The measurement of $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau)$ at the LHCb experiment

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Outline

- Semitauonic B decays
  - Lepton Flavour Universality (Violation ?)
  - Experimental status
  - Interest of this particular channel
- LHCb: a beautiful detector
- Overview of the key features of the analysis
  - vertex inversion
  - Isolation
  - Partial reconstruction
  - BDT and extraction of signal
- Conclusion

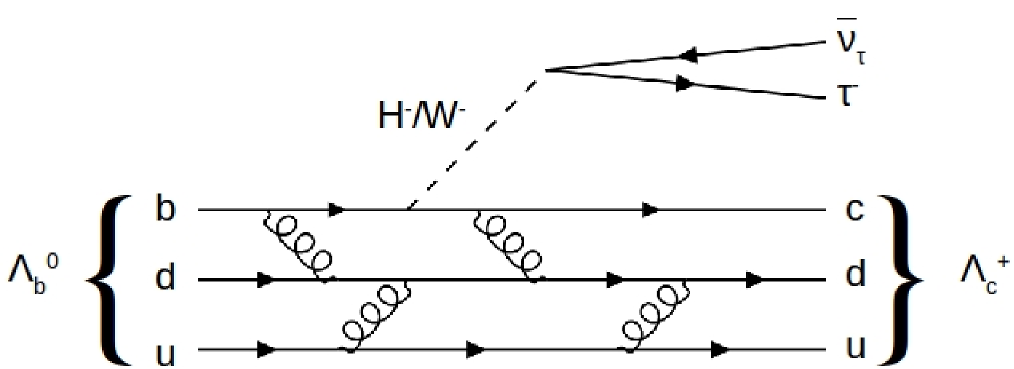
Introduction

In the Standard Model, all leptons ($l = e,\ \mu,\ \tau$) **behave the same**, up to phase space effect.

Discovering LFUV = clear sign of New Physiscs

How can we do it ?

- Several NP models (2HDM, ...) have new couplings rising with m_l.
- τ = heaviest lepton $\longrightarrow$ **enhanced** sensitivity !



What to measure ?

$b \to c\tau\nu$ transitions are a great tool to probe LFU :

- theoretically clean (up to 2% error)
- Several measurements from BaBar, Belle and LHCb.

Key observable :

$$R(X_c) = \frac{\mathcal{B}(X_b \to X_c\tau\nu)}{\mathcal{B}(X_b \to X_c\mu\nu)}$$

Shared systematics are cancelled in the ratio

(X_b, X_c) can be :

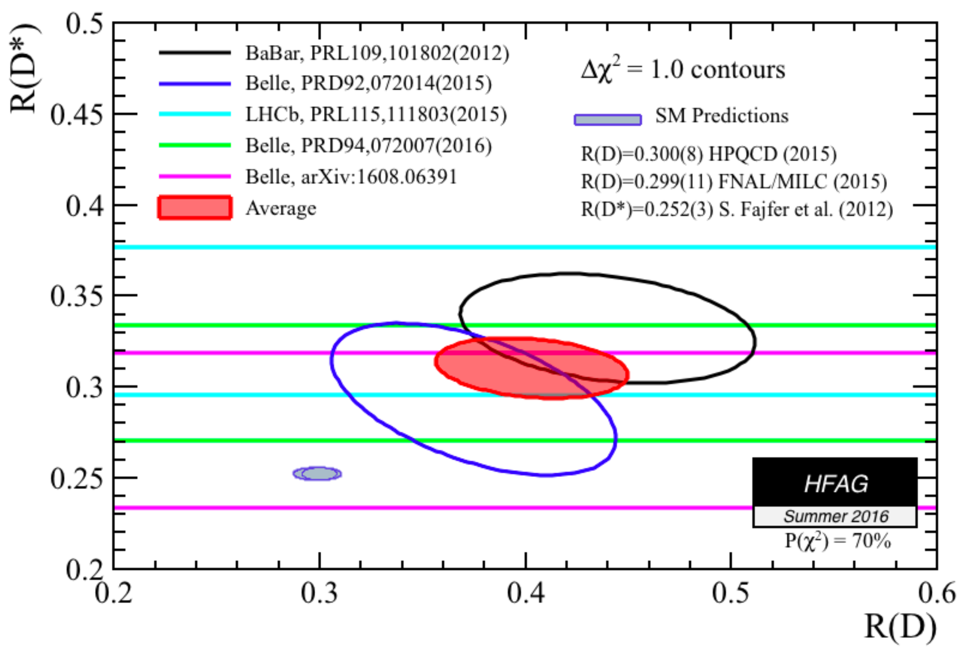
- $(B^0, D^{(*)})$ for $R(D^{(*)})$
- $(\Lambda_b^0, \Lambda_c^{(*)})$ for $R(\Lambda_c^{(*)})$, ...

Current experimental status

Exisiting measurements of $R(D^{(*)})$ from Belle, BaBar and LHCb:

- most of them are using $\tau \to \mu\bar{\nu}_\mu\nu_\tau$.
- Tension with the SM : discrepancy of **3.9σ !**

  Hot topic : latest paper on arXiv published this week 1612.00529.



Our goal : measure $R(D^*)$ and $R(\Lambda_c)$ with $\tau \to \pi^+\pi^-\pi^+\nu_\tau$

Why $R(\Lambda_c)$?

In addition to the $R(D^{(*)})$ analyses, **growing interest** for $R(\Lambda_c)$:

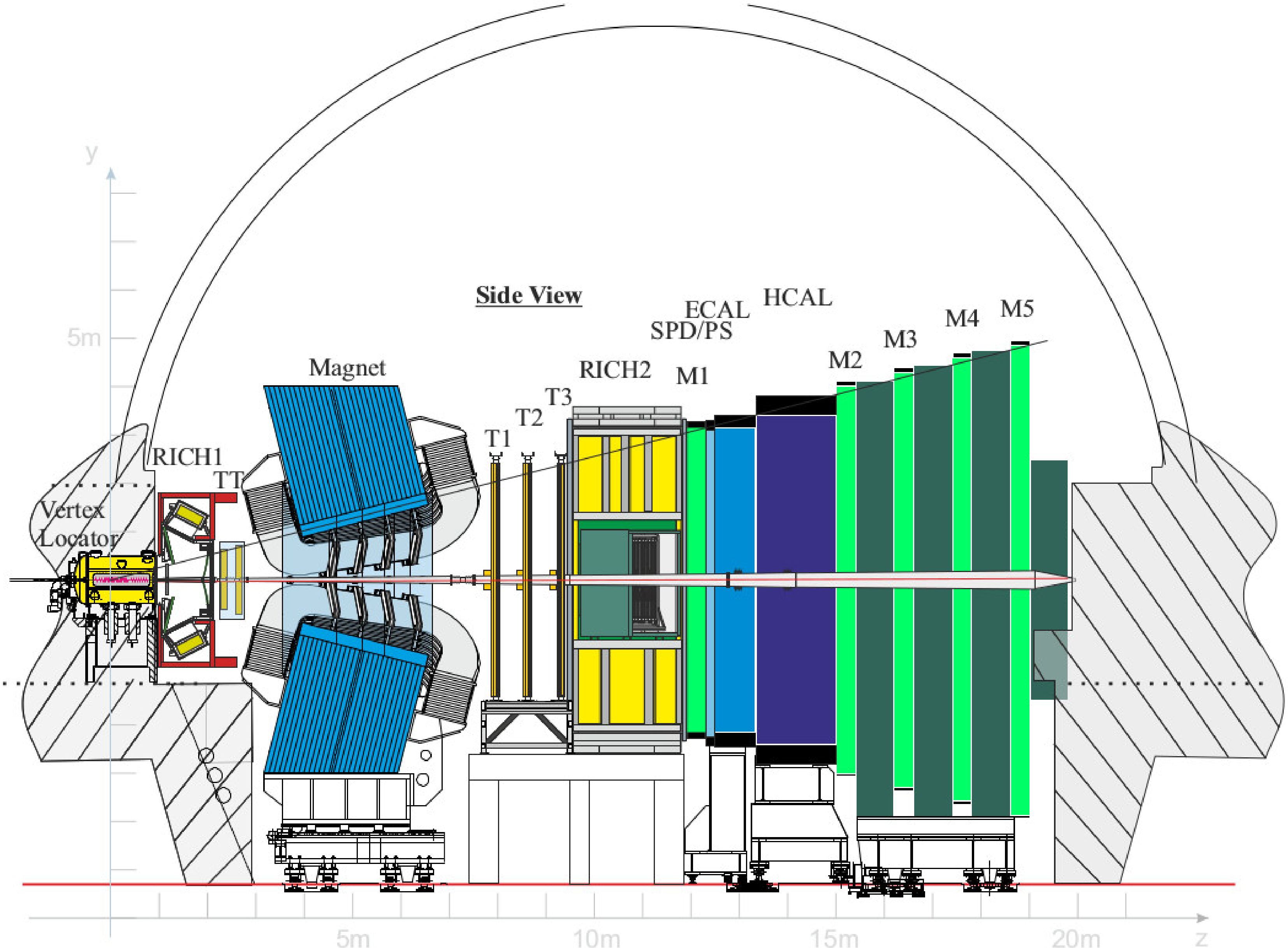
- **Baryon channel** complentary of existing meson channels.
- New Lattice result for $R(\Lambda_c) = 0.3328 \pm 0.0074 \pm 0.0070$.

Hadronic $R(D^*)$ and $R(\Lambda_c)$ analyses share:

- background sources
- same general procedure and lots of tools

This analysis could lead to :

- The first measurement of $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \tau \bar{\nu}_\tau)$
- A computation of $R(\Lambda_c)$ (using normalisation procedure)
- Helicity amplitudes computations (not possible with $D^{(*)}$)


Side View
Magnet
RICH1
TT
Vertex
Locator
T1
T2
T3
RICH2
SPD/PS
ECAL
HCAL
M1
M2
M3
M4
M5
y
5m
5m
10m
15m
20m
z

LHCb: a beautiful detector

Detector built to study b-physics and CP violation.
Forward spectrometer $\rightarrow$ **precise** measurements of the $b\bar{b}$ pair.

- **good Vertexing and Impact Parameter (IP) measurement**:
  - VELO and tracking stations to find B vertices and reconstruct tracks.
  - $\sigma_z = 100\ \mu$m & $\sigma_{IP} = 20\mu$m.
- **Momentum and mass resolution**:
  - $\frac{\Delta p}{p} = 1.0\%$ @ 200 GeV/c.
  - mass resolution typically $10 - 100\ MeV/c^2$.
- **High efficiency Particle ID**:
  - using two Ring Imaging Cherenkov detectors (RICH1 & RICH2) & Muons chambers (M1-M5).
  - good discrimination between p, K, π and μ particles.

$\tau \to \pi\pi\pi\nu$

Why we want to use it ? $\Rightarrow$ Allow to reconstruct the τ **vertex**.

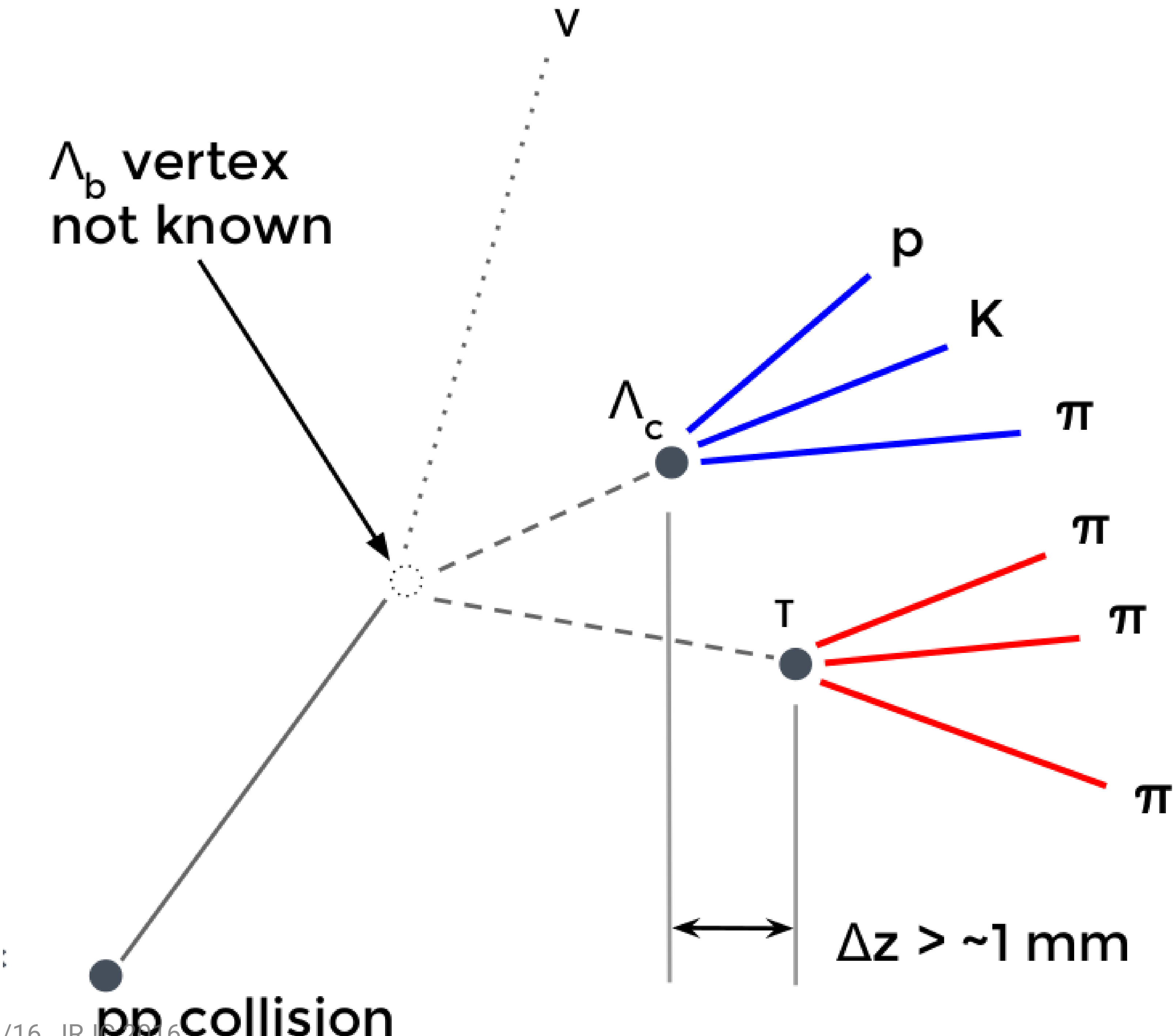
At first, it seems hopeless:

- **Huge background** coming from $\Lambda_b^0 \to \Lambda_c^+ \pi\pi\pi X$.
- The Λ_b^0 vertex and its energy are **unknown** (missing ν).

Our method: relying on Λ_c and τ vertices and their decay time:

- background events: 3π vertex **upstream** to the Λ_c one.
- signal-like events: due to the lifetime of the τ, 3π vertex can be **downstream** to the Λ_c one.

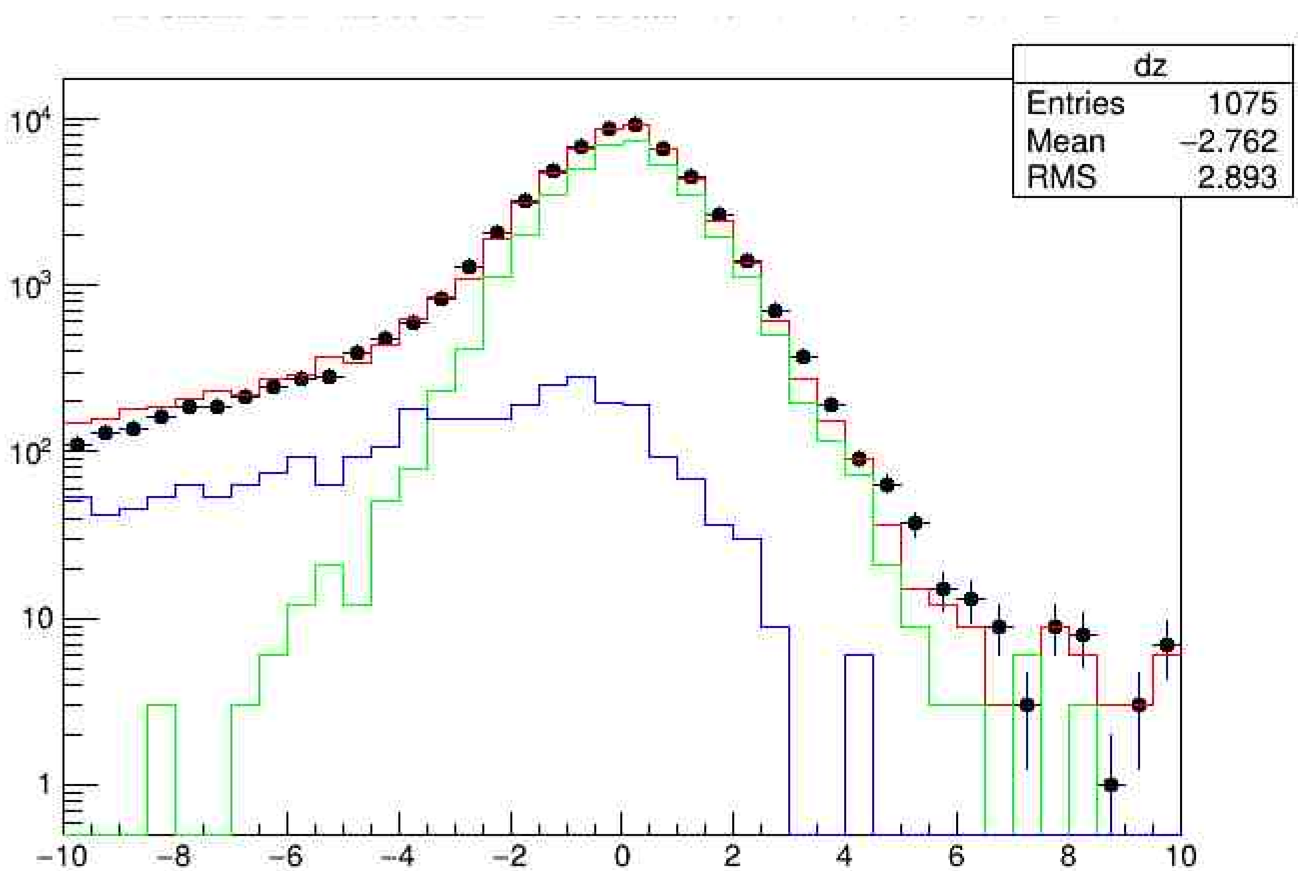
$\Longrightarrow$ **relative inversion of Λ_c and τ vertices** is the key to suppress $\Lambda_c^+ \pi\pi\pi X$ background events



ν
Λb vertex
not known
p
K
Λc
π
π
τ
π
π
Δz > ~1 mm
pp collision

Composition after inversion cut

Almost every $\Lambda_b^0 \to \Lambda_c^+ \pi\pi\pi X$ event is suppressed but every Λ_c + displaced 3π event is there...

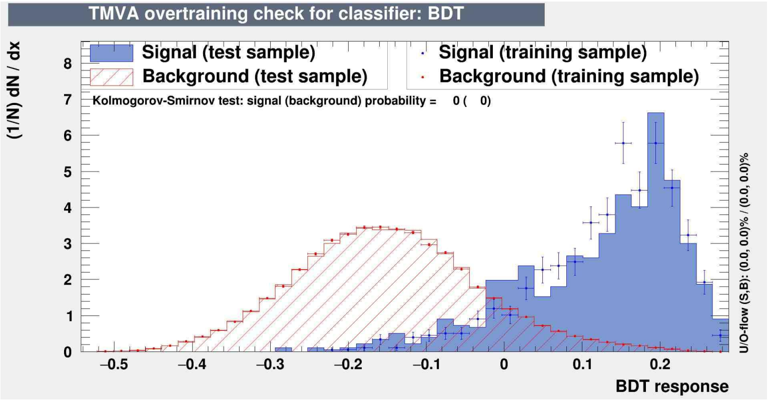


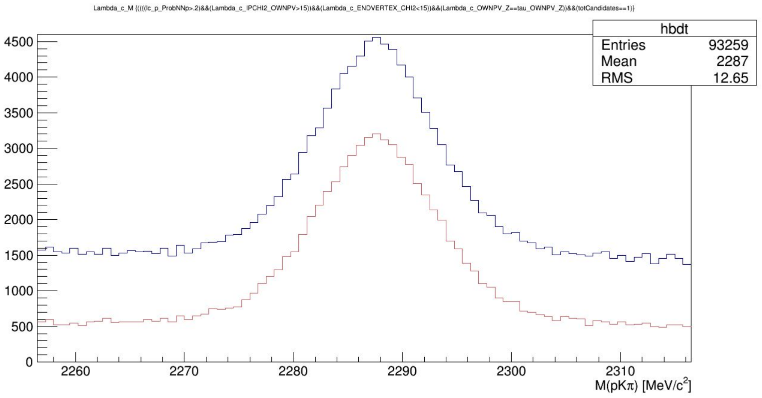
Selection of the Λ_c

There is a need for dedicated selection of the Λ_c:

The Λ_c is first selected using a cut-based selection (kinematics and PID). The same variables are used to train a BDT.

We have a 90% efficiency on Signal (MC signal) and 15% on Background (Data 2012, ~$1 fb^{-1}$).





How to extract the signal ?

- Several sources of background remain:
  - $\Lambda_b \to \Lambda_c D_{(s)}^{(*)} X$ such as $D^0 \to 3\pi K^0$, $D^+ \to K^0 3\pi$, $D_s \to 3\pi N$,...
  - No clear peak to fit

Plan:

- **Isolation tools** to detect every charged or neutral particle coming with $\Lambda_c \ + \ 3\pi$
- Use of **Multivariate analysis technique**
- **Fit** to extract the signal yield
  - template for each background source extracted from simulation

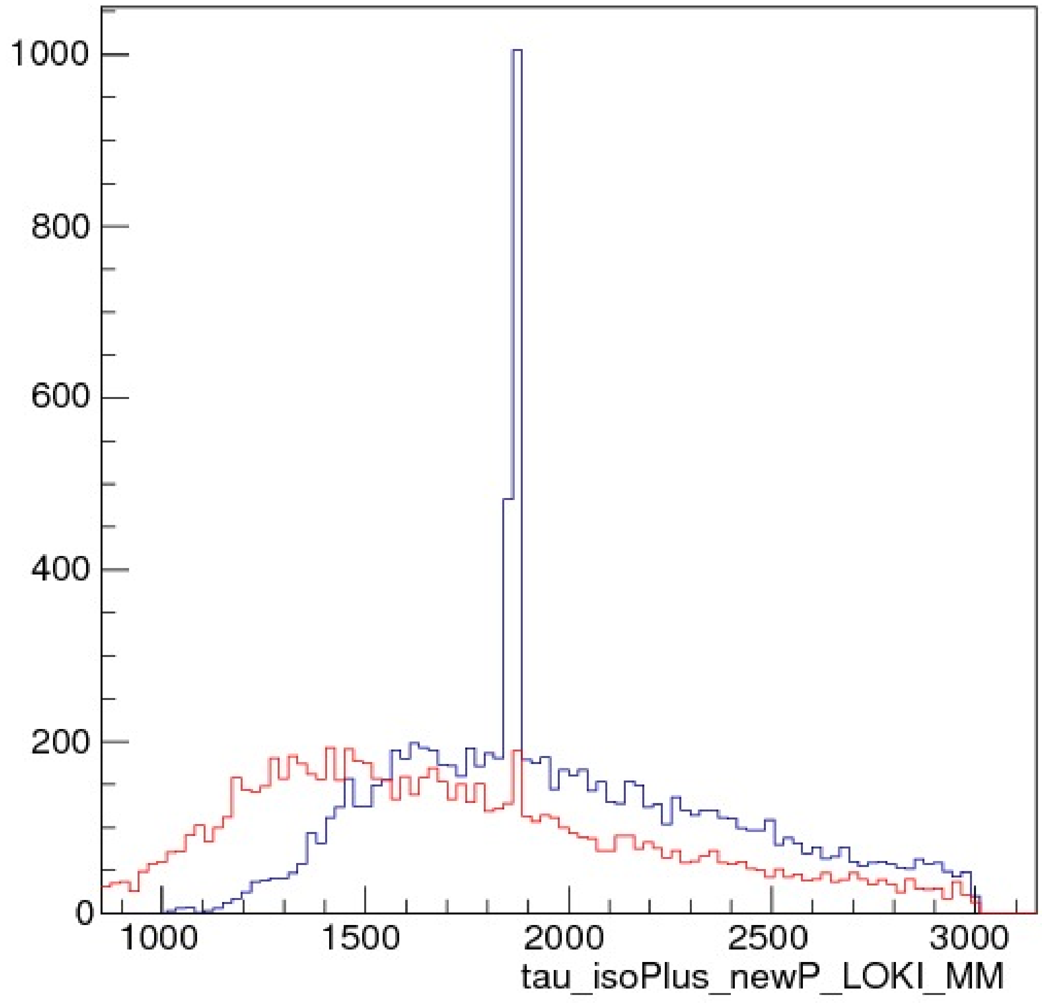
Isolation

Neutral Isolation:

A cone around the 3π axis is used to look for related neutral energy in the calorimeter $(\gamma, \pi^0, K^0, ...)$.

Charged track isolation:

If some track of the event is able to form a good vertex with the 3π ones, the event is vetoed.


1000
800
600
400
200
0
1000
1500
2000
2500
3000
tau_isoPlus_newP_LOKI_MM

Signal Reconstruction

Signal hypothesis:

- τ and Λ_b^0 momenta obtained using:

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

- Two-fold ambiguity solved forcing both root squares to be zero:

  $$\theta_{max} = \arcsin\left(\frac{m_\tau^2-m_{3\pi}^2}{2m_\tau|\vec{p}_{3\pi}|}\right)$$

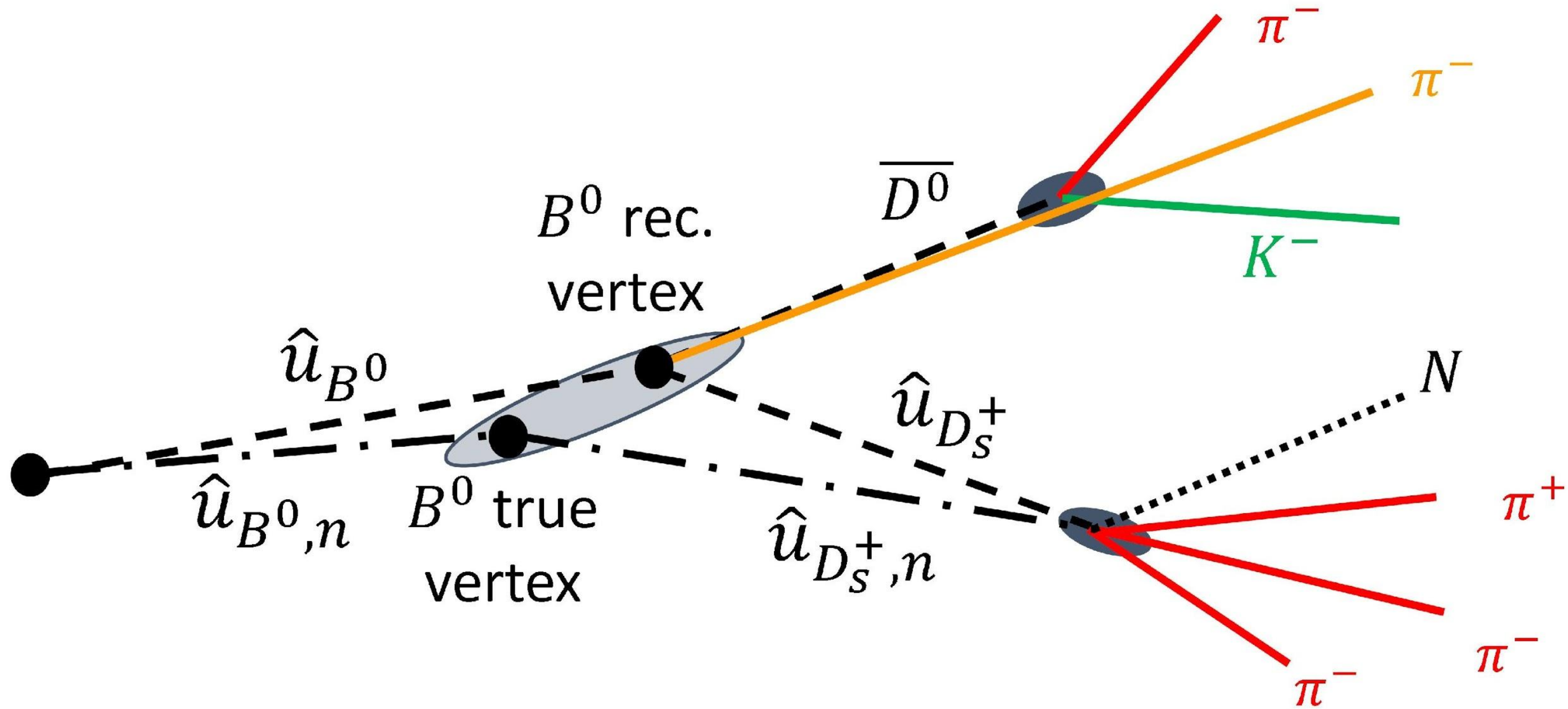
- Allow to measure τ decay time and q^2 transfered to the $\tau-\nu$ system

Background Reconstruction

- $\Lambda_b^0 \to \Lambda_c D_s^{(*(*))}$ background events can be partially reconstructed by using the following algebra:

$$|\vec{p}_{\Lambda_b^0}|\hat{u}_{\Lambda_b^0} = |\vec{p}_{D_s}|\hat{u}_{D_s} + \vec{p}_{\Lambda_c}$$

- In this way, the momentum of the Λ_b^0 and D_s can be estimated.


π^-
π^-
$\overline{D^0}$
B^0 rec.
vertex
K^-
$\hat{u}_{B^0}$
N
$\hat{u}_{D_s^+}$
π^+
$\hat{u}_{B^0,n}$
B^0 true
vertex
$\hat{u}_{D_s^+,n}$
π^-
π^-

Machine Learning to the rescue !

A set of variables from :

- isolation algorithms.
- kinematics and 3π dynamics.
- background and signal reconstruction.

will be used in a Boosted Decision Tree (BDT) to suppress $\Lambda_b^0 \to \Lambda_c D_{(s)}^{(0,+)} X$ events.

It is train on MC signal and a set of different simulation of background datasets.

Monte-Carlo simulations

To extract the result we need a really well described background:

- Inputs of the simulation is a cocktail of different channels weighted by their branching fraction
- To populate every background template we need:
  - careful choices in the inputs
  - lots of generated events
- Also need to correctly take into account the τ polarization
- Multiple reweighting are then taken into account (trigger, PID efficiencies, ...)

Fit strategy

An extended binned maximum likelihood fit will be performed to the data.

- **3D fit** using the q^2, the 3π decay time and the BDT output variable.
- The **signal** is described by the sum of $\tau \to \pi\pi\pi\nu$ and $\tau \to \pi\pi\pi\pi^0\nu$ components accounting for their branching ratios end efficiencies.
- The **background** is described by MC simulation and constrained using precisely measured branching fractions.
  - each background category is described by a template.
  - The combinatorial part will be extracted directly from the data.

Conclusion

- Benefit a lot from the $R(D^*)$ analysis (soon to be finished).
- Initial selection in good shape, room for some optimization.
- Some dedicated MC is already available, some still needs to be produced.
- Analysis with both Run1 and Run2 data.
- We aim a result with an uncertainty comparable with published LHCb $R(D^*)$ result in 2017.

Tank you for you attention !

Any question ?

Backups

Normalization procedure

- Three normalisations procedures are possible :
  - direct : using $\Lambda_c 3\pi$ channel, requires $f_{\Lambda_b^0}$ and $\mathcal{B}(\Lambda_c \to pK\pi)$. (~10% error)
  - crossed : using $\frac{\Lambda_c \tau\nu}{\Lambda_c \mu\nu}$ which will require $\frac{\epsilon_{trig} \times \epsilon_{acc}(3\pi)}{\epsilon_{trig} \times \epsilon_{acc}(\mu)}$ (~10% error).
  - **external** : using theoretical prediction of f_{th} and the precise $\mathcal{B}(B^0 \to D^* 3\pi)$ from BaBar (~5% error).

$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^{*+}\pi^-\pi^+\pi^-)} = \frac{N_{obs}(\Lambda_c^+ \tau^- \bar{\nu}_\tau)}{N_{obs}(\Lambda_c^+ 3\pi)} \times \frac{N_{obs}(\Lambda_c 3\pi)}{N_{obs}(D^* 3\pi)}$$

$$\div \frac{N_{obs}(\Lambda_c \mu\nu)}{N_{obs}(D^* \mu\nu)} \times \frac{\tau_{\Lambda_b^0}}{\tau_{\bar{B}^0}} \times f_{th} \times \epsilon_{MC}$$

Normalization procedure

f_{th} is defined as follow :

$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c \mu\nu)}{\mathcal{B}(\bar{B}^0 \to D^* \mu\nu)} = \frac{\tau_{\bar{B}^0}}{\tau_{\Lambda_b^0}} \times f_{th}$$

WIth the help of Stefan Meinel from University of Arizona, the relative uncertainty on f_{th} is ~7-10%

Input	$\frac{\Gamma(\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu)}{\Gamma(\bar{B}^0 \to D^+ \mu^- \bar{\nu}_\mu)}$
DLM+HPQCD	2.47 ± 0.26
DLM+FNAL/MILC	2.30 ± 0.23
DLM+FNAL/MILC+Babar	2.45 ± 0.19
DLM+FNAL/MILC+Babar+Belle	2.37 ± 0.16

comparison of Run1 and Run2 data (preliminary study).