Lepton Flavour Universality tests using semitauonic decays at LHCb

2nd RED LHC workshop
CIEMAT (Madrid)
9-11th May 2018

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Outline

Introduction
- Lepton Flavour Universality
- Semitauonic decays: $R(D^{*-})$

Method
- Features of the analysis
- Analysis method

Results
- Fit results

Conclusions
- Global picture
- Conclusions

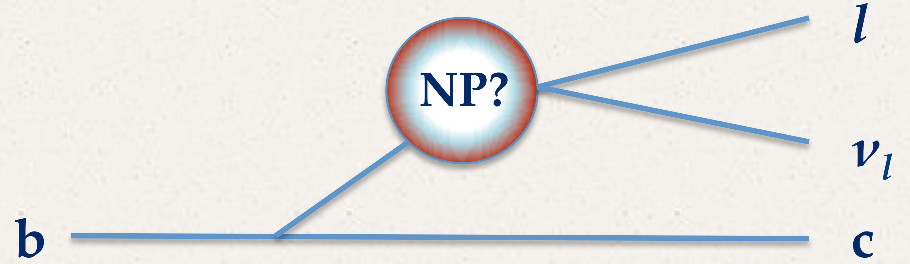
Lepton Flavour Universality

- SM predicts **Lepton Flavour Universality** (LFU): equal couplings between gauge bosons and the three lepton families

- Tensions between SM expectacion and experimental results:
  - <u>Charged currents</u>: b → $cl\nu$: this talk ☺
  - <u>Neutral currents</u>: b → sll transitions

- Observation of violation of LFU: sign of **new physics**

- A large class of BSM models contain new interactions that involve third generations of quarks and leptons:
  - Charged Higgs, leptoquarks, W'…



Why semitauonic decays?

Tree level decays in the SM, mediated by a W boson

$$R(\mathcal{H}_c) = \frac{\mathcal{B}(\mathcal{H}_b \to \mathcal{H}_c \tau \nu_\tau)}{\mathcal{B}(\mathcal{H}_b \to \mathcal{H}_c \mu \nu_\mu)}$$

$$\mathcal{H}_b = B^0, B^+_{(c)}, \Lambda^0_b ...$$

$$\mathcal{H}_c = D^*, D^0, D^+, D_s, \Lambda_c^{(*)}, J/\psi ...$$

- **Clean predicion from SM**
  - Partial cancelation of form factors uncertainties in the ratio
  - Deviation from unity due to different available phase space
- **Large rate** of charged current decays BR(B→D*$\tau\nu$)~1.2 % in SM
- **Sensitivity to NP** contributions at tree level

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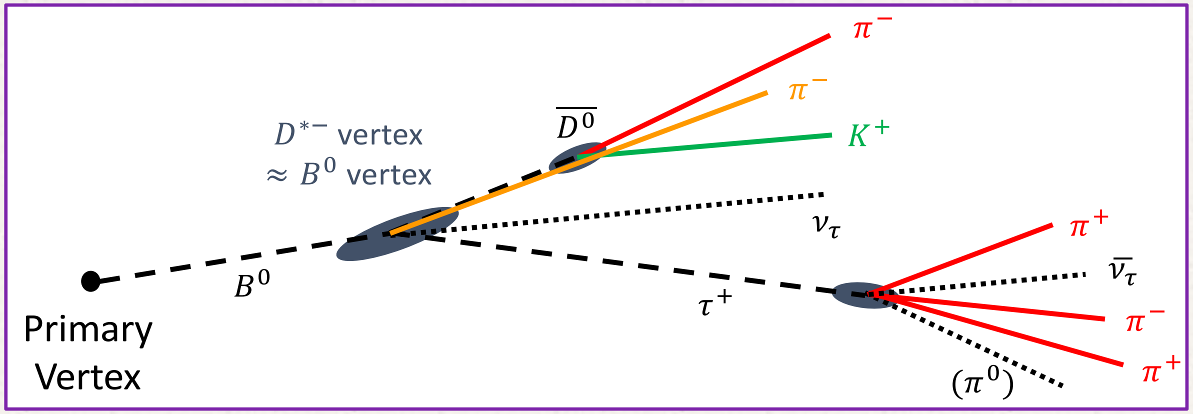
In this talk...**R(D*-)**

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

[PhysRevD.97.072013]
[PhysRevLett.120.171802]

- τ lepton reconstructed using the $\tau^+ \to \pi^+ \pi^- \pi^+ (\pi^0) \nu_\tau$ decay mode
- Semileptonic decay without charged leptons in final state



Features of the analysis

[PhysRevD.97.072013]
[PhysRevLett.120.171802]

- **Testing LFU with R(D*-).** What we measure:

$$R_{had}(D^{*-}) = \frac{\mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\mu)}{\mathcal{B}(B^0 \to D^{*-}\pi^+\pi^-\pi^+)} = \frac{\mathbf{N_{sig}}}{\mathbf{N_{norm}}} \times \frac{\epsilon_{norm}}{\epsilon_{sig}} \times \frac{1}{\mathcal{B}(\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\overline{\nu}_\tau)}$$

- Signal and normalization share same visible state: $D^{*-}\pi^+\pi^-\pi^+$
- Most of the theoretical and experimental uncertainties on luminosity, cross sections and hadronization probability cancel out in the ratio

- **R(D*-)** obtained from:

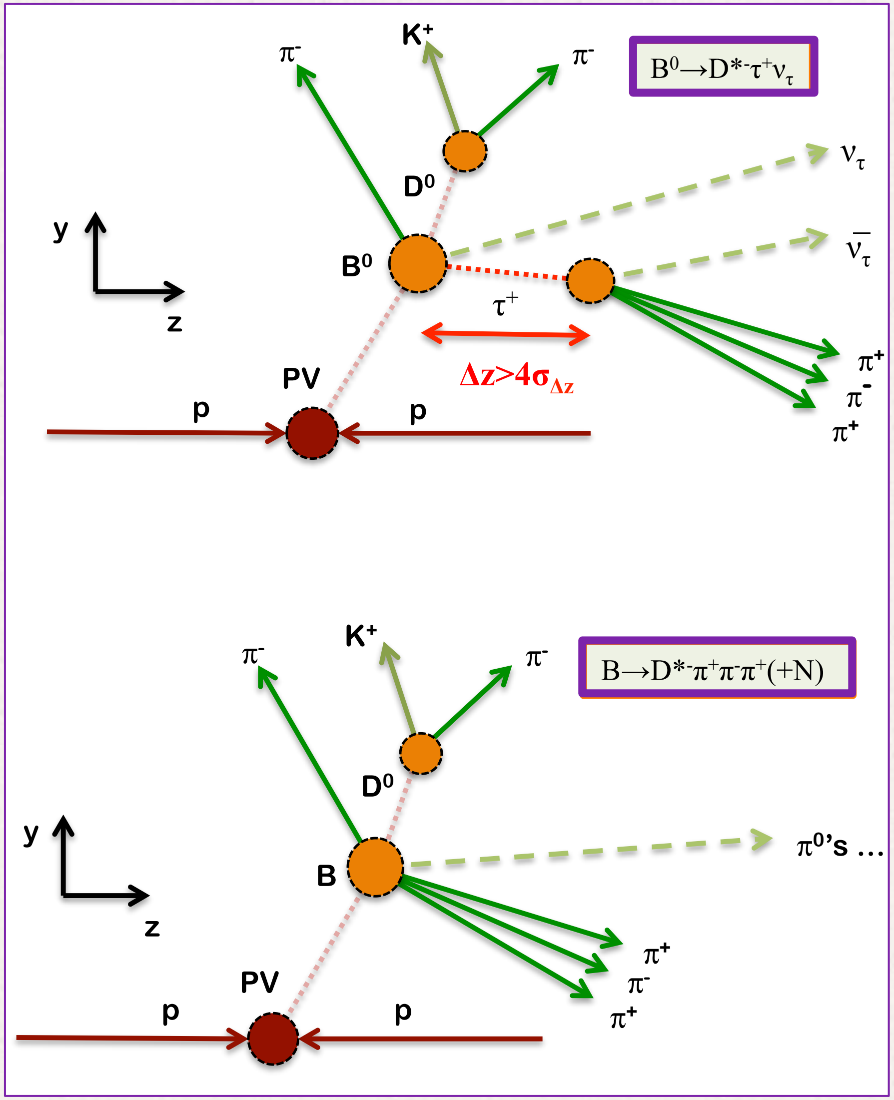
$$R(D^{*-}) = R_{had}(D^{*-}) \times \frac{\mathcal{B}(B^0 \to D^{*-}\pi^+\pi^-\pi^+)}{\mathcal{B}(B^0 \to D^{*-}\mu^+\nu_\mu)}$$

[4.0 % precision, PDG2017]

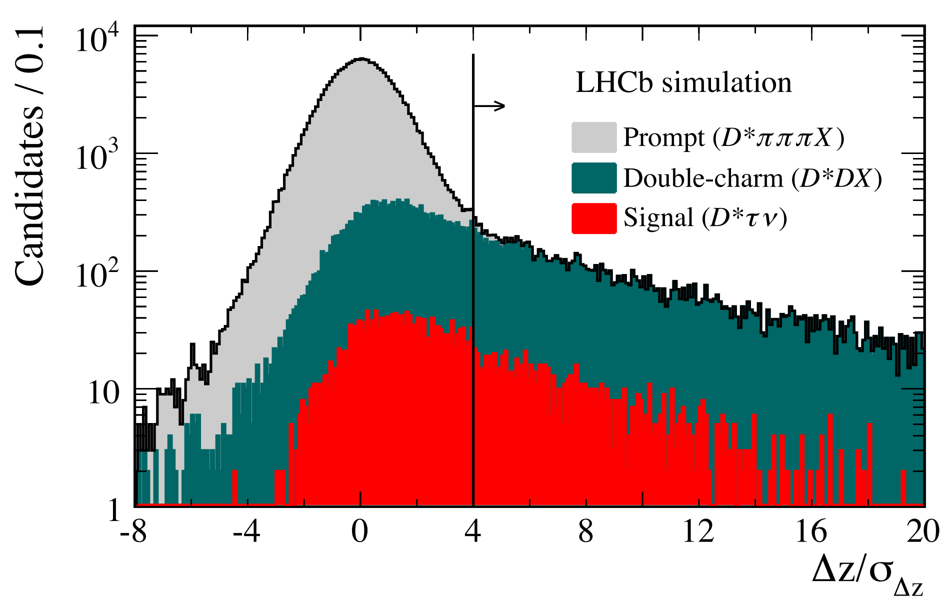
[2.2 % precision, HFLAV 2016]

[PhysRevD.97.072013]

R(D*-) hadronic: strategy

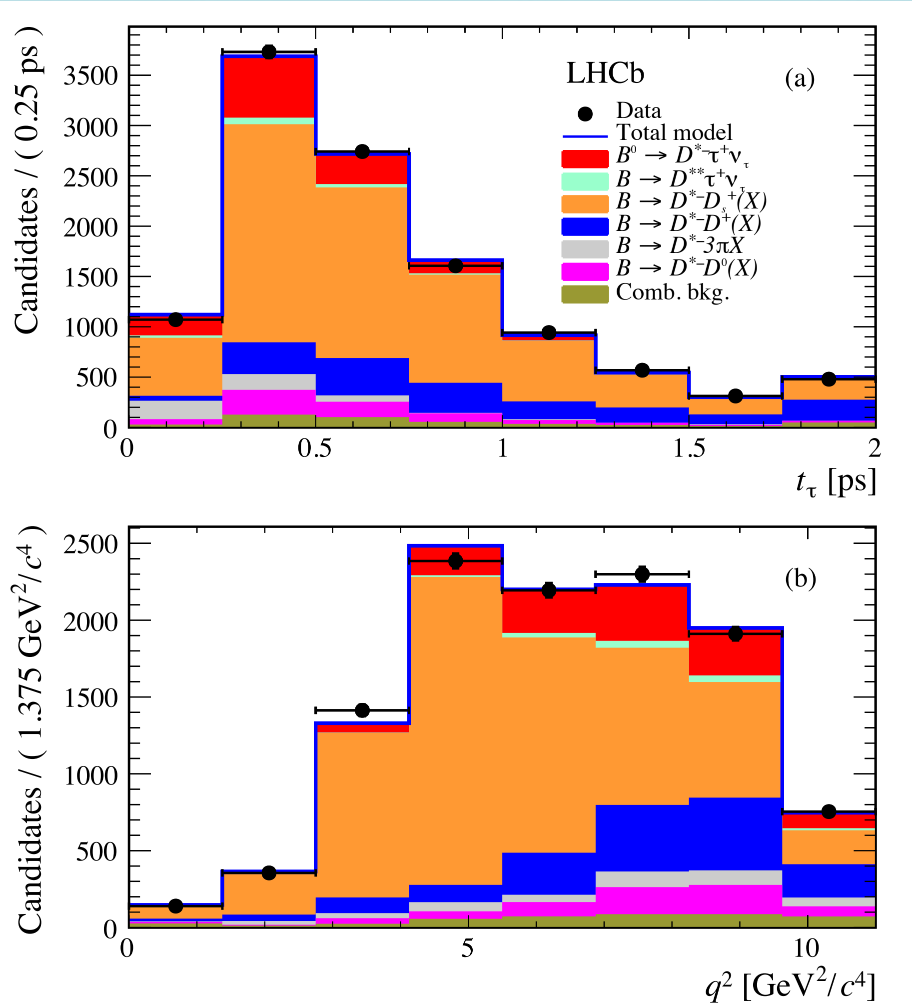


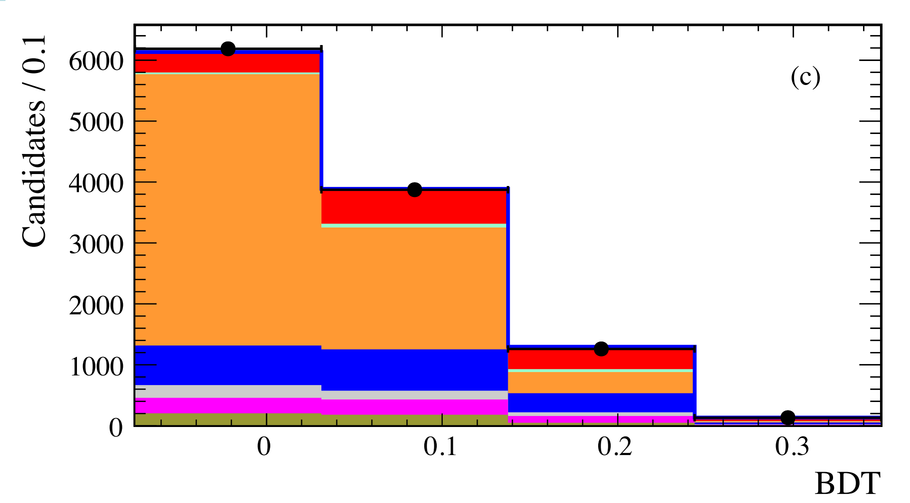
- Most important background due to $B \to D^{*-}\pi^+\pi^-\pi^+ X$ (neutrals), where 3 pions come from the B vertex (100 higher than the signal)
- Requirement: decay topology with minimum distance between B and τ vertices $>4\,\sigma_{\Delta z}$. Suppressed by 3 orders of magnitude
- 2nd most important background comes from $B \to D^{*-} D_s^+ X$. Multivariate Analysis



[PhysRevD.97.072013]

R(D*-) fit results





Result run 1 data:

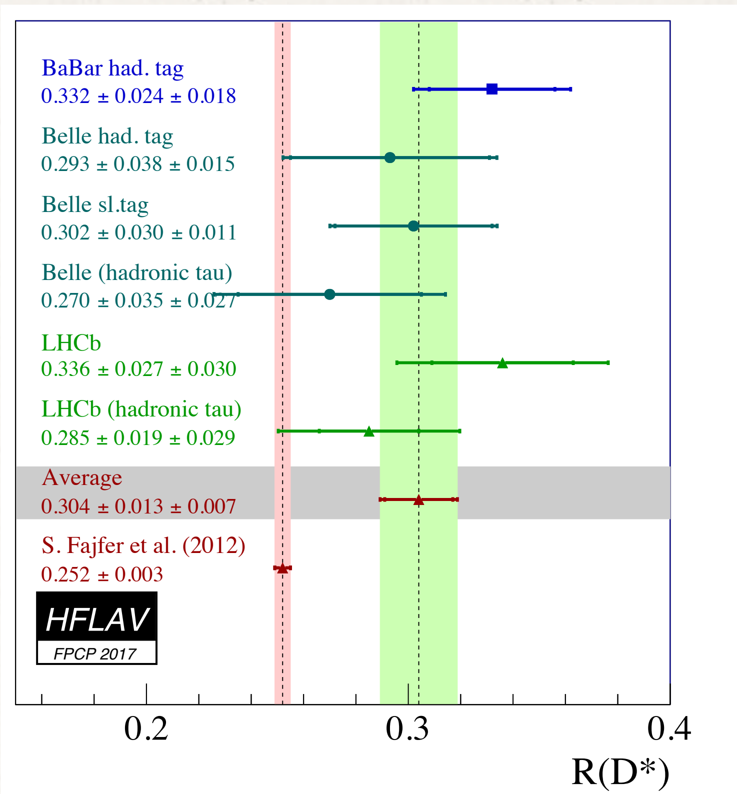
- N($B^0 \to D^{*-}\pi^+\pi^-\pi^+$) unbinned likelihood fit to M($D^{*-}\pi^-\pi^+\pi^-$)
- N($B^0 \to D^{*-}\tau^+\nu_\tau$) three dimensional binned fit to data

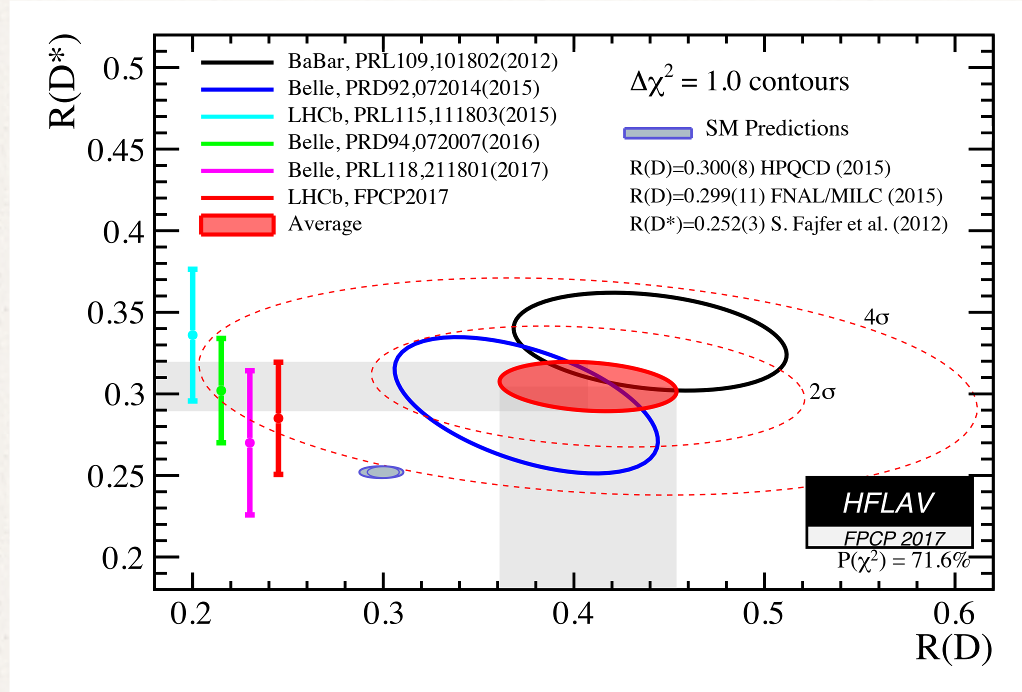
  Variables: τ decay time, q^2, BDT output

$$R(D^{*-}) = 0.291 \pm 0.019(stat) \pm 0.026(syst) \pm 0.013(ext)$$

Conclusions & future prospects

LFUV new road to NP!





[HFLAV]

WA combination of R(D*)/R(D) in tension with SM at the 4.1 σ level

Exciting program ahead! Updates and new analysis with run 2 data, 5 fb^{-1}

Statistical and systematic uncertainties will be reduced.

- $R(D^*)$, $R(D^0)$, $R(D^+)$, $R(D_s)$, $R(J/\psi)$, $R(\Lambda_c)$…

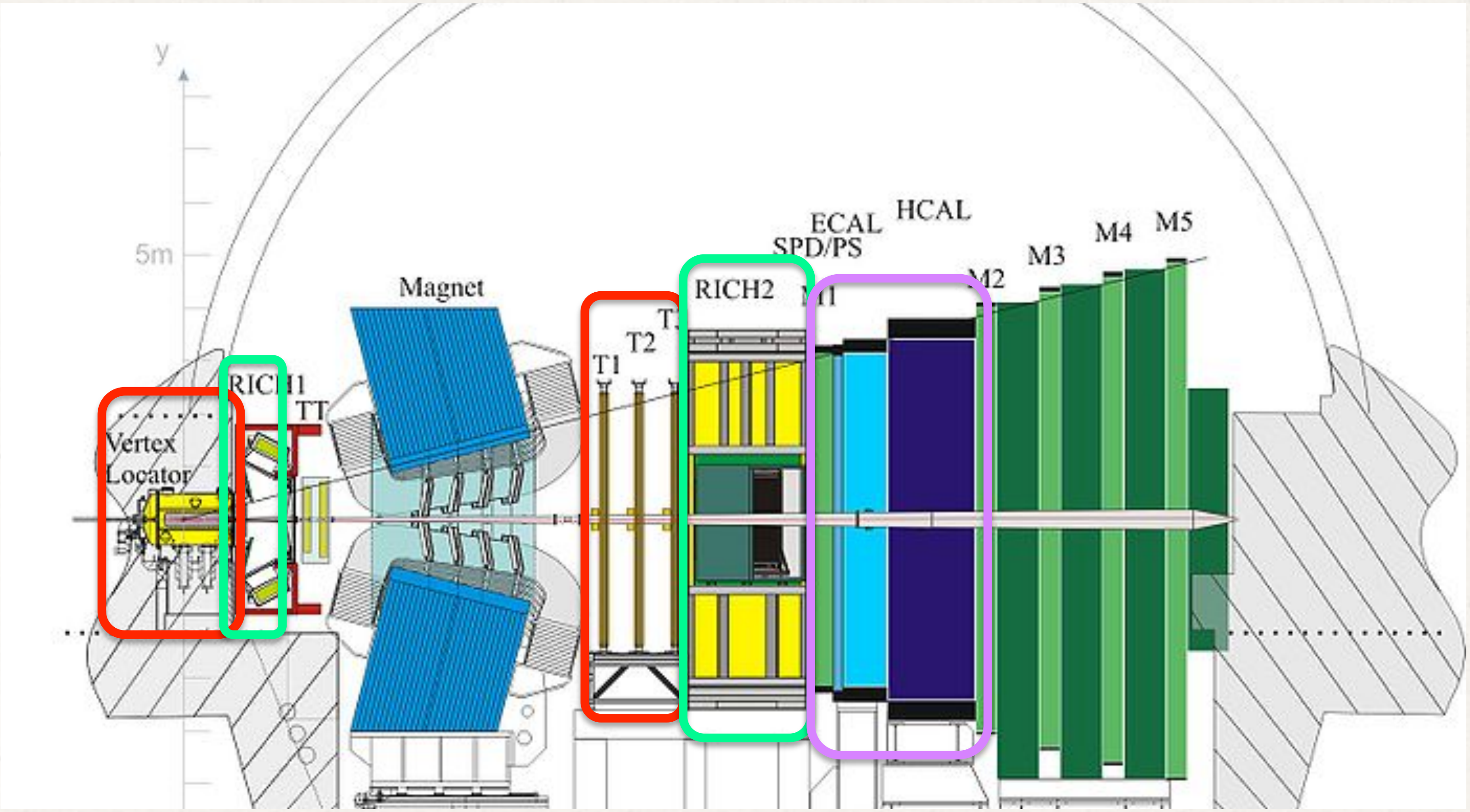
STAY TUNED!

Thank you for your attention

Any question?

Backup slides

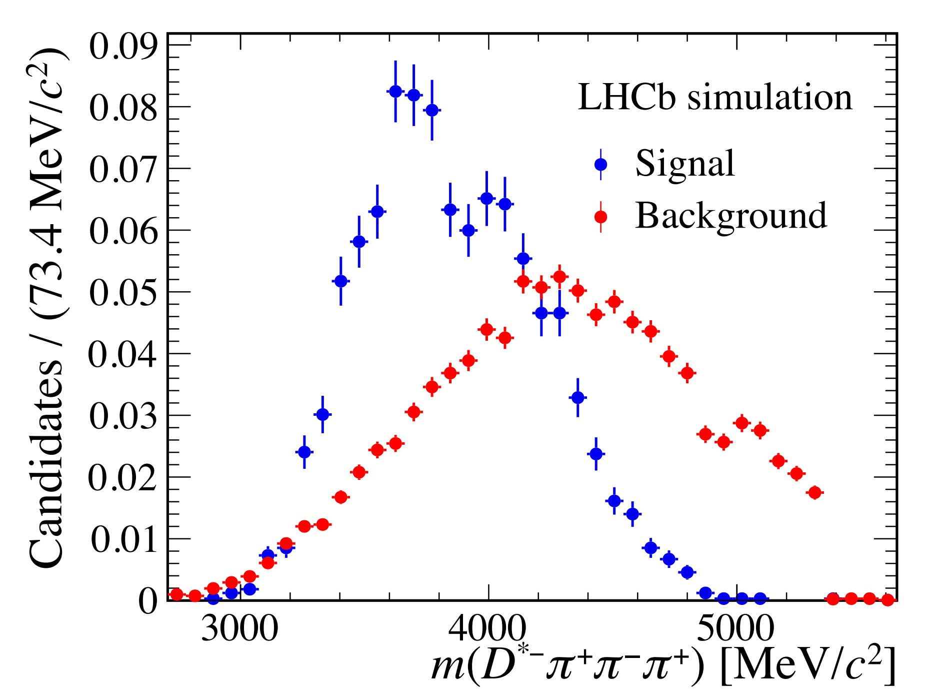
LHCb detector

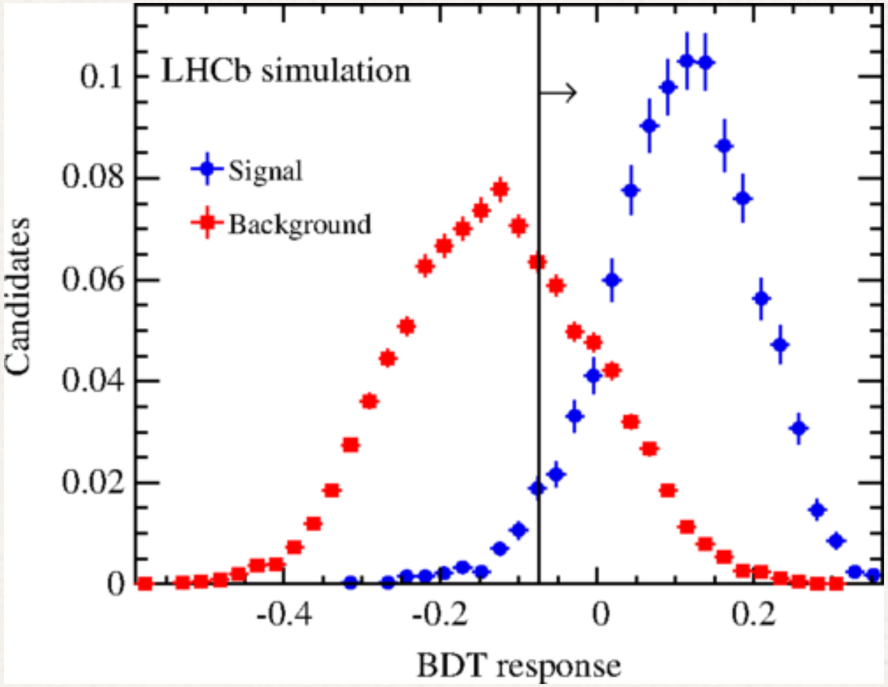


- Excellent **vertex resolution**: 20μm resolution on impact parameter
- Excellent **particle identification**
- **Calorimeter systems**: supress events with missing neutral energy (π^0, K^0, Υ)

BDT

- Most important background after the inversion cut comes from $B \rightarrow D^{*-} D_s^+ X$
- Multivariate Analysis: 18 variables combined in a **BDT**:
  - 3 π variables
  - $D^{*-}3\pi$ dynamics
  - Neutral isolation variables



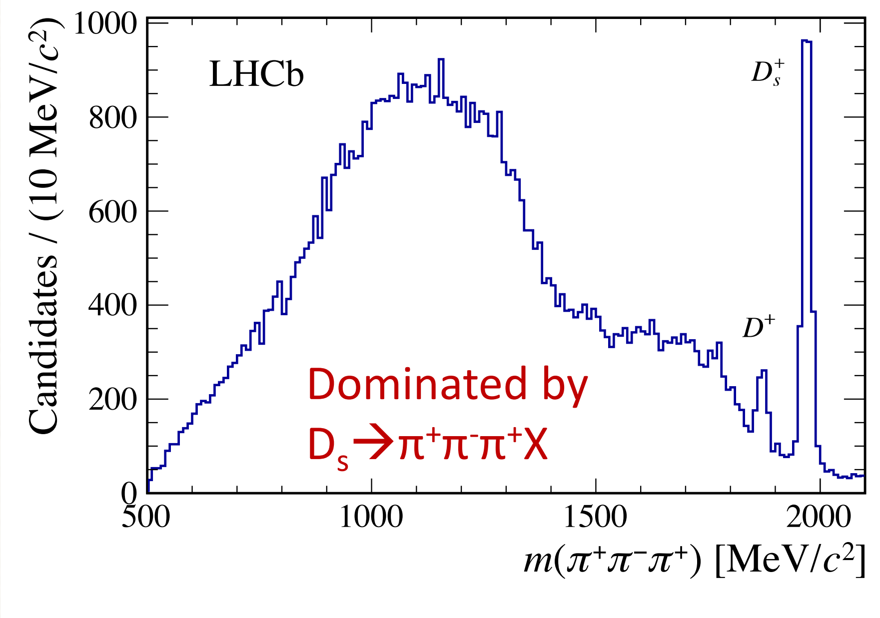


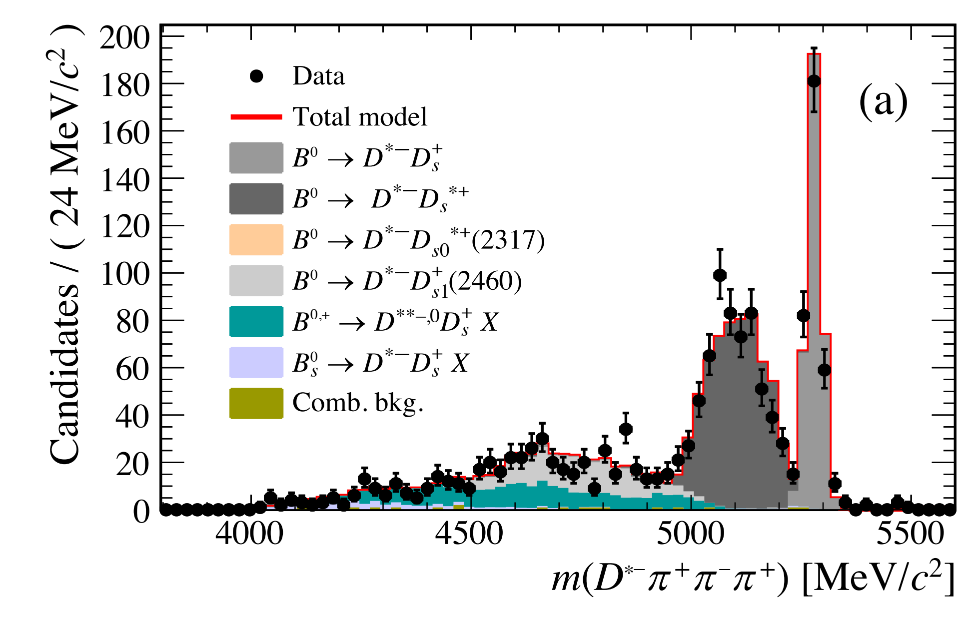
BDT used as variable in the fit to extract signal yield

R(D*⁻) systematics

Main systematic uncertainties due to:

- Size of **simulated sample**
- Shape of the **background** $B \rightarrow D^{*-} D_s^+ X$
- $D_{(s)}^+ \rightarrow \pi^+\pi^-\pi^+ X$ decay mode. **BESII** future measurement will reduce this uncertainty. Improvement as well of the upgraded ECAL
- Branching fraction of normalisation mode $B^0 \rightarrow D^{*-}\pi^+\pi^-\pi^+$ known with ~4% precision. **Belle II** can measure it precisely





[PhysRevD.97.072013]

R(D^{*-}) systematics

Contribution	Value in %
$\mathcal{B}(\tau^+ \to 3\pi\overline{\nu}_\tau)/\mathcal{B}(\tau^+ \to 3\pi(\pi^0)\overline{\nu}_\tau)$	0.7
Form factors (template shapes)	0.7
τ polarization effects	0.4
Other τ decays	1.0
$B \to D^{**}\tau^+\nu_\tau$	2.3
$B_s^0 \to D_s^{**}\tau^+\nu_\tau$ feed-down	1.5
$D_s^+ \to 3\pi X$ decay model	2.5
D_s^+, D^0 and D^+ template shape	2.9
$B \to D^{*-}D_s^+(X)$ and $B \to D^{*-}D^0(X)$ decay model	2.6
$D^{*-}3\pi X$ from B decays	2.8
Combinatorial background (shape + normalization)	0.7
Bias due to empty bins in templates	1.3
Size of simulation samples	4.1
Trigger acceptance	1.2
Trigger efficiency	1.0
Online selection	2.0
Offline selection	2.0
Charged-isolation algorithm	1.0
Normalization channel	1.0
Particle identification	1.3
Signal efficiencies (size of simulation samples)	1.7
Normalization channel efficiency (size of simulation samples)	1.6
Normalization channel efficiency (modeling of $B^0 \to D^{*-}3\pi$)	2.0
Form factors (efficiency)	1.0
Total uncertainty	9.1