LHCb latest results

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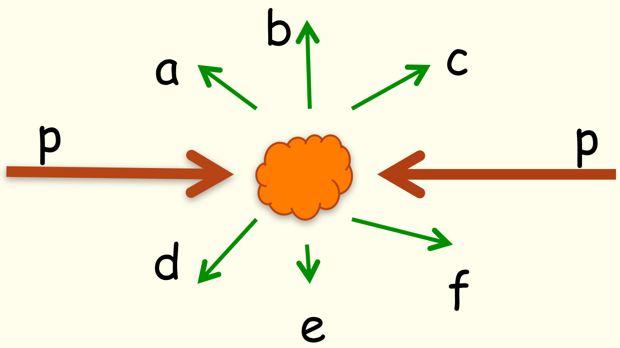
Introduction

Search for New Physics (NP) is pursued in two **complementary** approaches

High **energy** (direct) approach:

If the energy in particle collisions is large enough to create new **"real"** particles



ATLAS and CMS approach

High **precision** (indirect) approach:

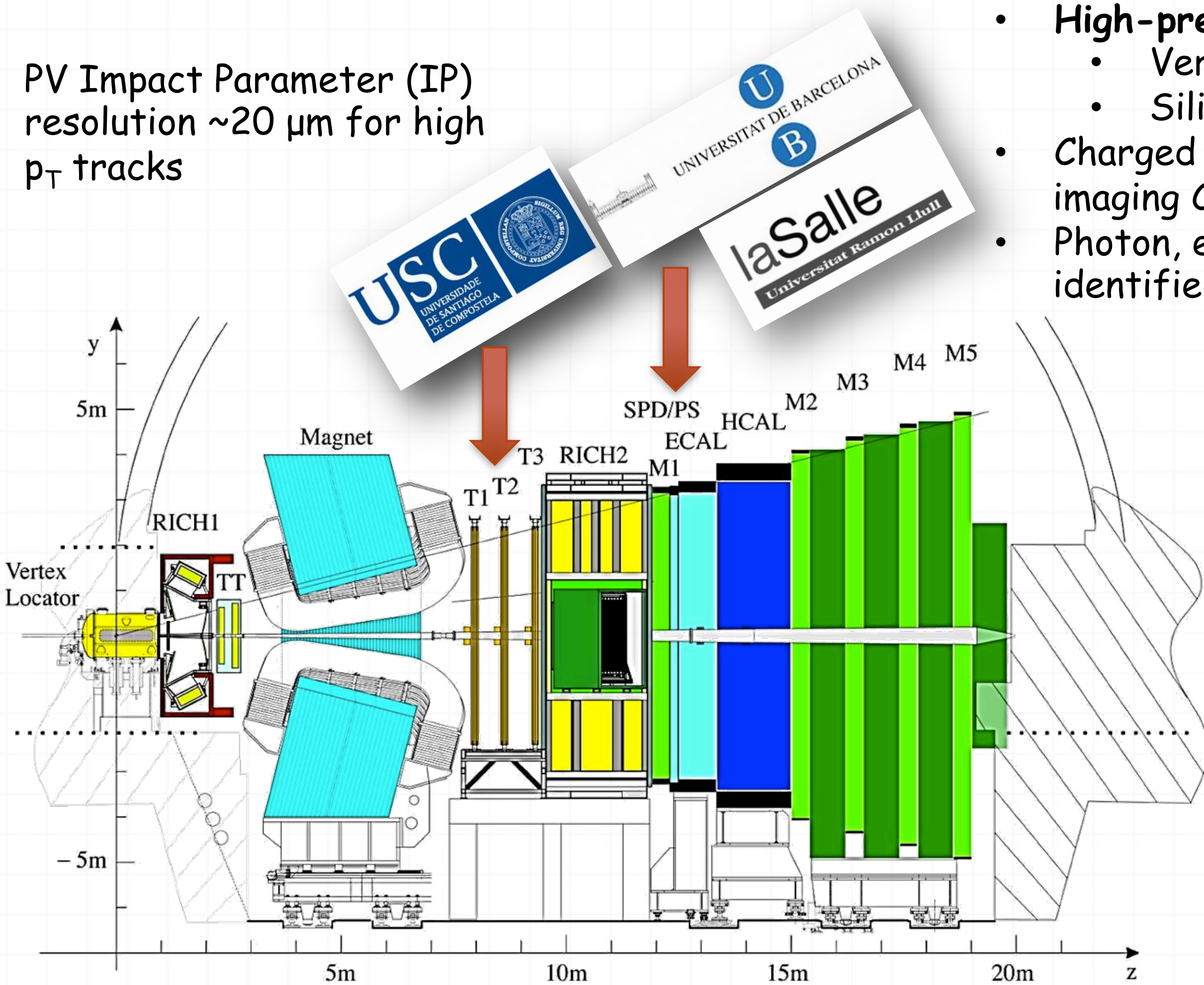
If the precision of the measurement is high enough to detect NP effects due to new **"virtual"** particles in **loops**

LHCb approach

Single-arm forward spectrometer designed for the study of particles containing **b** or **c** quarks

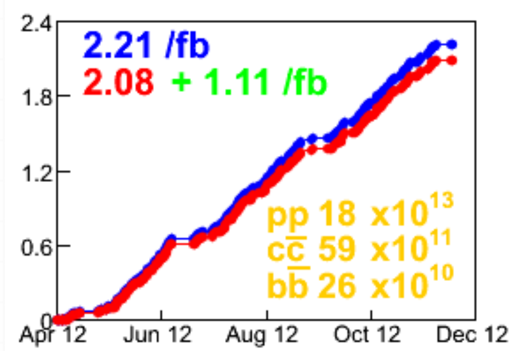
PV Impact Parameter (IP) resolution ~20 μm for high p_T tracks

- **High-precision** tracking system (Δp/p~0.5):
  - Vertex detector
  - Silicon-strip detector
- Charged hadrons identified using a two ring-imaging Cherenkov detectors (**RICH**)
- Photon, electron and hadron candidates identified by a **calorimeter** system



pseudorapidity 2<η<5

Collected luminosity:



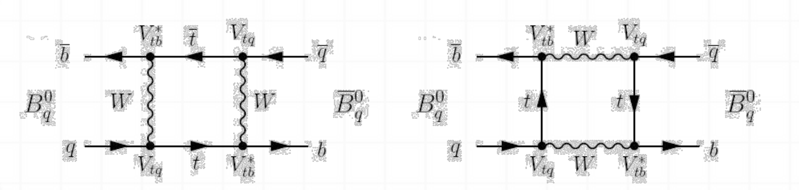
- 1.11 fb^{-1} at $\sqrt{s}$=7TeV (2011)
- 2.08 fb^{-1} at $\sqrt{s}$=8TeV (2012)

see X. Vilasis-Cardona @ red tematica de fisica del LHC

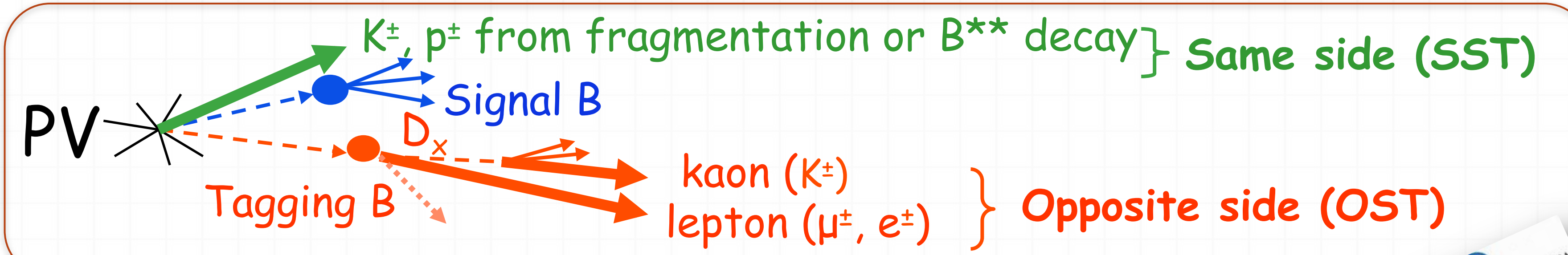
Oscillations: $B_s^0 \to D_s^- \pi^+$

A known property of the **neutral meson** system is the **mixing**:

- neutral mesons can transform into their antiparticles
- Mixing (particle-antiparticle oscillation) proceeds via a box diagram in the SM:



- Mixing has been observed in different neutral meson systems (B_s^0, B^0, K^0, D^0)
- The flavour of the neutral meson at production must be known → **B-tagging**. Two algorithms: Same side (**SST**) and Opposite side tagging (**OST**)



Effective tagging efficiency : → $\varepsilon_{eff} = \varepsilon\,(1-2\omega)^2 \sim 2\text{-}3\%$

ε : tagging efficiency ~20 %

ω : mistag probability ~30%

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Oscillations: $B_s^0 \to D_s^- \pi^+$ (2)

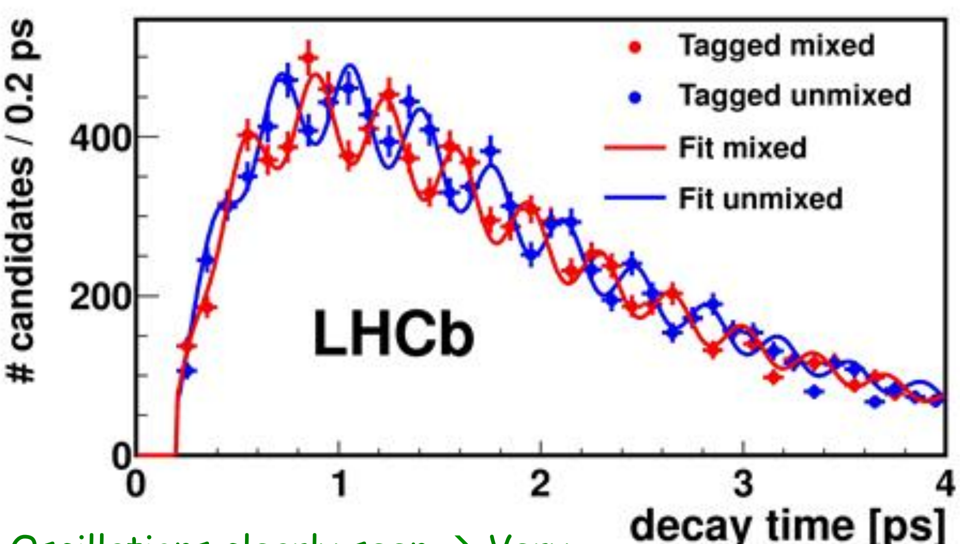
[arXiv:1304.4741]

- $B_s^0 \to D_s^- \pi^+$ analysis to measure the oscillation frequency Δm_s
- $B_s^0 \to D_s^- \pi^+$ is a flavor-specific decay mode. The B_s^0 flavor at the **decay** time is determined by the charge of the pion

Δm_s: mass difference m_H-m_L between the heavy and light mass eigenstates B_H and B_L

- B_s^0 flavour at production point determined by the B-tagging algorithms
- Decay time PDF:

$$P(t|\sigma_t) \propto \left\{\Gamma_s e^{-\Gamma_s t} \frac{1}{2}\left[\cosh\left(\frac{\Delta\Gamma_s}{2}t\right) + q[1-2\omega]\cos(\Delta m_s)\right]\theta(t)\right\} \otimes G(t, S_{\sigma_t}\sigma_t)\varepsilon_t(t)\varepsilon$$



Γ_s: B_s^0 decay width
$\Delta\Gamma_s$: B_s^0 decay width difference between light and heavy mass eigenstates
G: resolution function
$\Theta(t)$: restriction to positive decay times
$\varepsilon_t(t)$: time efficiency | ε: tagging efficiency
q: tagging decision

~34000 candidates using 1 fb^{-1} of 2011 data at $\sqrt{s}$ = 7TeV

$\Delta m_s = 17.768 \pm 0.023(\text{stat}) \pm 0.006(\text{syst})\ \text{ps}^{-1}$

Oscillations clearly seen → Very good detector performance

Rare decays

b->d(s) transitions, mediated by Flavour Changing Neutral Currents (FCNC)

can proceed only via loop processes → suppressed in the Standard Model

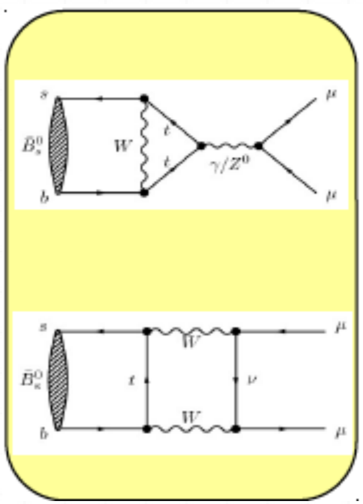
new particles can enter in the loops → New Physics can appear at the same level as Standard Model

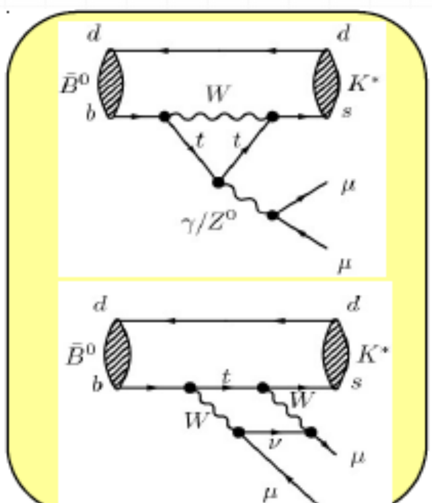
Examples:

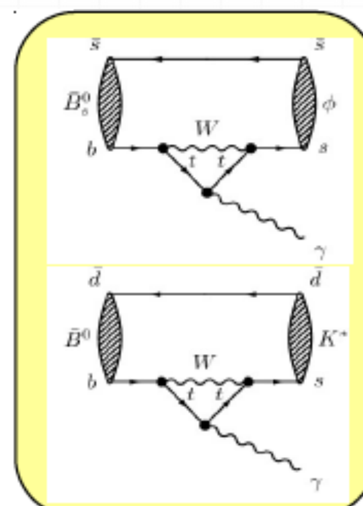
$B_{(s)}^0 \to \mu^+ \mu^-$
Branching fraction

$B^0 \to K^{*0} \mu^+ \mu^-$
angular distributions

$B^0 \to K^{*0} \gamma$ and $B_s^0 \to \varphi \gamma$
photon polarization

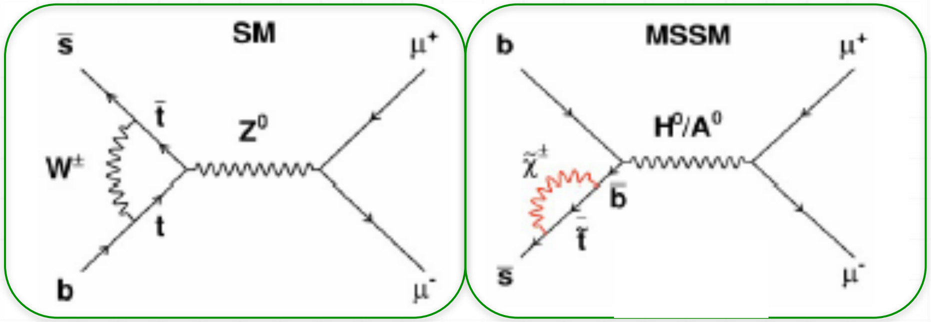




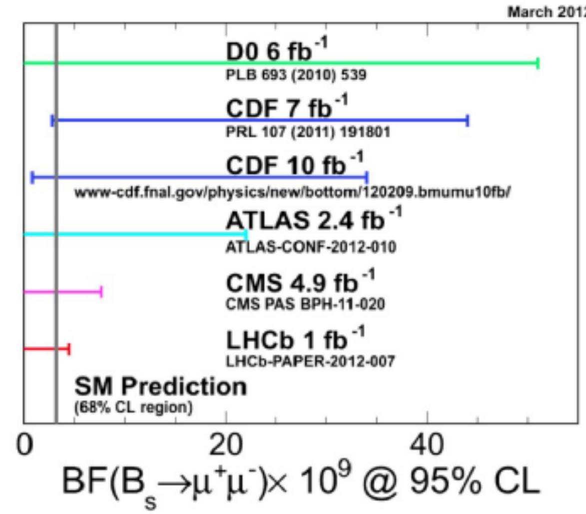


$B_{(s)}^0 \to \mu^+ \mu^-$

- $B^0_s \to \mu^+ \mu^-$ and $B^0 \to \mu^+ \mu^-$ decays are very rare in the SM. FCNC and helicity suppresed.



[March 2012]



- Branching fractions can be precisely predicted
  - $BF(B_s^0 \to \mu^+ \mu^-) = (3.56 \pm 0.29) \times 10^{-9}$ (time integrated)
  - $BF(B^0 \to \mu^+ \mu^-) = (1.07 \pm 0.10) \times 10^{-10}$ (at t=0)

[Buras, Isidori. arXiv:1208.0934]

- Comparison between measured and predicted branching fractions is an interesting probe for New Physics (NP)

- First evidence reported by LHCb with 3.5σ

[arXiv:1211.2674]
Nov 2012

$$BF(B_s^0 \to \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$$

$B_{(s)}^0 \rightarrow \mu^+ \mu^-$ (2)

- Full data analysis **3 fb^{-1}** :
  - 1 fb^{-1} 2011 data at $\sqrt{s}$=7TeV
  - 2 fb^{-1} 2012 data at $\sqrt{s}$=8TeV

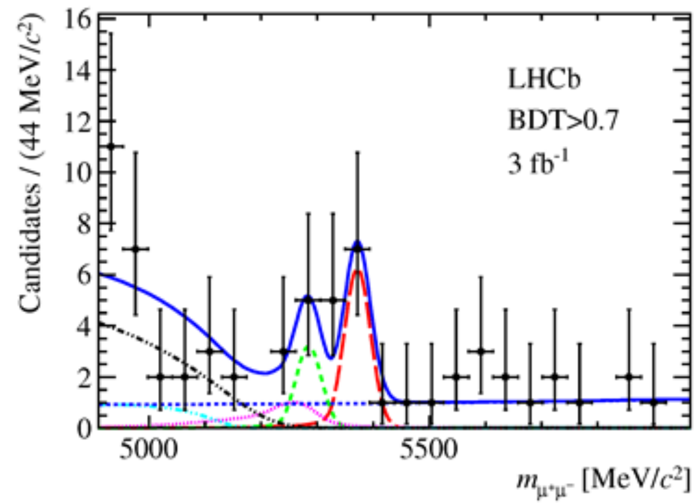
- Selection based on Boost Decision Tree (BDT) :
  - $B_s^0 \rightarrow \mu^+ \mu^-$ simulated events for the signal
  - $b\bar{b} \rightarrow \mu^+ \mu^- X$ events for the background
  - Variables selected to avoid correlation with mass

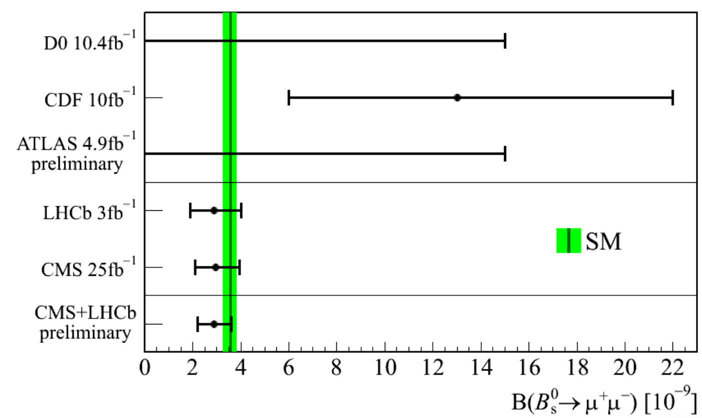
- Branching fraction measured from a simultaneous fit to different BDT bins

$$BF(B_s^0 \rightarrow \mu^+\mu^-) = (2.9^{+1.1}_{-1.0}) \times 10^{-9}$$ (4σ)

$$BF(B^0 \rightarrow \mu^+\mu^-) < 7.4 \times 10^{-10}$$ (at 95% CL)

- Average with CMS measurement exceeds 5σ

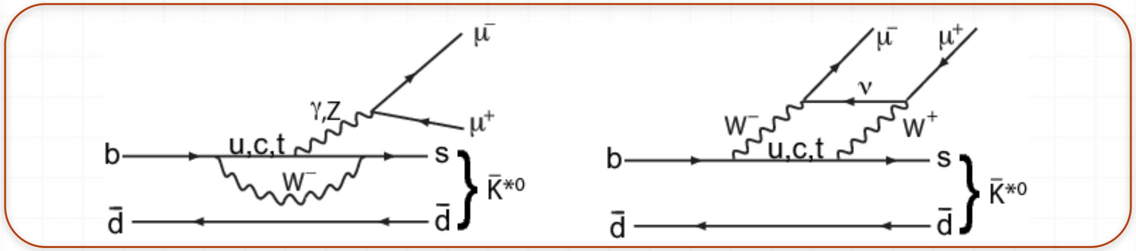




Compatible with SM !

$B^0 \to K^{*0}(892)\ \mu^+ \mu^-$

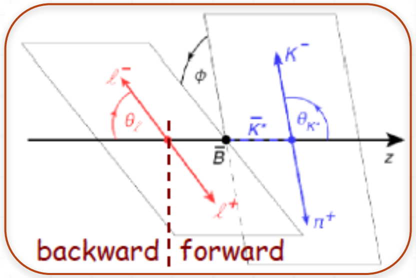
- $B^0 \to K^{*0}\ \mu^+ \mu^-$ is a FCNC decay proceeding via a loop or box diagram



- It can be fully described by three angles (θ_l, θ_K, φ) and the dimuon invariant mass squared $q^2=m^2(\mu^+ \mu^-)$

- Differential angular distribution gives rise to 8 independent observables for which precise predictions can be made as a function of q^2

- Example: Forward/backward (A_{FB}) asymmetry of the dimuon system
  - SM predicts zero-crossing of A_{FB} in a well defined point of q^2



- Sensitive to NP contributions that affect the helicity structure of the decay (i.e.: new scalar, pseudo-scalars)

$B^0 \to K^{*0}(892)\, \mu^+ \mu^-$ (2)

- Differential branching fraction and angular analysis of the $B^0 \to K^{*0} \mu^+ \mu^-$ are performed using **1 fb⁻¹** of 2011 data at **√s = 7 TeV**

- A first measurement of the zero-crossing point of the forward-backward asymmetry A_{FB} of the dimuon mass is also performed

- Differential angular distribution given by:

$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_l d\cos\theta_k d\varphi dq^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_k + F_L\cos^2\theta_k + \frac{1}{4}(1-F_L)\sin^2\theta_k\cos(2\theta_l) - F_L\cos^2\theta_k\cos(2\theta_l) + S_3\sin^2\theta_k\sin^2\theta_l\cos(2\varphi)$$
$$+S_4\sin(2\theta_k)\sin(2\theta_l)\cos\varphi + S_5\sin(2\theta_k)\sin\theta_l\cos\varphi + S_6\sin^2\theta_k\cos\theta_l + S_7\sin(2\theta_k)\sin\theta_l\sin\varphi + S_8\sin(2\theta_k)\sin(2\theta_l)\sin\varphi + S_9\sin^2\theta_k\sin^2\theta_l\sin(2\varphi)\Big]$$

from where we can obtain the observables:

[J. Matias et al. arXiv:1202.4266]

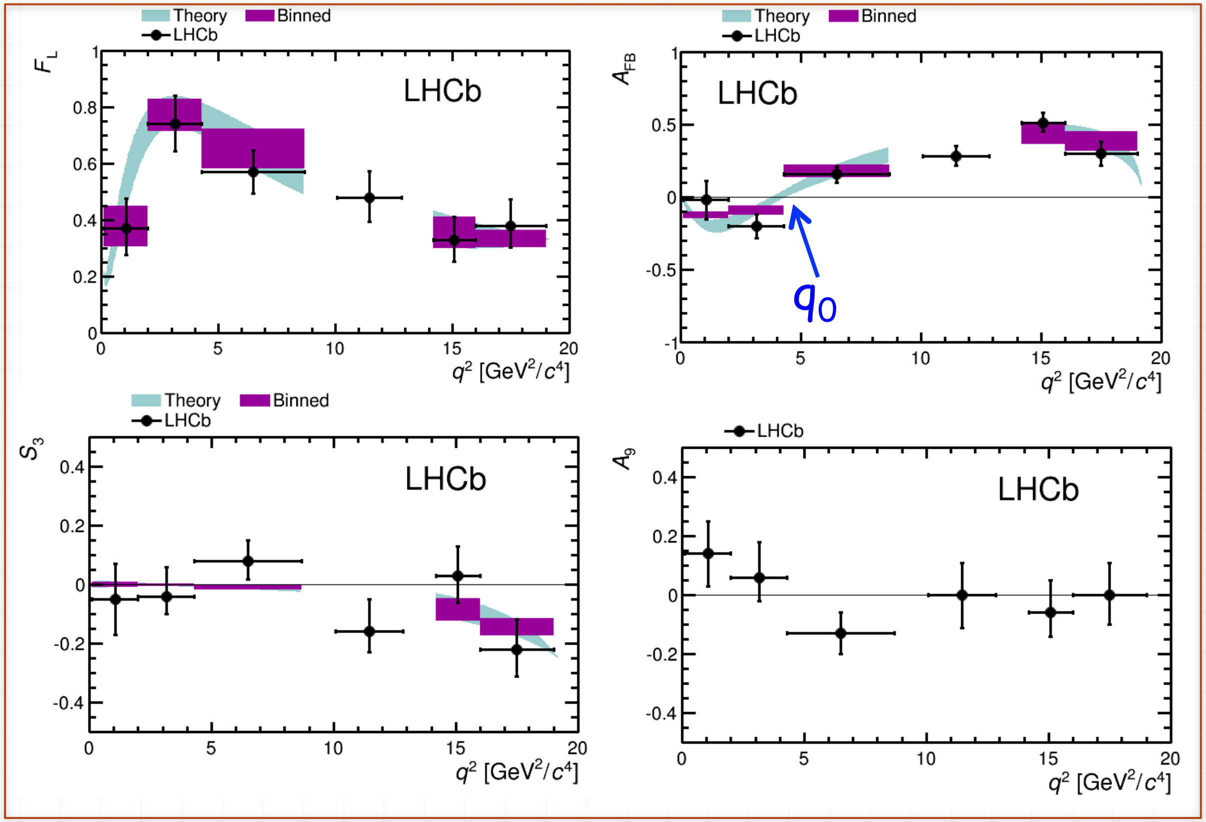
F_L : K^{*0} logitudinal polarization fraction
S_3 : ∝ K^{*0} transverse polarization asymmetry
A_{FB} : Forward/backward asymmetry of the dimuon system
A_9 : CP asymmetry for S_9

$$P'_{4,5,6,8} = \frac{S_{4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$

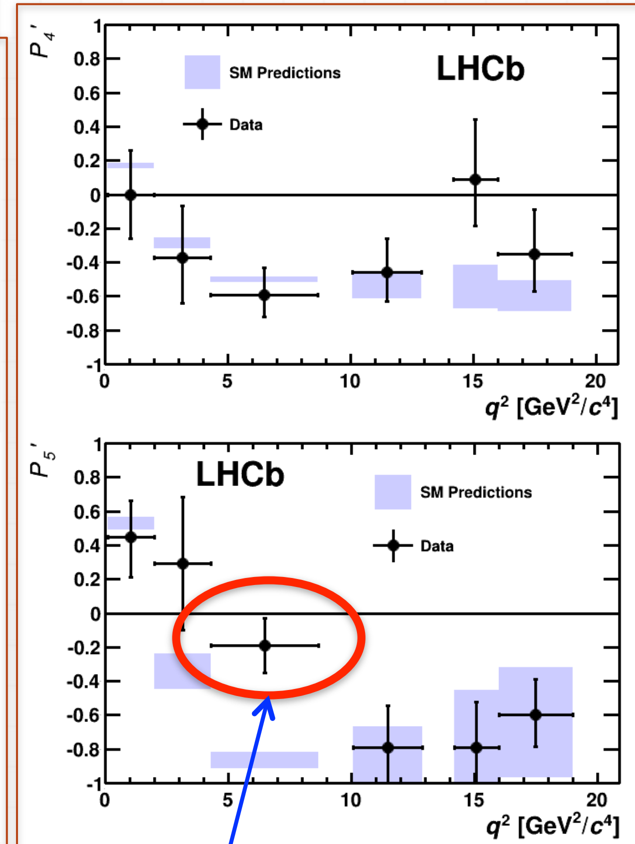
In the larger recoil limit (low q^2) $P'_{4,5,6,8}$ are largely free from form-factor uncertainties

$B^0 \to K^{*0}(892)\,\mu^+\mu^-$ (3)

Results from the angular analysis: [arXiv:1304.6325]



[arXiv:1308.1707]



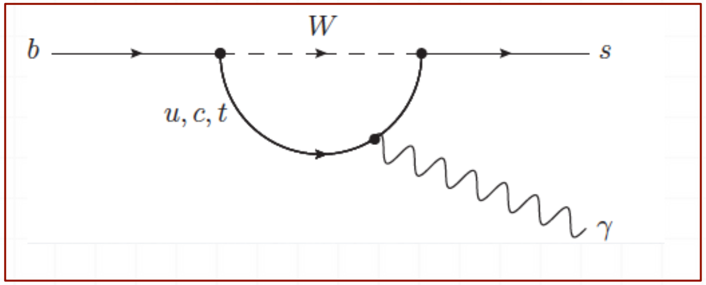
First determination of well predicted A_{FB} zero-crossing point :

$$q_0 \equiv q^2(A_{FB}=0) = (4.9 \pm 0.4) GeV^2 / c^4$$

Measurements in good agreement with SM predictions !

- 3.7σ discrepancy in 1/24 bins
- it triggered very interesting discussions
- 0.5% probability to observe such a discrepancy or larger considering al 24 measurements

- **$B^+ \to [K^+\pi^-\pi^+]_{res}\gamma$** is a Flavour-Changing Neutral-Current (FCNC) radiative process



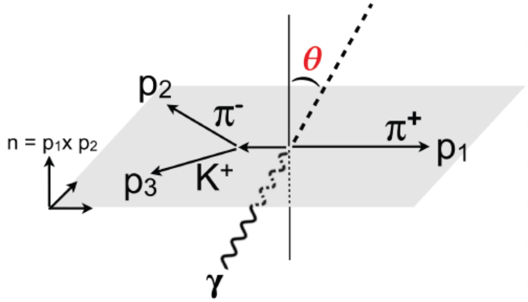
BF($B^+ \to [K^+\pi^-\pi^+]_{res}\gamma$) = $(27.6 \pm 1.8)\times 10^{-6}$

FCNC b->sγ processes forbidden at tree level in SM. Therefore they are sensitive to NP contributions in electroweak penguin diagrams

- SM model predicts the photon emitted to be predominantly left-handed (up to 10% corrections). This predominance has not been observed yet

- the presence of three hadrons in the [$K^+\pi^-\pi^+ \gamma$] final state allows to build a parity-odd **triple product** that can be used to describe the photon helicity through simple kinematic considerations

- we can obtain information about the photon polarization from angular correlations between the three hadrons



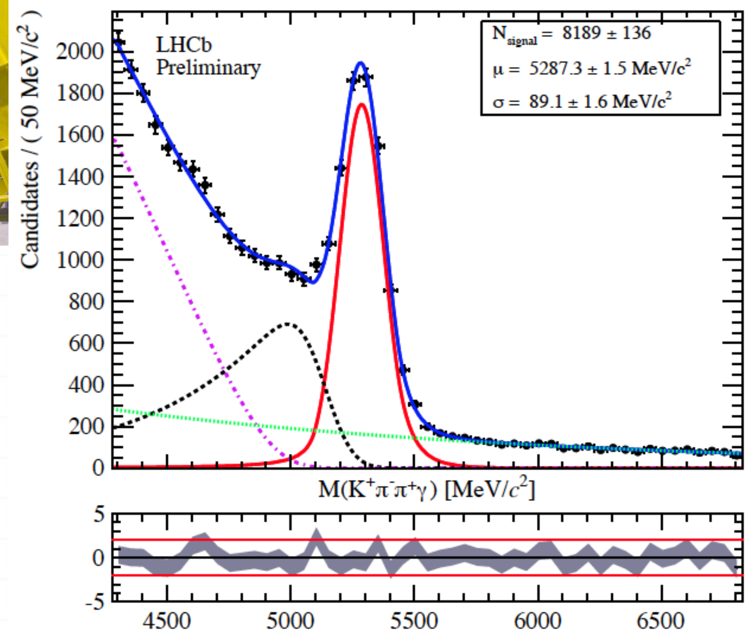
- Up-Down A_{UD} and A_{CP} are measured in this study

- Measuring $A_{UP} \neq 0$ → photon is polarized (parity is violated)

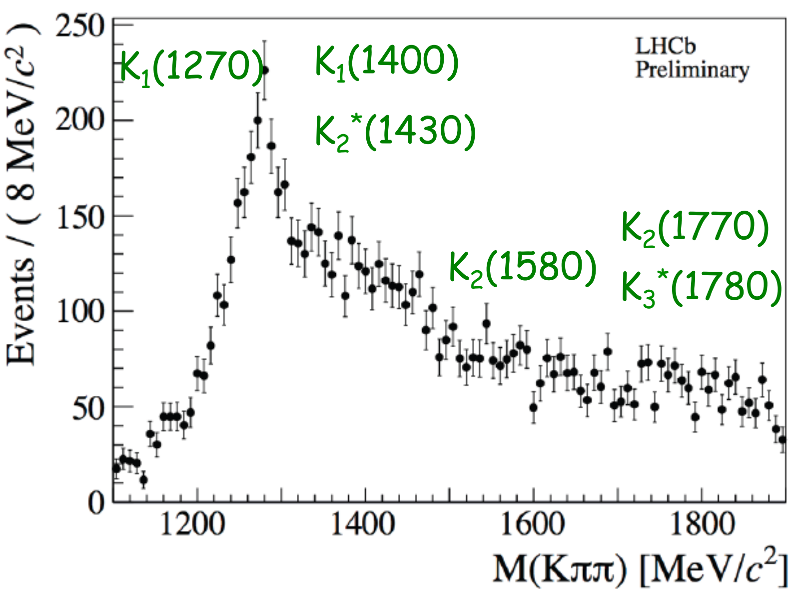
Up-Down asymmetry defined respect to the three hadrons decay plane. Proportional to the photon polarization

see A. Oyanguren talk @ red tematica de fisica del LHC and P. Ruiz Valls @ red de fisica del sabor

First evidence of photon polarization in b -> sγ transitions (2)



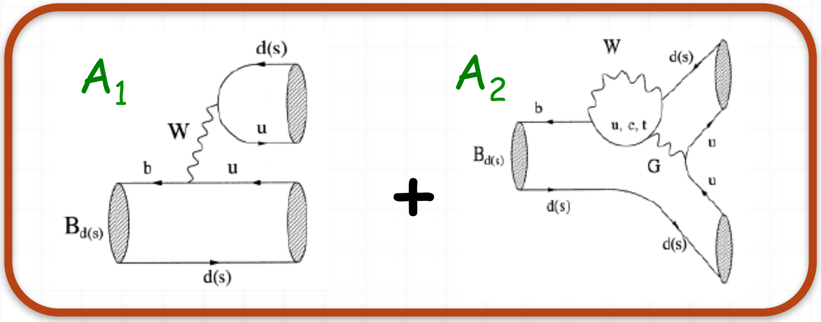
- 8000 signal events using 2 fb^{-1} of $\sqrt{s}$=8 TeV 2012 data
- sample contains all possible intermediate resonances in the $K^+\pi^-\pi^+$ system



- $A_{CP}(B^+ \to K^+\pi^-\pi^+ \gamma)$=-0.007 ± 0.015(stat) ± 0.008(syst) (measured for the first time and compatible with zero)
- $A_{UD}(B^+ \to K^+\pi^-\pi^+ \gamma)$=-0.085 ± 0.019(stat) ± 0.003(syst) (proportional to the photon polarization)
- **First evidence of photon polarization** (**parity** violation) with significance 4.6σ

Direct CP asymmetry: $B_s^0 \to K^- \pi^+$ and $B^0 \to K^+ \pi^-$

Interference between **tree** and **penguin** diagrams -> Direct CP asymmetry



$$A_f = |A_1| e^{i\delta_1} e^{i\phi_1} + |A_2| e^{i\delta_2} e^{i\phi_2}$$
$$\bar{A}_f = |A_1| e^{i\delta_1} e^{-i\phi_1} + |A_2| e^{i\delta_2} e^{-i\phi_2}$$

$$A_{CP} = \frac{|\bar{A}_f|^2 - |A_f|^2}{|\bar{A}_f|^2 + |A_f|^2} = \frac{2|A_1||A_2|\sin\delta\sin\phi}{|A_1|+|A_2|^2 + 2|A_1||A_2|\cos\delta\cos\phi}$$

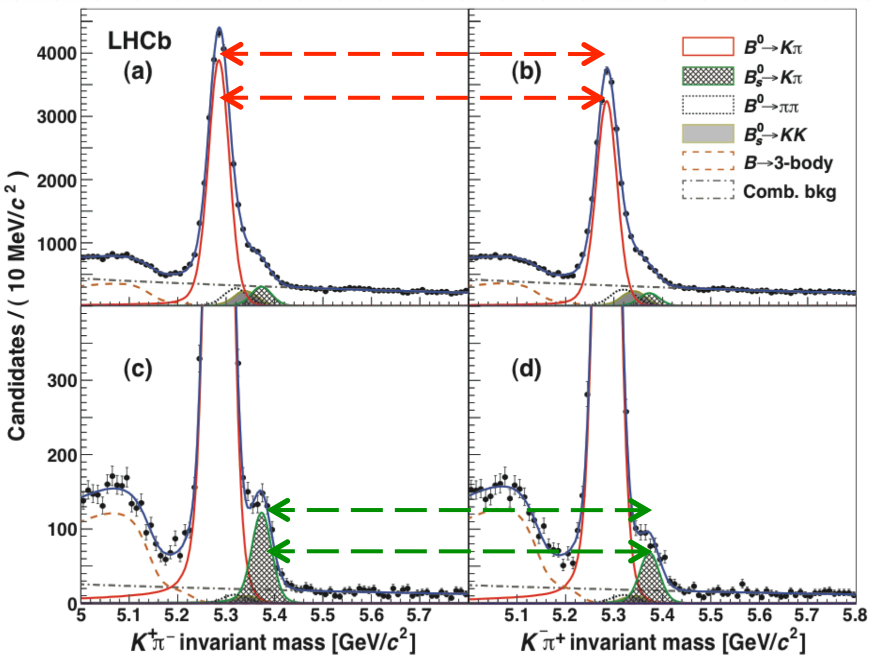
$\delta=\delta_2-\delta_1$: strong phase difference (between amplitudes)
$\varphi=\varphi_2-\varphi_1$: weak phase difference

- 1 fb^{-1} of 2011 data at $\sqrt{s}$=7 TeV

Non trivial prediction of Standard Model:

$$\Delta = \frac{A_{CP}(B^0 \to K^+\pi^-)}{A_{CP}(B_s^0 \to K^-\pi^+)} + \frac{BF(B_s^0 \to K^-\pi^+)}{BF(B^0 \to K^+\pi^-)} \frac{\tau_d}{\tau_s} = 0$$

He, Eur. Phys. J. C9 443 (1999). Lipkin, PLB 621, 126 (2005)



$$A_{CP}(B^0 \to K^+\pi^-) = -0.08 \pm 0.007(stat) \pm 0.003(syst)$$

$$A_{CP}(B_s^0 \to K^-\pi^+) = 0.27 \pm 0.004(stat) \pm 0.01(syst)$$

(First observation of CPV in the B_s system)

[PRL 110, 221601 (2013)]

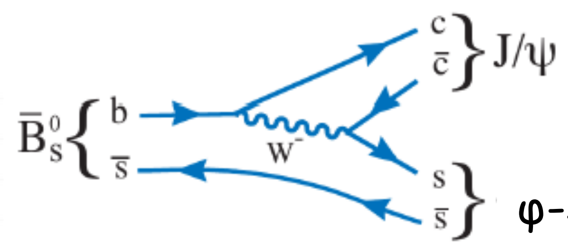
Compatible with SM!

$$\Delta = -0.02 \pm 0.05(stat) \pm 0.04(syst)$$

B -> VV' angular analyses

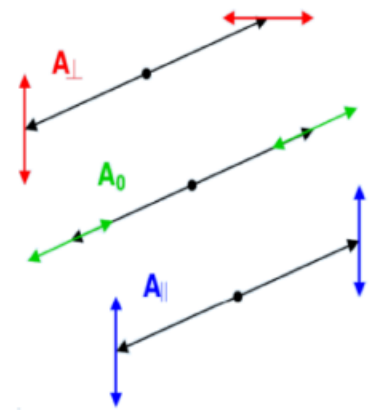
B->VV' decays are very sensitive to NP
pseudoscalar to two Vector mesons ($J^{PC}=1^{--}$)

Example: $B_s^0 \to J/\psi\,(\mu^+\mu^-)\,\varphi\,(K^+K^-)$

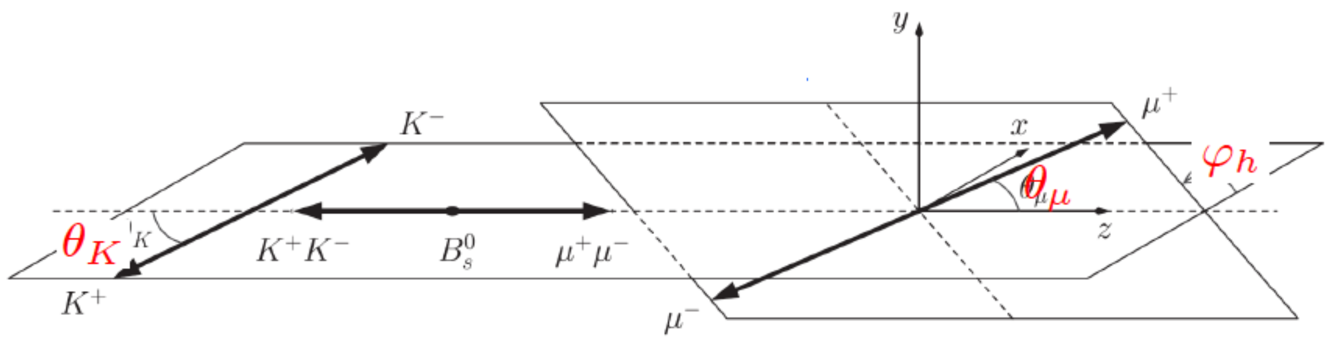


φ->K⁺K⁻

- 3 polarization amplitudes and phases needed (relative momentum in between vector mesons l=0,1,2):
  - $|A_0|^2$, $|A_{||}|^2$, δ_0 , $\delta_{||}$ (CP even)
  - $|A_\perp|^2$, $\delta_\perp$ (CP odd)



- Additional S-wave component included in the fit
  - $|A_S|^2$, δ_S (CP odd)
- Angular analysis is needed to extract the amplitudes



See P. Alvarez Cartelle talk @ red tematica de fisica del LHC and C. Vazquez Sierra talk @ red de fisica del sabor

B ->VV' angular analyses

- $B_s^0 \to J/\psi\ \varphi$
  - Precise measurement of the weak phase φ_s performed

[PRD 87, 112010 (2013)]

- $B_{(s)}^0 \to J/\psi\ K^{*0}$
  - $B_s^0 \to J/\psi\ K^{*0}$ used to determine the penguin pollution in $B_s^0 \to J/\psi\ \varphi$
- $B_s^0 \to \varphi\varphi$
  - Time dependent analysis with 1 fb^{-1} performed to extract the weak phase $\varphi_s^{s\bar{s}s}$

[PRL 110, 240802 (2013)]

- $B_{(s)}^0 \to \varphi K^{*0}$
  - Pure penguins amplitude. $B_s^0 \to \varphi \bar{K}^{*0}$ first observation, measurement of the branching fraction and angular analysis performed with $1fb^{-1}$
  - $B^0 \to \varphi K^{*0}$ angular analysis to be published very soon

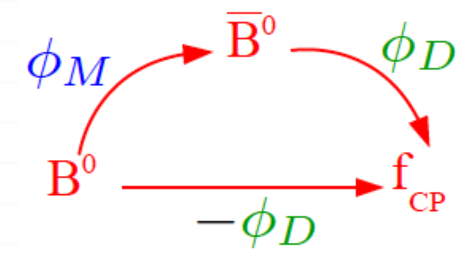
doi:10.1007/JHEP11(2013)092

- $B_{(s)}^0 \to K^{*0}\bar{K}^{*0}$
  - $B_s^0 \to K^{*0}\bar{K}^{*0}$ first observation, measurement of the branching fraction and angular analysis performed with 0.035 fb^{-1}
  - Analysis with more statistics ongoing. Aims to measure the $\varphi_s^{d\bar{d}s}$ weak phase
- $B^0 \to \rho^0\ \rho^0$
  - Analysis using the full data set ($3fb^{-1}$) very well advanced. Publication in few months
- $B_{(s)}^0 \to \rho^0 K^{*0}$
  - Angular analysis ongoing

- For final states CP eigenstates f_{CP} **interference between mixing (φ_M) and decay (φ_D)** is possible

- CP asymmetry in function of time is given by:

$$A_{CP} = \frac{\Gamma(B_s^0 \to f_{CP};t) - \Gamma(\bar{B}_s^0 \to f_{CP};t)}{\Gamma(B_s^0 \to f_{CP};t) + \Gamma(\bar{B}_s^0 \to f_{CP};t)} = -\eta_f \sin\varphi_s \sin(\Delta m_s t)$$



with

$\varphi_s = \varphi_M - 2\varphi_D$ and η_f : CP eigenvalue of final state f_{CP} $\varphi_M = \arg(M_{12})$

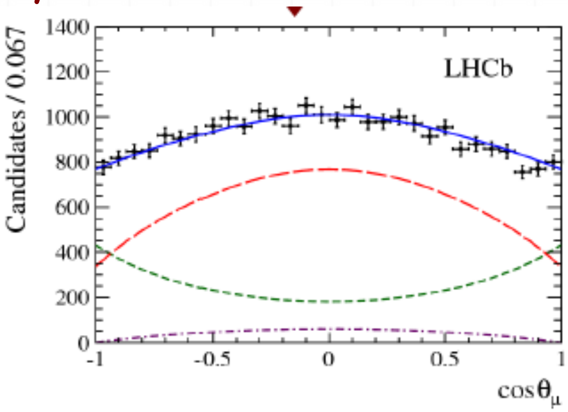
- φ_s depends on the final state:

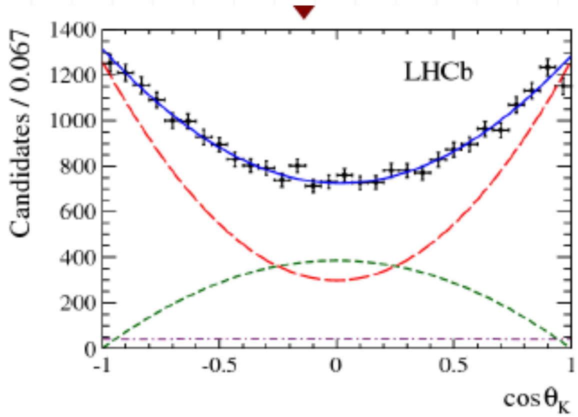
	SM prediction	LHCb measurements
$b \to c\bar{c}s$	$\varphi^{c\bar{c}s} = -0.036 \pm 0.002$ rad [PRD 84, 033005 (2011)]	$B_s^0 \to J/\psi\varphi$ $B_s^0 \to J/\psi\pi^+\pi^-$ [PRD 87, 112010 (2013)]
$b \to s\bar{s}s$	$\varphi^{s\bar{s}s} = 0.0 \pm 0.2$ rad [PRD 80, 114026 (2009)]	$B_s^0 \to \varphi\varphi$ (sensitivity) [PRL 110, 240802 (2013)]

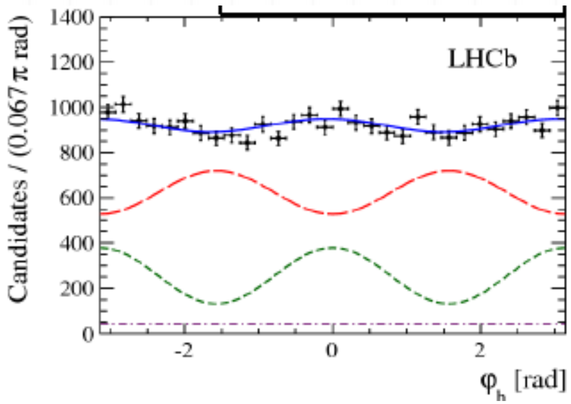
Clear separation of CP-even and CP-odd components by a maximum likelihood fit in angular distributions

[PRD 87, 112010 (2013)]

[Total Fit, CP-even, CP-odd, S-wave]

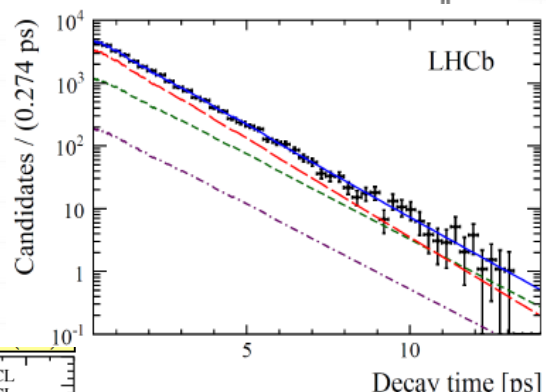






Allows to determine different lifetimes for CP-odd and CP-even components

$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \approx \Gamma_{CP\text{-}even} - \Gamma_{CP\text{-}odd}$$

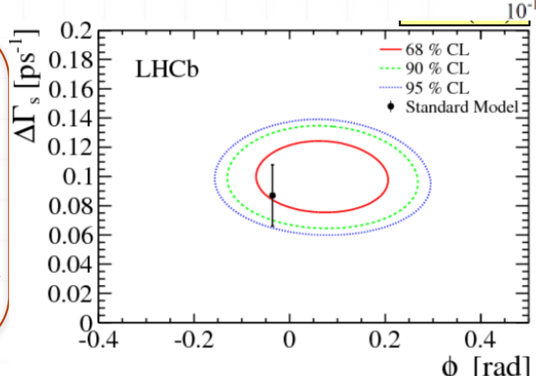


[φ_s^{SM}=-0.036±0.002 rad]

$\varphi^{c\bar{c}s}$ = 0.07 ± 0.09(stat) ± 0.09(syst) rad

Γ_s = 0.661 ±0.004(stat) ± 0.006(syst) ps^{-1}

$\Delta\Gamma_s$ = 0.110 ±0.016(stat) ± 0.003(syst) ps^{-1}



sign of $\Delta\Gamma_s$ measured from phase dependence of δ_S on m_{KK} to be "+"

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CPV in the charm sector

- CPV in the charm sector predicted to be very small ($\sim 10^{-4}$)
- Production and detection asymmetries hard to control at this level, thus careful choice of the observables needed to minimize systematics
- New Physics can enhance CPV observables. Observation of CP asymmetry in the charm sector provide a unique probe of physics beyond the Standard Model
- CPV contributions:
  1. CPV in decay: amplitude for a process and its CP conjugate differ

$$\left|\frac{\bar{A}_f}{A_f}\right|^2 = 1 - 2a_{CP}^{dir}$$

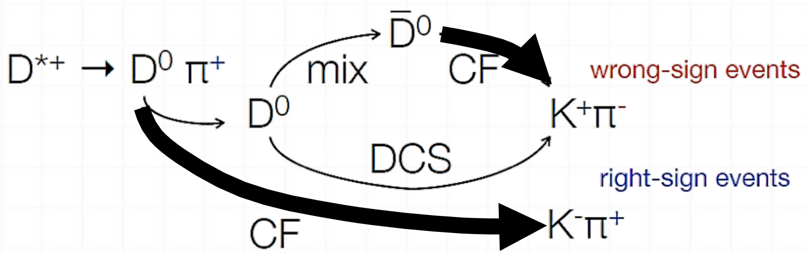
a_{CP}^{dir} : direct CP asymmetry

  2. In mixing : rate of $\bar{D}^0 \to D^0$ and $D^0 \to \bar{D}^0$ differ: $\left|\frac{p}{q}\right|^2 = 1 + A_m$
  3. In Interference between mixing and decay $\lambda_f = -\eta_{CP}\left|\frac{q}{p}\right|\left|\frac{\bar{A}_f}{A_f}\right| e^{i\varphi}$

Indirect CP violation $a_{CP}^{ind} = -\frac{A_m}{2} y\cos\varphi + x\sin\varphi$

A_m : CPV from mixing
x,y : mixing parameters
$x=\Delta m/\Gamma$, $y=\Delta\Gamma/2\Gamma$
φ : weak phase

- DCS $D^{*+} \to D^0[K^-\pi^+]\,\pi^+_s$ decay is analysed. Mixing parameters measurement and search for CPV is performed.
- Use low momentum pion π^+_s in $D^{*+} \to D^0[K^-\pi^+]\,\pi^+_s$ to tag initial flavor of D^0



WS: double Cabibbo suppressed (DCS) $D^0 \to K^+\pi^-$

RS: Cabibbo favored (CF) $D^0 \to K^-\pi^+$

- Ratio between right-sign and wrong-sign events is analysed :

$$R(t) = \frac{N_{WS}(t)}{N_{RS}(t)} = R_D + \sqrt{R_D}\,y'\frac{t}{\tau} + \frac{x'^2 + y'^2}{4}\left(\frac{t}{\tau}\right)^2$$

$$\frac{A(D^0 \to K^+\pi^-)}{A(\bar{D}^0 \to K^+\pi^-)} = -\sqrt{R_D}\,e^{-i\delta}$$

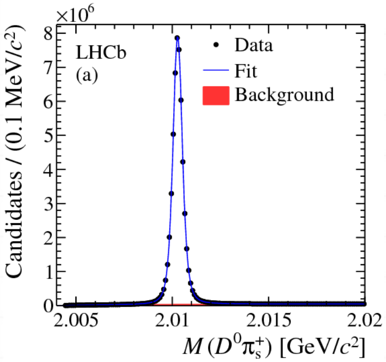
δ: strong phase difference
x',y': mixing parameters
x'= xcosδ+ysinδ
y'= ycosδ-xsinδ
t: decay time
τ : average D^0 lifetime
|x|,|y|<<1

- R(t) permitted to be different for initially produced D^0 and anti-D^0. [$R^+(t)$ and $R^-(t)$]

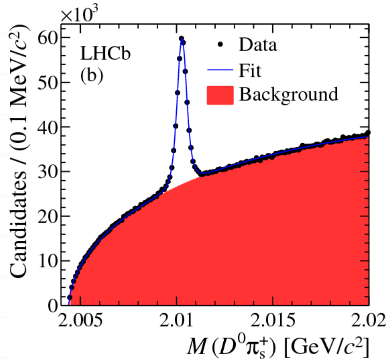
$R_D^+ \neq R_D^-$: referred as direct CP violation
$(x'^+, y'^+) \neq (x'^-, y'^-)$: referred as indirect CP violation

Mixing and CPV in DCS $D^0 \to K^+\pi^-$

(Right-sign events)



(Wrong-sign events)

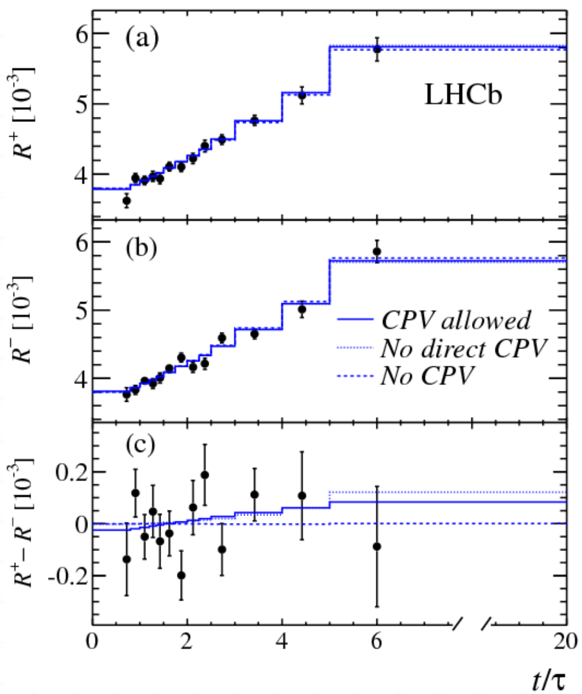


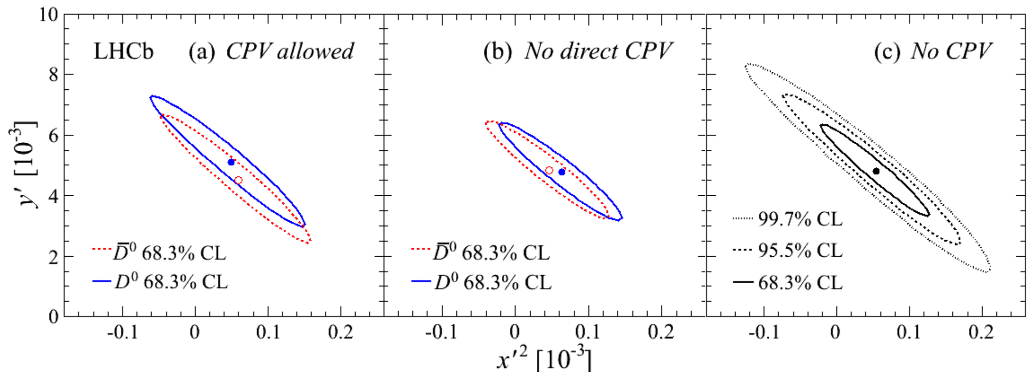
In the limit of CP conservation:

$x'^2=(5.5\pm4.9)\times10^{-5}$
$y'=(4.8\pm1.0)\times10^{-3}$
$R_D=(3.568\pm0.066)\times10^{-3}$

Allowing CPV:

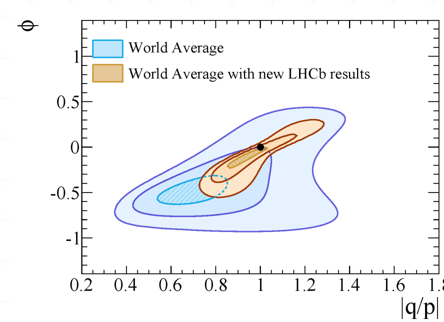
$$A_D = \frac{R_D^+ - R_D^-}{R_D^+ + R_D^-} = (-0.7\pm1.9)\%$$





$$x'^{\pm} = \left|\frac{q}{p}\right|^{\pm1} (x'\cos\varphi \pm y'\sin\varphi)$$

$$y'^{\pm} = \left|\frac{q}{p}\right|^{\pm1} (y'\cos\varphi \mp x'\sin\varphi)$$



No evidence for CPV !

LHCb upgrade

- LHC and LHCb are a spectacular success
- and so is the SM … so far
- current precision of measurements still leaves room for NP contributions
- almost all LHCb results dominated by statistical uncertanties
- leading systematic uncertainties will also decrease with increasing statistics

Need more statistics

↓

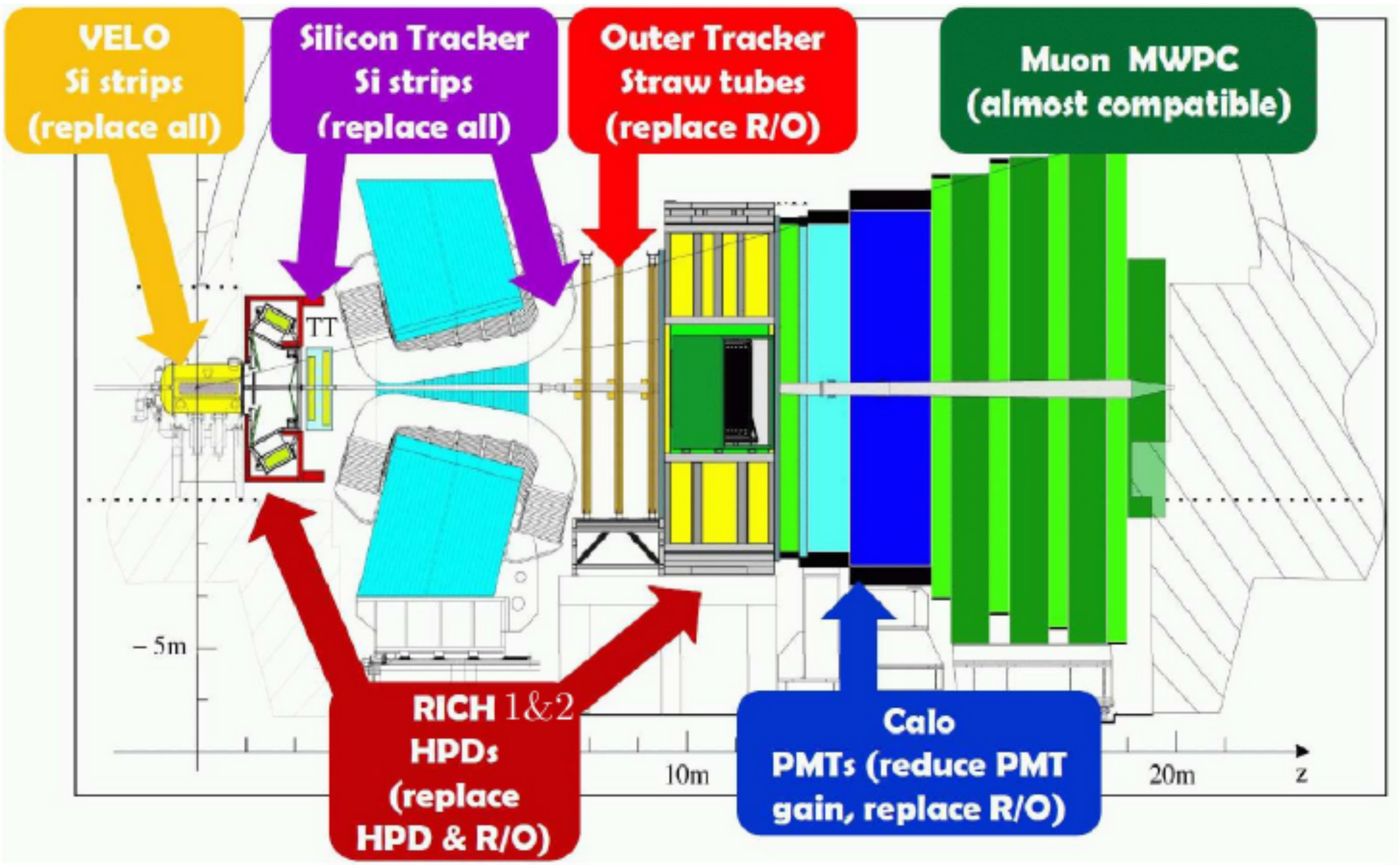
LHCb upgrade

2010	0.037 fb^{-1} @ 7 TeV
2011	1 fb^{-1} @ 7 TeV
2012	2 fb^{-1} @ 7 TeV
2013 2014	LHC S1
2015 2016 2017	5 fb^{-1} @ 13 TeV
2018 2019	LHC LS2, LHCb Upgrade
2020 2021 2022	5fb^{-1} per year

see A. Dosil talk @ red tematica de fisica del LHC

LHCb upgrade (2)

Aim: match theory precision in key observables
How: Software trigger, upgrade all detectors for read-out at 40 MHz
Yield increase: x10(20) in channels with (without) muons



Conclusions

- Many topics not discussed in this talk: CKM γ angle, Λ_b lifetime, spectroscopy …
- Results compatible with SM prediction but still room for NP
- LHCb detector performance is optimal
- Many analyses ongoing

THANK YOU !

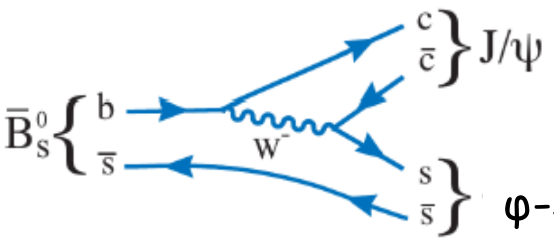
BACKUP

Precision on measurements

Type	Observable	Current precision	LHCb 2018	Upgrade ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s$ ($B_s^0 \to J/\psi\ \phi$)	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s$ ($B_s^0 \to J/\psi\ f_0(980)$)	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\mathrm{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\mathrm{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\ A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	6 %	2 %	7 %
	$A_{\mathrm{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.25 [15]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [16]	8 %	2.5 %	~ 10 %
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	γ ($B \to D^{(*)}K^{(*)}$)	~ 10–12° [19, 20]	4°	0.9°	negligible
	γ ($B_s^0 \to D_s K$)	–	11°	2.0°	negligible
	β ($B^0 \to J/\psi\ K_S^0$)	0.8° [18]	0.6°	0.2°	negligible
Charm CP violation	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–

B_s^0->J/ψ φ

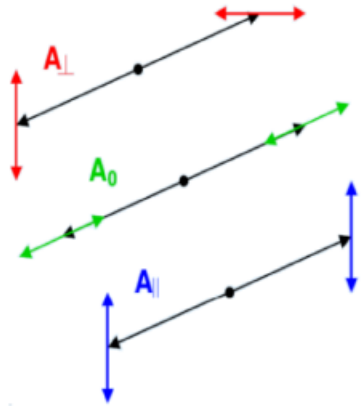
B_s^0 -> J/ψ ($\mu^+ \mu^-$) φ (K^+K^-)



φ->K^+K^-

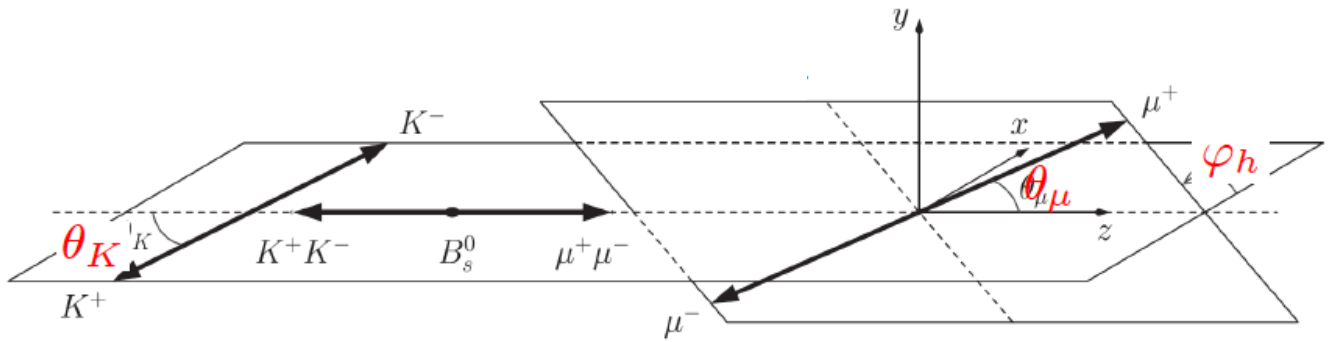
pseudoscalar to two Vector mesons ($J^{PC}=1^{--}$)

- 3 polarization amplitudes and phases needed:
  - $|A_0|^2$, $|A_{||}|^2$, δ_0 , $\delta_{||}$ (CP even)
  - $|A_\perp|^2$, $\delta_\perp$ (CP odd)



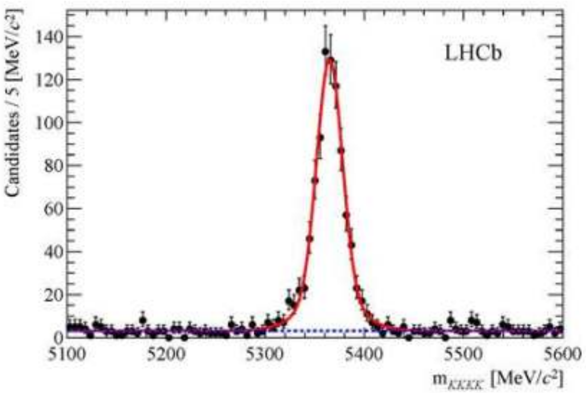
- Additional S-wave component included in the fit
  - $|A_S|^2$, δ_S (CP odd)

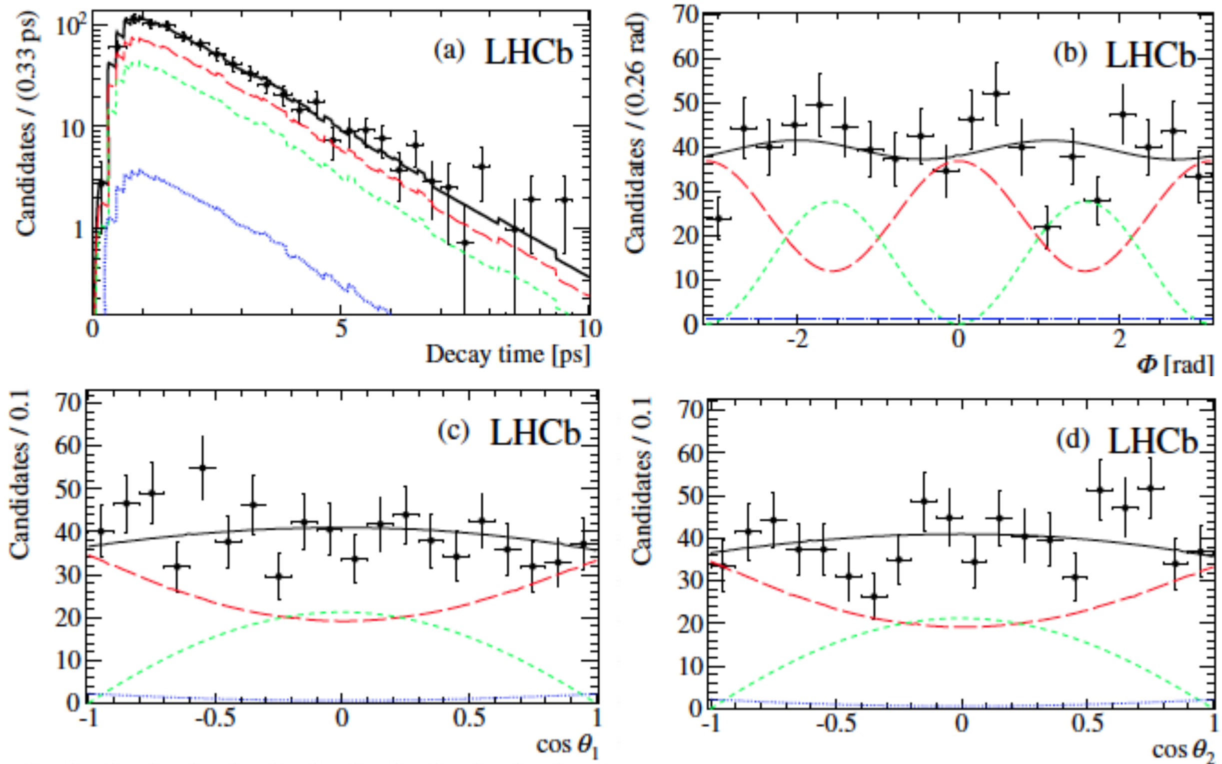
- Time dependent angular analysis is needed



See P. Alvarez Cartelle talk @ red tematica de fisica del LHC and C. Vazquez Sierra talk @ red de fisica del sabor

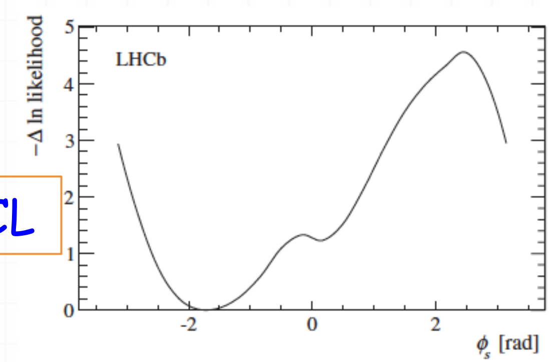
$B_s^0 \to \varphi\varphi$: Time dependent analysis





- analysis with $1 fb^{-1}$ of $\sqrt{s}=7$ TeV 2011 data
- about 1200 candidates
- time dependent analysis
- S-wave component found to be compatible with zero

$\varphi^{s\bar{s}s}$ [-2.37, -0.92] (0.22) (syst) at 68% CL

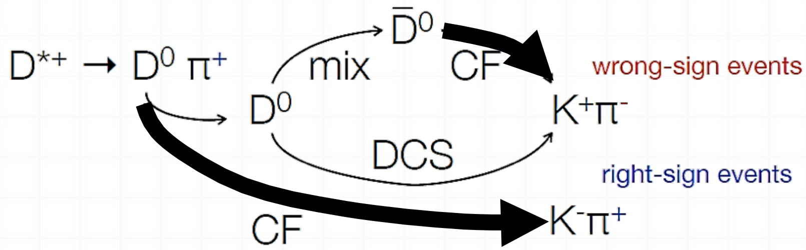


Compatible with SM !

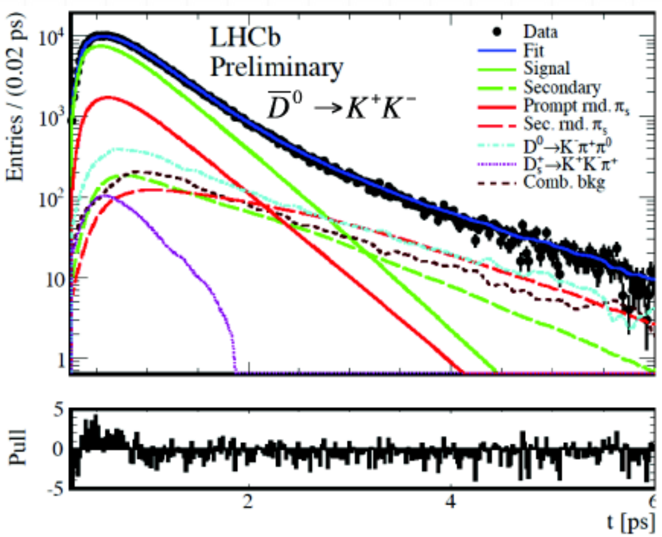
see B. Sanmartin Sedes talk @ red de fisica del sabor

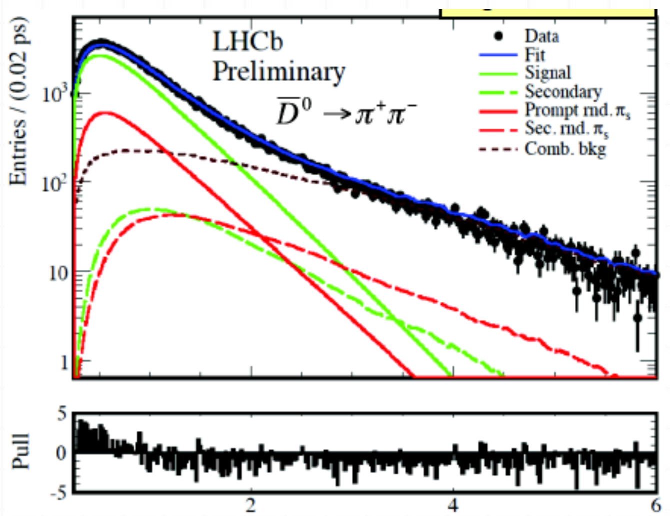
Results on A_Γ

- Use π^+_s in $D^{*+} \to D^0[K^-\pi^+]\,\pi^+_s$ to tag initial flavor of D^0



$$A_\Gamma = \frac{\tau(\bar{D}^0 \to f) - \tau(D^0 \to f)}{\tau(\bar{D}^0 \to f) + \tau(D^0 \to f)}$$





Results:

$A_\Gamma(KK) = (-0.35 \pm 0.62\ (\text{stat}))\times 10^{-3}$

$A_\Gamma(\pi\pi) = (\ 0.35 \pm 1.06\ (\text{stat}))\times 10^{-3}$

Results compatible with CP conservation as expected in the SM

CPV in the charm sector

- CPV in the charm sector predicted to be very small ($\sim 10^{-4}$)
- Production and detection asymmetries hard to control at this level, thus careful choise of the observables needed to minimize systematics
- New Physics can enhance CPV observables
- Observation of CP asymmetry in the charm sector provides a unique probe of physics beyond the Standard Model

1. time evolution of DCS decay $D^0 \to K^- \pi^+$ (mixing parameters)
2. $A_{CP}(D^0 \to K^- \pi^+)$ (direct and indirect CPV)
3. asymmetries in lifetime difference (indirect CPV)

$$A_\Gamma = \frac{\tau(\bar{D}^0 \to f) - \tau(D^0 \to f)}{\tau(\bar{D}^0 \to f) + \tau(D^0 \to f)}$$

[arXiv:1310.7201]

4. $$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) \approx \Delta A_{dir}(1 + y_{CP}\frac{<t>}{\tau}) + \Delta A_{ind}\frac{\Delta <t>}{\tau}$$ (mainly direct CPV)

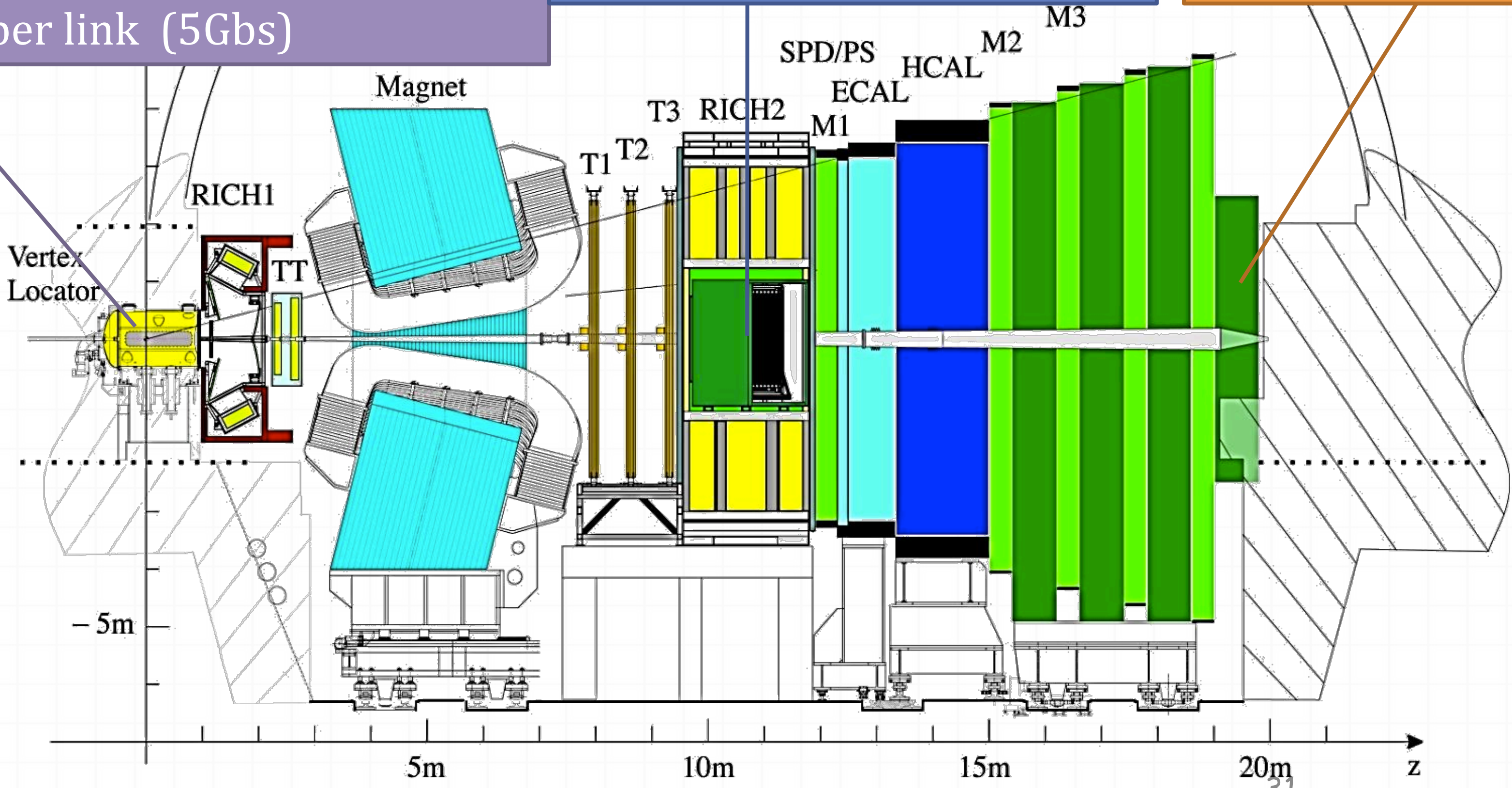
LHCb upgrade(2)

Replace. 2 options: strips or pixel
Santiago:
- **Pixel:** thinning, slim edges, rad had, tile construction
- **Micro-strip:** sensor design, prototyping and testing
- High-speed radiation hard cooper link (5Gbs)

To be upgraded

Replace. Outer straw tubes
Inner: strips or **fibers.**
Barcelona:
input stage, shaper for FE ASIC

Decrease PMT gain → lower noise tolerance in R/O electronics.
Barcelona: preamp and integrator for FE ASIC

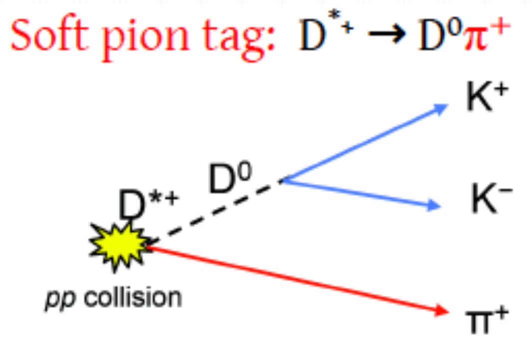


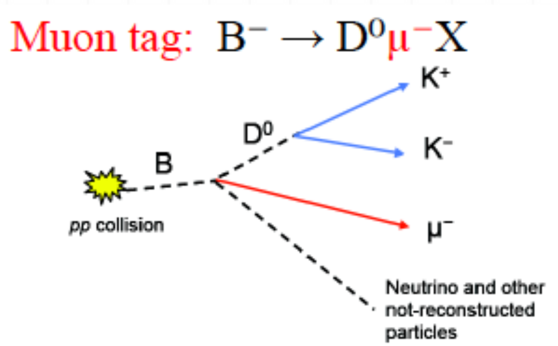
Results on ΔA_{CP}

- Two analyses, with largely independent systematics

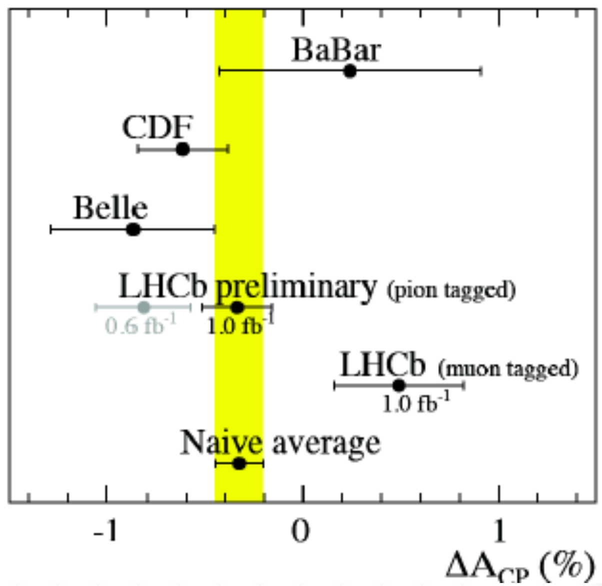
LHCb-CONF-2013-003

[PLB 723 (2013) 33-34]





- Prompt analysis (soft pion tag) :
  - ΔA_{CP} = (-0.34 ± 0.15 (stat) ± 0.10 (syst))%
- Semi-leptonic analysis (muon tag) :
  - ΔA_{CP} = (0.49 ± 0.30 (stat) ± 0.14 (syst))%

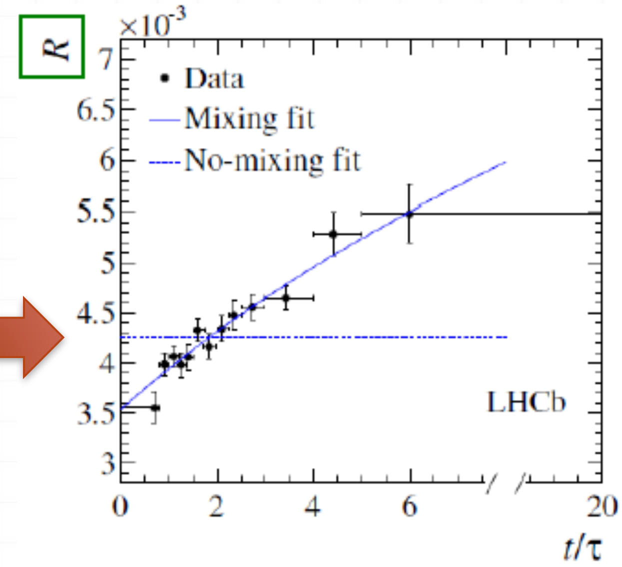


Results on mixing and CPV in DCS $D^0 \to K^-\pi^+$

- Use π^+_s in $D^{*+} \to D^0[K^-\pi^+]\,\pi^+_s$ to tag initial flavor of D^0

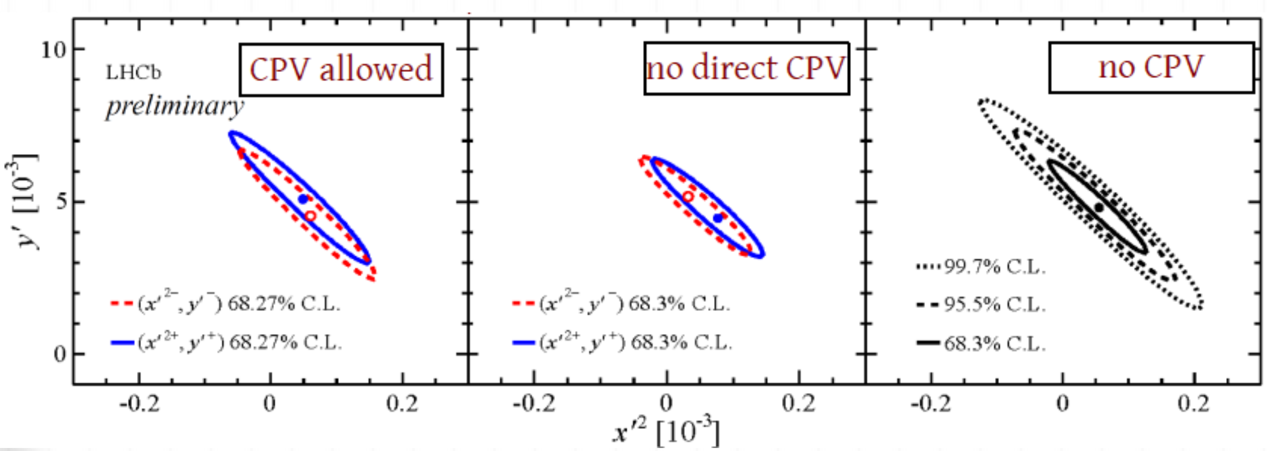
$$R(t) = \frac{N_{WS}(t)}{N_{RS}(t)}$$

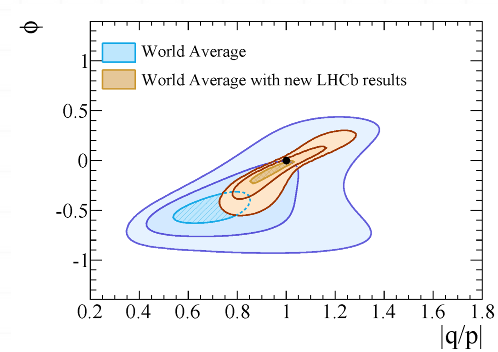
WS: DCS $D^0 \to K^-\pi^+$
RS: CF $D^0 \to K^+\pi^-$



No mixing scenario excluded at **9.1σ**

…but consistent with CP conservation





$B_{(s)}^0$ -> VV decays:

- $B_s^0 \to J/\psi\ \varphi$
- $B_{(s)}^0 \to J/\psi K^{*0}(892)$
- $B_s^0 \to \varphi\varphi$
- $B_{(s)}^0 \to \varphi \bar{K}^{*0}$
- $B_{(s)}^0 \to K^{*0}\bar{K}^{*0}$
- …

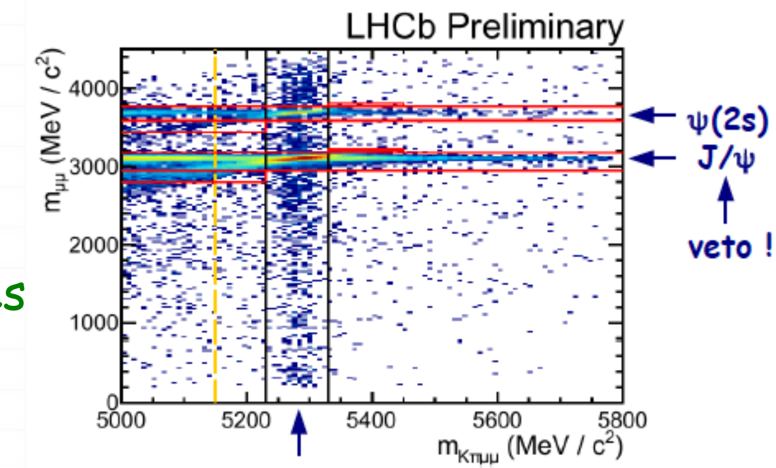
Rare decays: $B^0 \to K^{*0}(892)\, \mu^+ \mu^-$ (2)

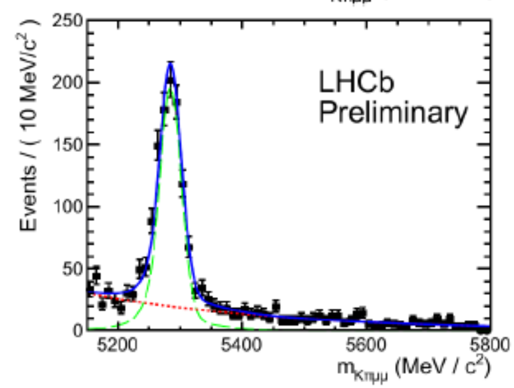
- ~ **900** signal events from **1 fb^{-1}** of 2011 data at at $\sqrt{s}$=7TeV

- BDT:
  - Track quality criteria
  - Kinematic and topological event properties

- Veto in $\mu^+ \mu^-$ mass windows around J/Ψ and $\Psi(2s)$ to supress backgrounds from $B^0 \to J/\Psi\, K^{*0}$ and $B^0 \to \Psi(2s)\, K^{*0}$

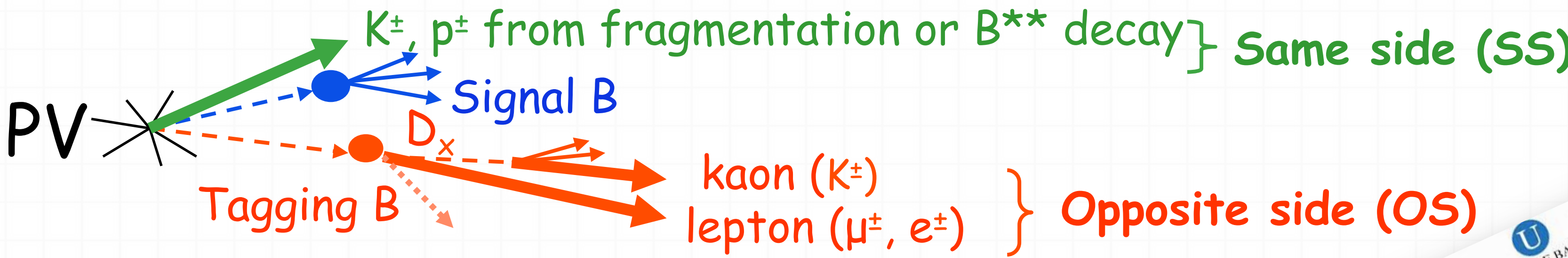
- Large sample of $B^0 \to J/\Psi\, (\mu^+ \mu^-)\, K^{*0}$ used to train the BDT. Also, ideal control sample to study angular acceptance effects





Oscillations: $B_s^0 \to D_s^- \pi^+$

The **B-tagging** (identification of the B flavour at production) is implemented trough two algorithms:

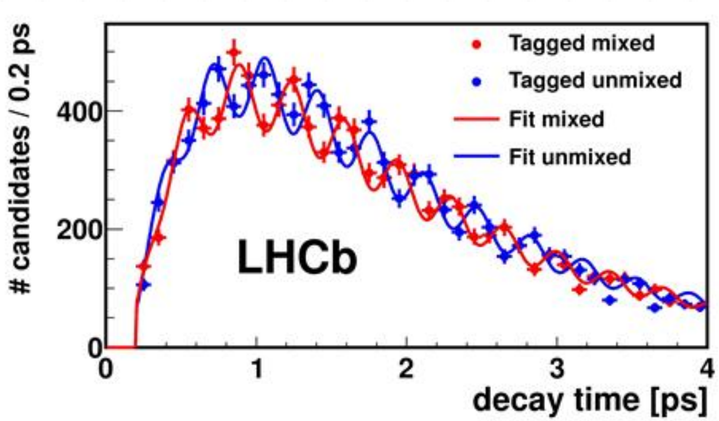


Effective tagging efficiency : → $\varepsilon_{eff} = \varepsilon\,(1-2\omega)^2$

ε : tagging efficiency ~20 %

ω : mistag probability ~30%

$B_s^0 \to D_s^- \pi^+$ decays are analyzed:



- 34000 $B_s^0 \to D_s^- \pi^+$ candidates using 1 fb^{-1} of 2011 data at $\sqrt{s}$=7TeV
- Δm_s = 17.768 ± 0.023(stat) ± 0.006(syst) ps^{-1}
- ε_{eff} = (2.6 ± 0.4)% for SS
- ε_{eff} = (1.2 ± 0.3)% for OS

Rare decays: $B^0 \rightarrow K^{*0}(892)\, \mu^+ \mu^-$ (2)

- Decay rate

$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_l d\cos\theta_k d\varphi dq^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_k + F_L\cos^2\theta_k + \frac{1}{4}(1-F_L)\sin^2\theta_k\cos(2\theta_l) - F_L\cos^2\theta_k\cos(2\theta_l) + S_3\sin^2\theta_k\sin^2\theta_l\cos(2\varphi)$$
$$+ S_4\sin(2\theta_k)\sin(2\theta_l)\cos\varphi + S_5\sin(2\theta_k)\sin\theta_l\cos\varphi + S_6\sin^2\theta_k\cos\theta_l + S_7\sin(2\theta_k)\sin\theta_l\sin\varphi + S_8\sin(2\theta_k)\sin(2\theta_l)\sin\varphi + S_9\sin^2\theta_k\sin^2\theta_l\sin(2\varphi)\Big]$$

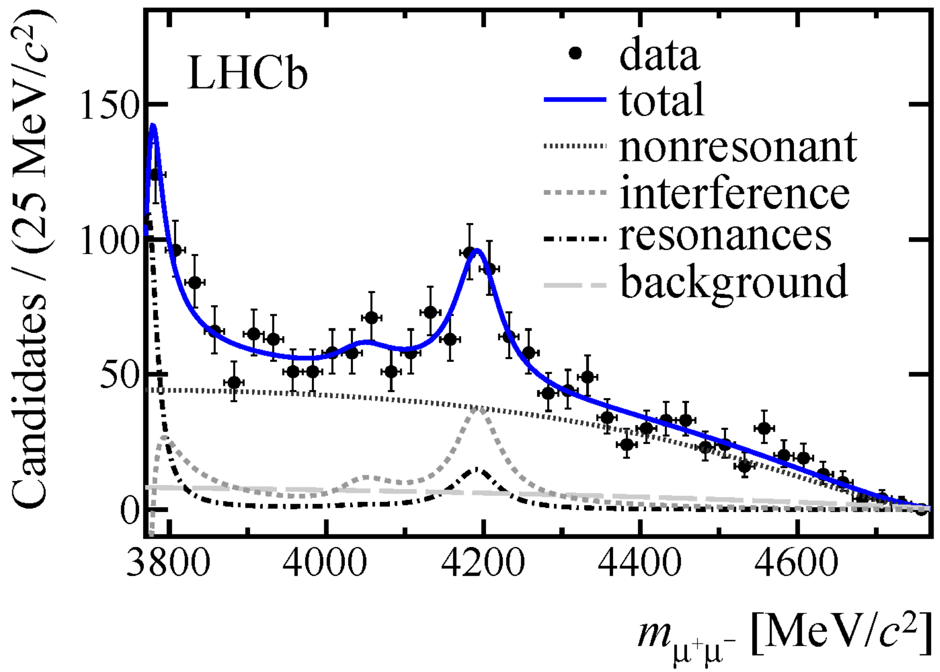
- F_L , S_i , i=3,…,9 . The observables we want to study are linear combination of these. They depend on the Wilson coefficients

$$P'_{4,5,6,8} = \frac{S_{4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$

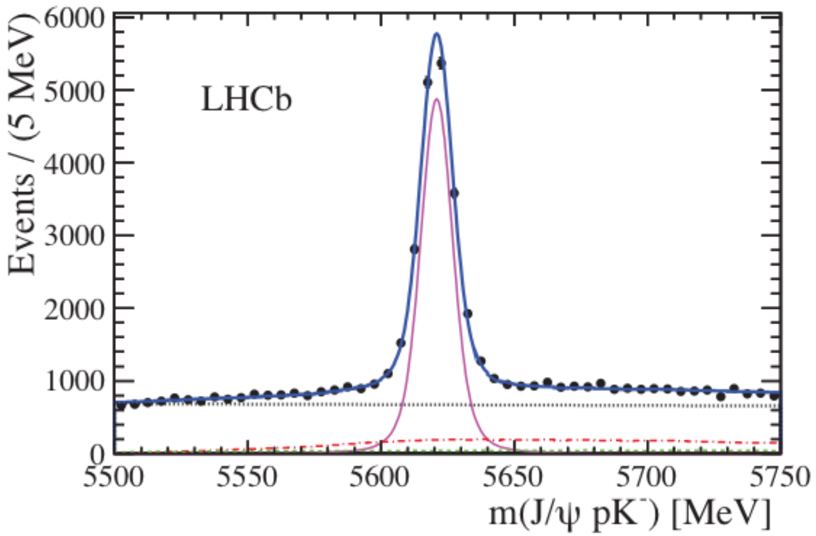
- F_L : K^{*0} longitudinal polarization fraction

- Event sample not (yet) large enough to fit all observables simultaneously
  - Apply "folding techniche" exploiting (anti)-simmetry of sin/cos functions
    i.e.: replacing $\varphi \rightarrow \varphi+\pi$ for $\varphi < 0$ cancels terms with S_4, S_5, S_7, S_8

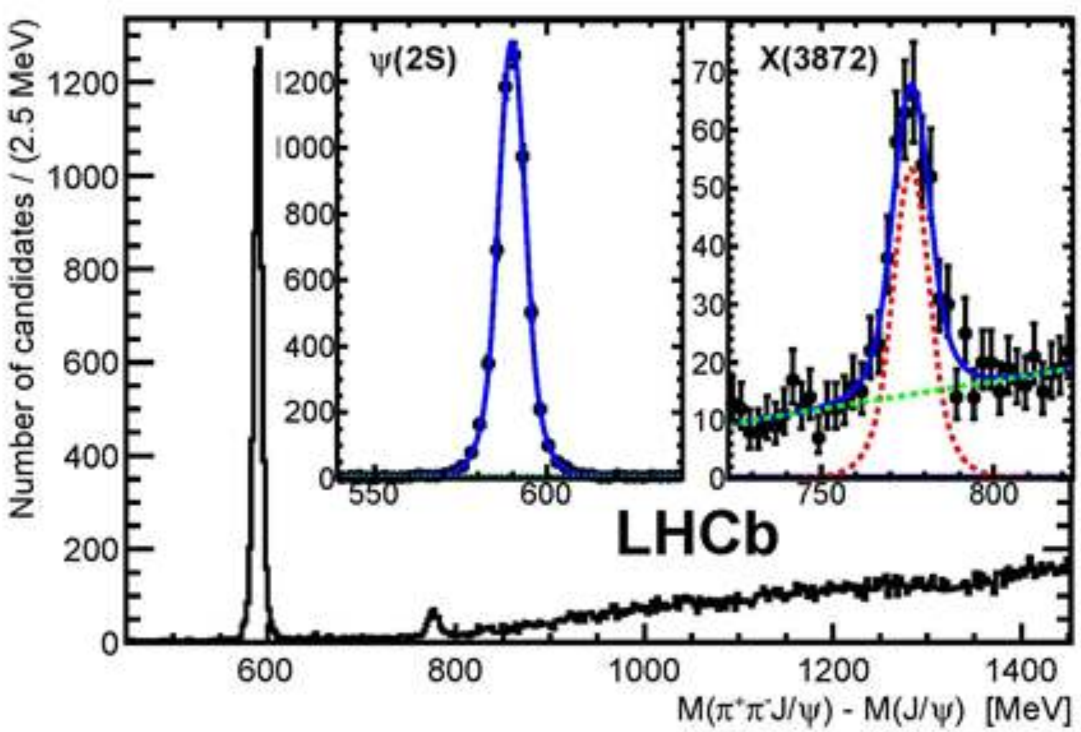
Unspected resonance in B -> K mu mu



Lambda_b


LHCb
Events / (5 MeV)
6000
5000
4000
3000
2000
1000
0
5500
5550
5600
5650
5700
5750
m(J/ψ pK⁻) [MeV]

X(3872)


ψ(2S)
X(3872)
LHCb
Number of candidates / (2.5 MeV)
M(π⁺π⁻J/ψ) - M(J/ψ) [MeV]
0
200
400
600
800
1000
1200
600
800
1000
1200
1400
550
600
750
800
10
20
30
40
50
60
70

XXX

XXX

OSCILLATIONS:

$B_s^0 \rightarrow D_s^- \pi^+$

Rare decays:

- $B_s^0 \to \mu^+\mu^-$
- $B^0 \to K^{*0}\mu^+\mu^-$
- $b \to s\,\gamma$

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Direct CP asymmetry: $B_s^0 \to K^- \pi^+$

B -> VV' angular analyses

Measurement of φ_s at LHCb

CPV in the charm sector

LHCb upgrade