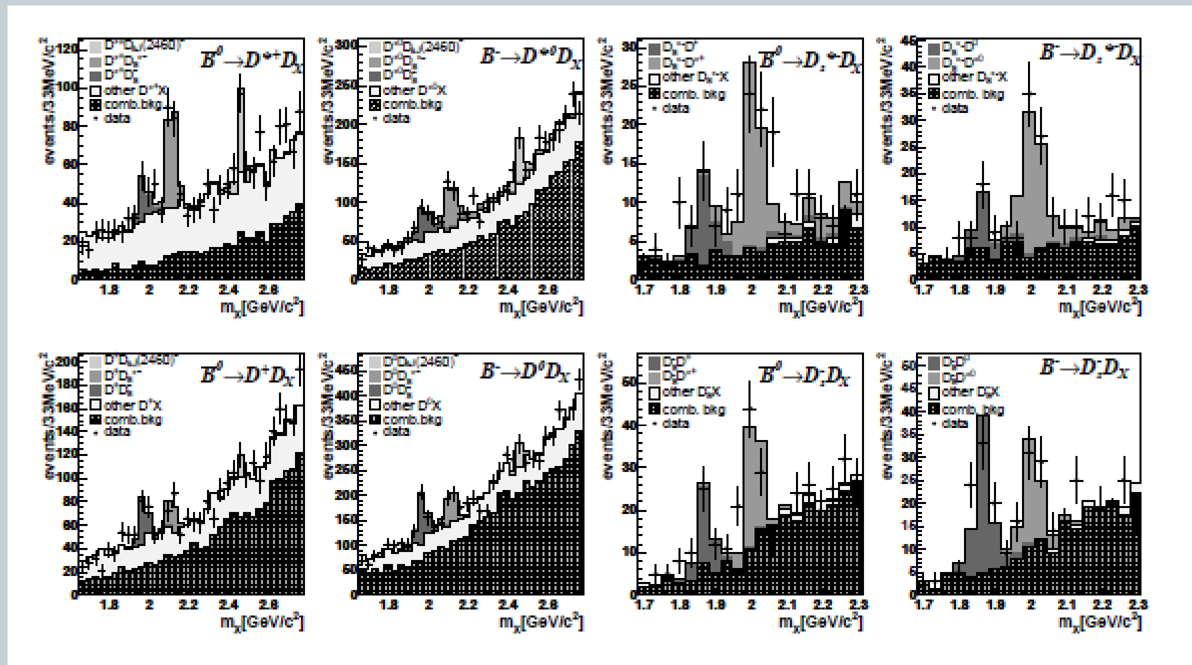
which can provide a very good measurement of the D** spectrum

- $D_s \rightarrow 3\pi\ X$, $D^+ \rightarrow 3\pi\ X$
- And of course all improvments in $D^*l\nu$ decays are very useful for theorist to furtehr improve R(D) and R(D**) predictions

D* and D_s recoil study from BABAR

Study of $B \to D(*)D(*)$ (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 **BR($B^0 \rightarrow D^*\tau\nu$)/BR($B^0 \rightarrow D^*3\pi$)** using the 3 π hadronic decay of the τ lepton has been performed at LHCb (Preliminary)

  R(D*)=0.285±0.019(stat) ±0.025(syst) ±0.013(ext)

  New preliminary LHCb average of R(D*)=0.306±0.026

- 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 3π 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(Λ_c) and R(J/ψ) 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

Backup

The 2012 BABAR results statistics

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

N($B^0 \to D^{*+}\tau\nu$)= 245±27 events
BR($B^0 \to D^{*+}\tau\nu$)= (1.76±0.19±0.12)%

Summary of the various efficiencies

Category	$B^0 \to D^* 3\pi$	Signal		Rel. eff.	Rel. eff. signal	
		$\tau \to 3\pi$	$\tau \to 3\pi\pi^0$	$D^* 3\pi$	$\tau \to 3\pi$	$\tau \to 3\pi\pi^0$
Acceptance (%)	14.65	15.47	14.64			
After stripping	1.382	0.826	0.729			
After cleaning	0.561	0.308	0.238	40.6	37.3	32.6
After trigger requirements	0.484	0.200	0.143	86.3	65.1	59.9
After vertex selection	0.270	0.0796	0.0539	55.8	39.8	37.8
After Charged isolation	0.219	0.0613	0.0412	81.2	77.0	76.3
After D0 sideband removal	0.207	0.0583	0.0393	94.5	95.3	95.5
After MW cut	-	0.0574	0.0390	-	98.4	99.1
After BDT cut	-	0.0541	0.0292	-	94.1	74.8
After PID cut	0.136	0.0392	0.0216	65.8	72.4	74.1
Overall efficiency (%)	19.97×10^{-3}	6.08×10^{-3}	3.23×10^{-3}			
Analysis efficiency (%)	9.86	4.76	2.95			

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 3π p and p_T spectrum for the signal induced by the presence of two extra neutrinos