Recent LHCb Results

On behalf of the LHCb collaboration

Phenomenology-2012 Symposium
Pittsburgh, U.S.A.

Science & Technology Facilities Council
RAL

Sajan Easo
May 8, 2012

Recent LHCb Results

- Introduction
  - LHCb detector, Performance of its sub systems
- Focus on results from
  - Rare decay channels $B_s \rightarrow \mu\mu$, $B_d \rightarrow K^* \mu\mu$
  - Mixing induced CP violation in $B_s \rightarrow J/\psi\ \phi$
  - CP violation in $B^+ \rightarrow D\ K$

Most results from full 2011 dataset

- Other selected results
- Summary

More Info

- 8 LHCb presentations in parallel sessions
- lhcb.cern.ch

Beauty and Charm production at LHC

- Huge production of b and c at $\sqrt{s} = 7\ \text{TeV}$
  LHCb measured :

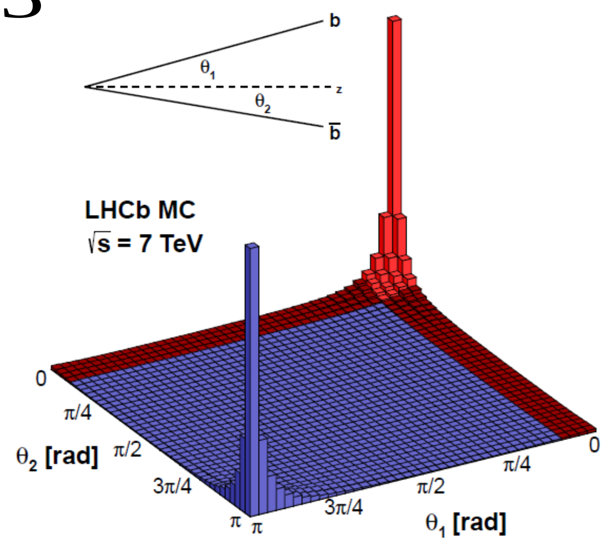
$$\sigma(pp \to b\bar{b}X) = (284 \pm 20 \pm 49)\ \mu b$$

$$\sigma(pp \to c\bar{c}X) = (6.10 \pm 0.93) mb$$

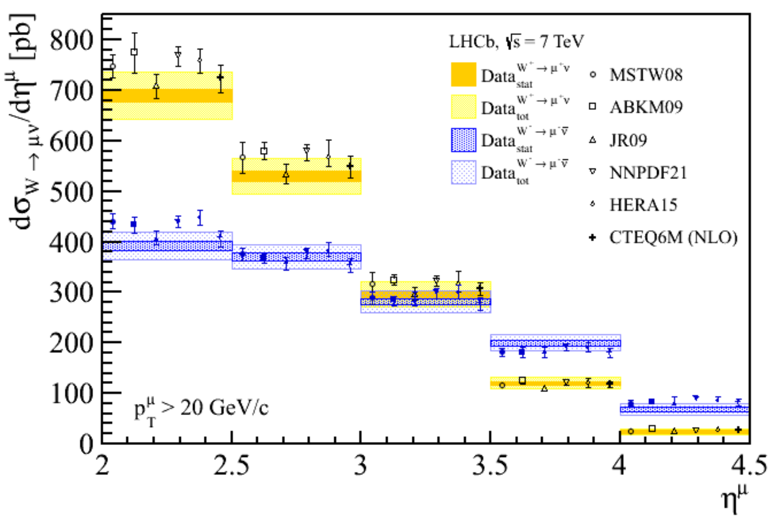
Phys.Lett.B694: 209-216, 2010
LHCb-CONF-2010-013

[preliminary]

- LHCb:
  - Forward spectrometer $2 < \eta < 5$
  - Mainly flavour physics, but not limited to this.



W differential cross-section



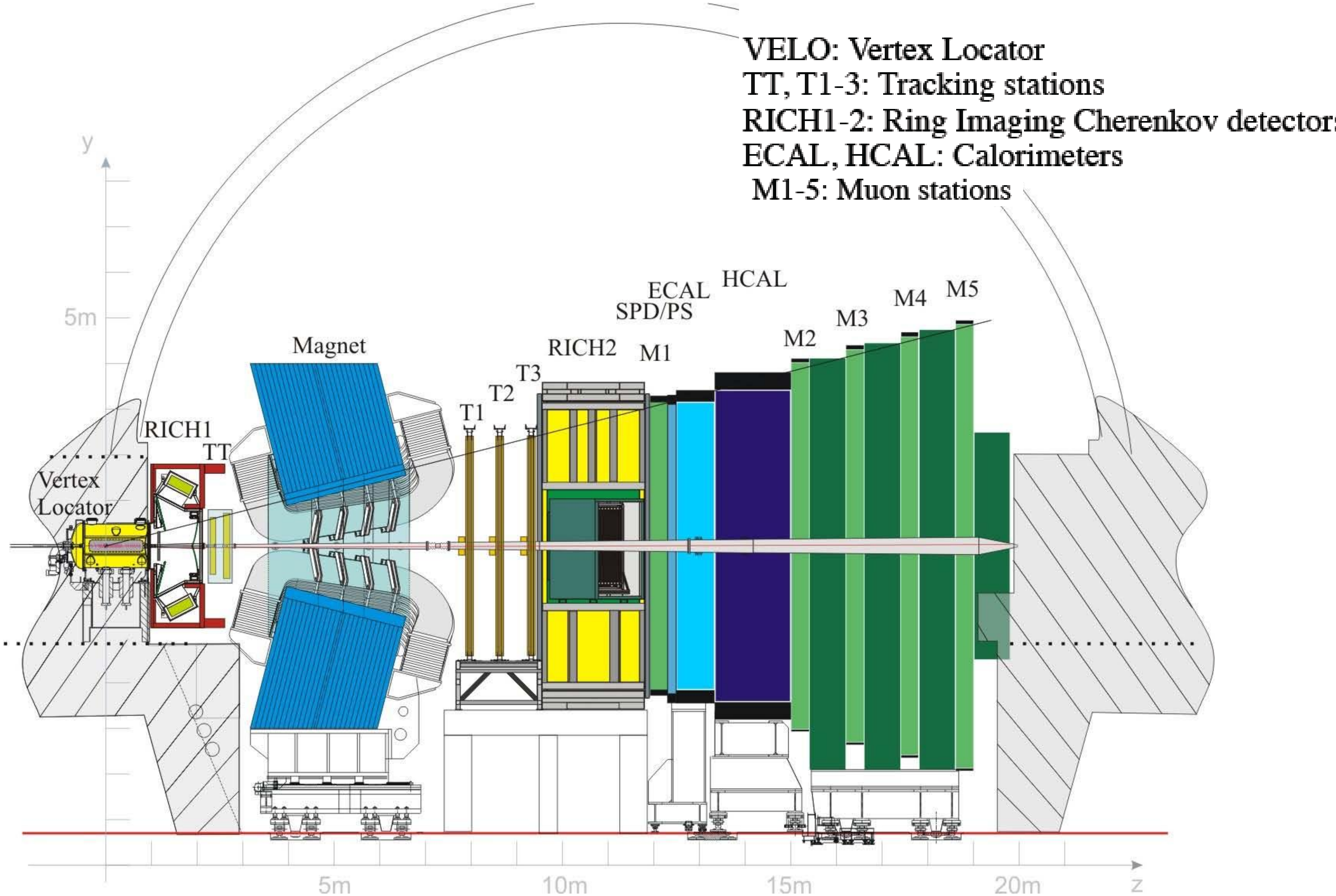
$W^+ \to \mu^+ \nu$

$W^- \to \mu^- \bar{\nu}$

Talk by Philip Ilten in parallel session

LHCb-PAPER-2012-008

LHCb Experiment



~ 760 Members from 55 institutes in 15 countries

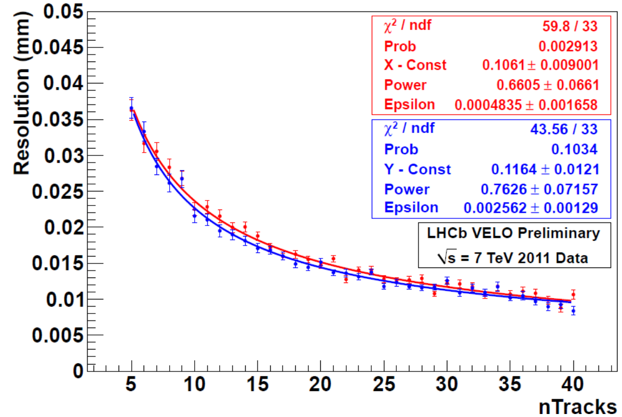
Detectors in LHCb : Velo

- 21 stations measuring R and ϕ coordinates, with silicon strips
- 8 mm from the beam during data taking.

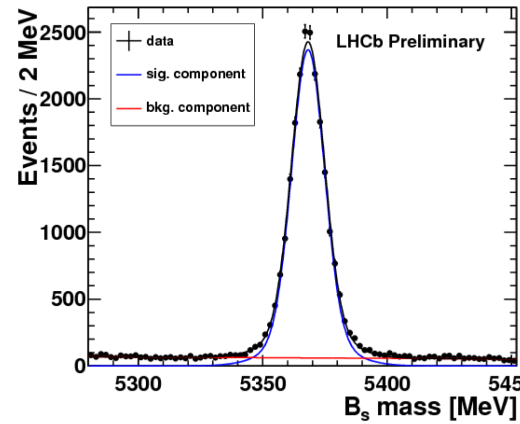
Vertex resolution: for 25 tracks σ_x ~16 μm , σ_y ~ 16 μ m

σ_z ~ 76 μm

April 2012



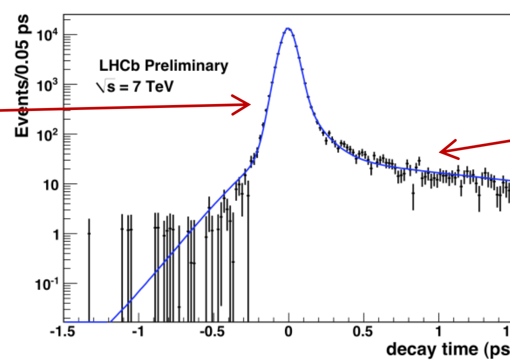
$B_s \to J/\psi\, \phi$



B_s mass resolution=6 MeV/c^2

LHCb-CONF-2012-002

Prompt J/ψ background



$B_s \to J/\Psi\, \phi$

Propertime resolution (Velo+tracking)

Resolution from prompt J/ψ:
σ_t = 45 fs

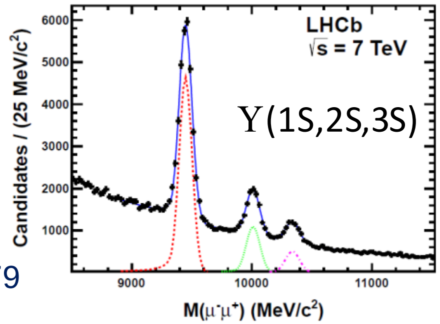
Decay time in $B_s \to J/\psi\, \varphi$

Detectors in LHCb

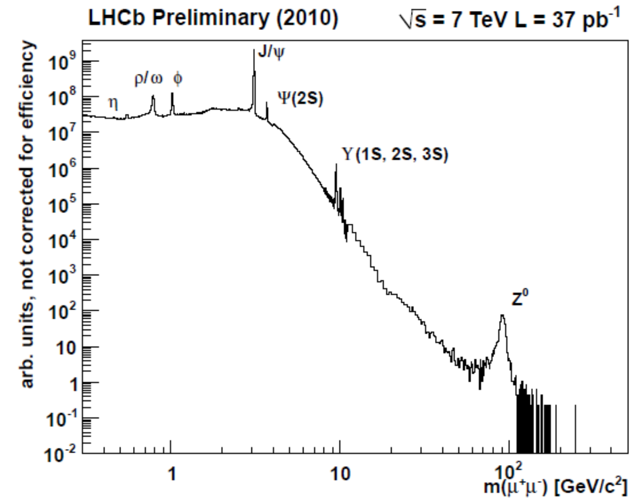
Dimuon mass spectrum

Tracking System:

- Stations upstream and downstream of the magnet.
- Upstream and inner downstream parts: Silicon
- Outer downstream part: Drift chambers
- Magnetic field reversed for different data taking periods.
- Momentum resolution : $\Delta p/p = 0.35 \rightarrow 0.55\ \%$

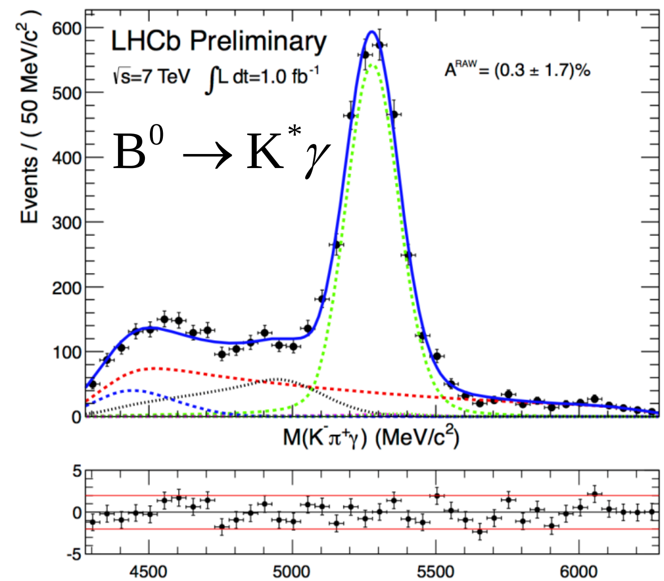


arXiv:1202.6579



Muon Stations:

5 stations, excellent μ/π separation:,
single hadron mis-id rate: 0.7%



LHCb-CONF-2012-004

Calorimeters:

ECAL: Shashlik technology with Pb-Scintillator
$s(E)/E = 10\%/\sqrt{E} + 1\%$

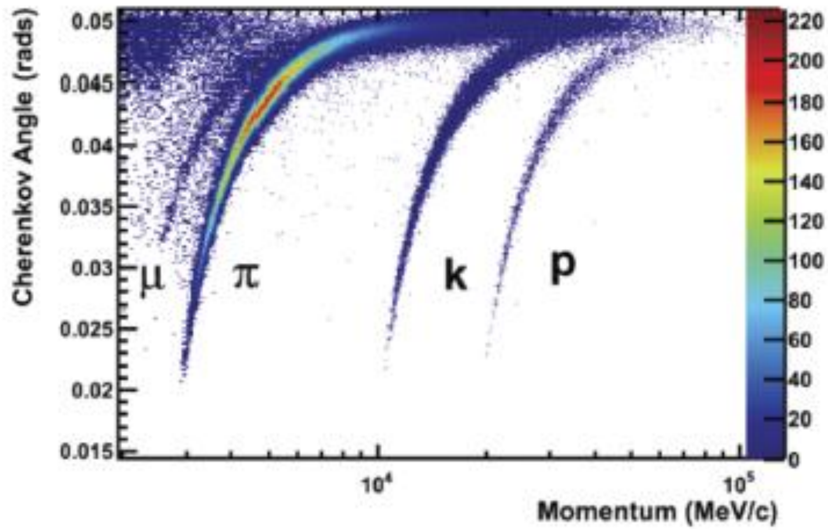
HCAL: Fe-Scintillator, $s(E)/E = 80\%/\sqrt{E} + 10\%$

Detectors in LHCb

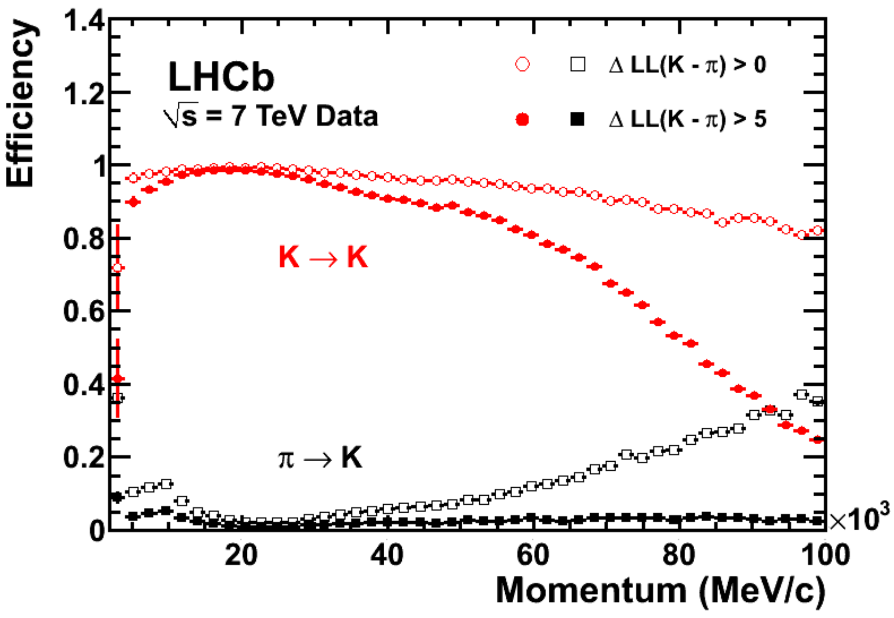
Particle Identification:

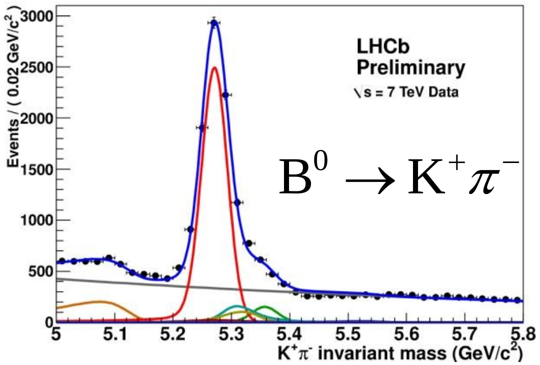
Two RICH detectors covering a momentum range 1-100 GeV/c with 3 radiators: aerogel, $C_4 F_{10}$, CF_4

From RICH1 Gas ($C_4 F_{10}$)



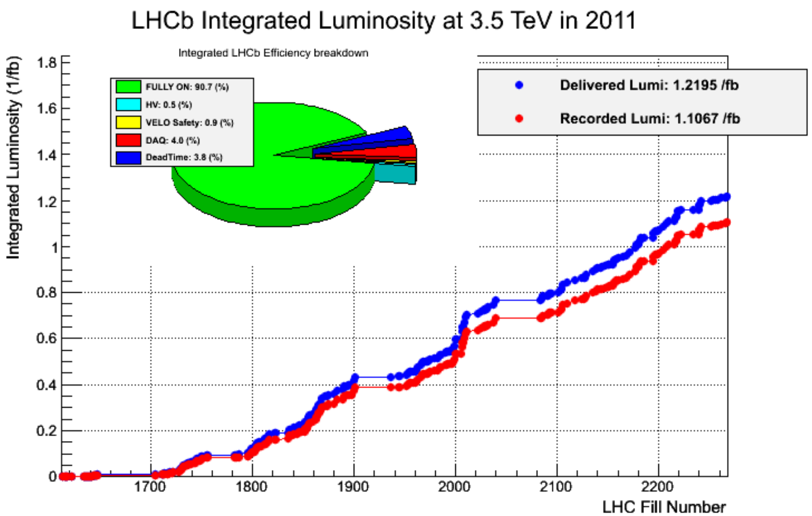
PID performance from calibration data





arXIV:1202.6251

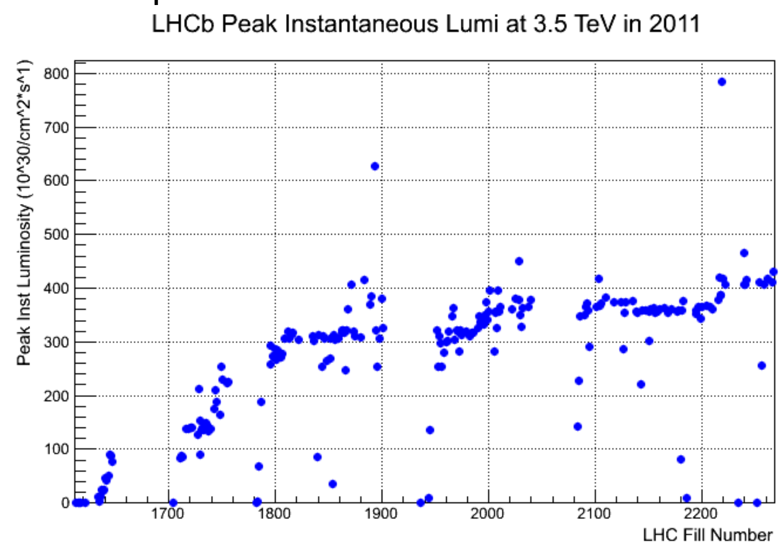
2011 data taking



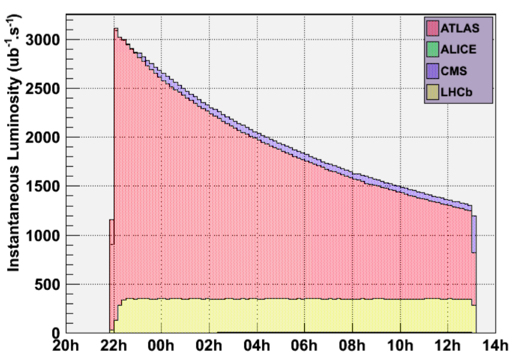
Excellent Efficiency

2011: 1.2 fb $^{-1}$ delivered,
1.1 fb $^{-1}$ recorded
1 fb^{-1} for Physics analysis

2012:
Another 1.5 fb^{-1}
expected with 4 TeV beams



Instantaneous Luminosity levelling at LHCb



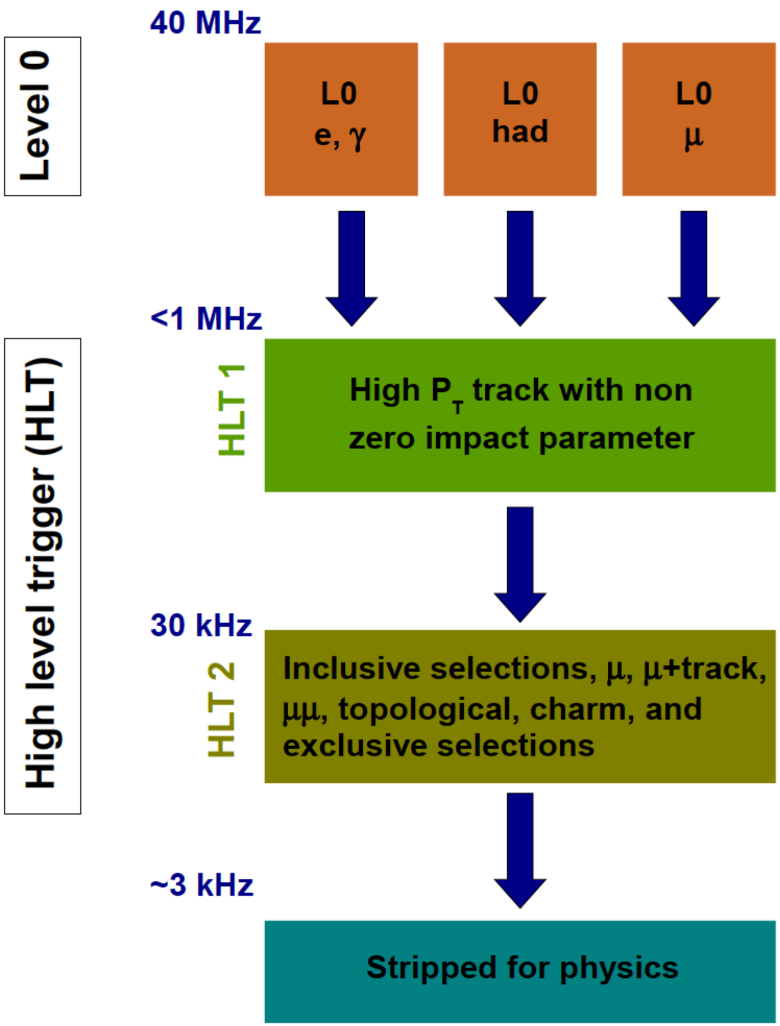
obtained through vertical beam displacements

Luminosity: Design: 2 x 10 ^{32} cm^{-2} s^{-1}
Actual: Typically 3-4 x 10 ^{32} cm^{-2} s^{-1}

Number of visible interactions per bunch crossing(μ): Design 0.4 (max 1.0)
Actual ~ 1.1 (max ~1.6)

We had to cope with higher occupancies than what LHCb was designed for.

LHCb Trigger Scheme



Level0:

- Using custom electronics to reduce the 11 MHz of visible interactions to 1 MHz.
- Select single objects with high P_T (or E_T)
  Typically P_T (μ) > 1 GeV/c,
  E_T (h, e, γ, π^0) > 3-4 GeV

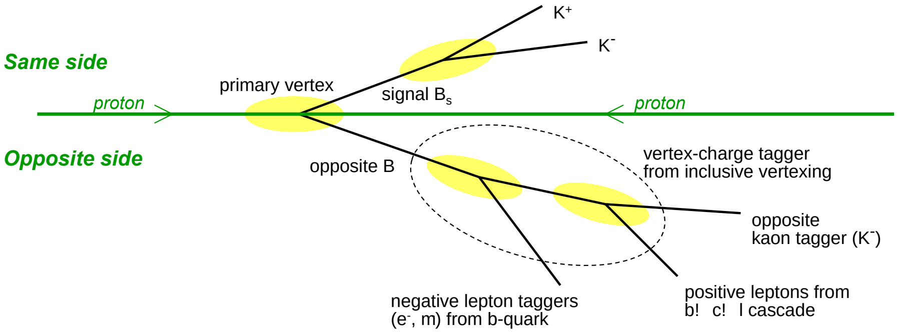
High Level Trigger : Software trigger, flexible

- Farm of 1500 multi-processor units
- Stage 1: Add tracking info,
  impact parameter cuts
- Stage 2: Full reconstruction+selection
  resulting in 3 KHz

LHCb Data Analysis

- Selection of events:
  - Event kinematics+ topology information

    P, P_T of the tracks,
    Vertex quality,
    impact parameters of tracks, etc

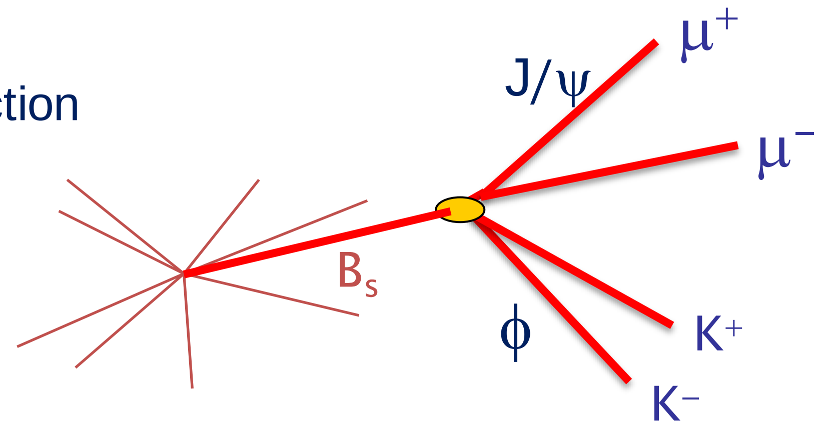


  - PID information
  - Cut based or multivariate selection

    Boosted Decision Tree (BDT),
    Neurobayes etc.

  - Optimize selection

    Using MC data
    Using small sample of real data



- Flavour tagging , if needed

- Various cross-checks with control channels , simulations as appropriate.

LHCb Data Analysis

Indirect search for New Physics (NP)

- Measure FCNC transitions, where NP is likely to emerge
  Example: OPE expansion for b →s transitions

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \sum_i [\underbrace{C_i(\mu) O_i(\mu)}_{\textit{left-handed part}} + \underbrace{C_i^{'}(\mu) O_i^{'}(\mu)}_{\substack{\textit{right-handed part} \\ \text{suppressed in SM}}}]$$

Misiak 93,
Buras, Münz 95

NP may
- modify short-distance Wilson coefficients , $C_i^{'}$
- add new long-distance operators, $O_i^{'}$

- Measure CKM elements in different ways
  Any inconsistency may be a sign of NP

Search for $B_{(s)} \rightarrow \mu^+ \mu^-$

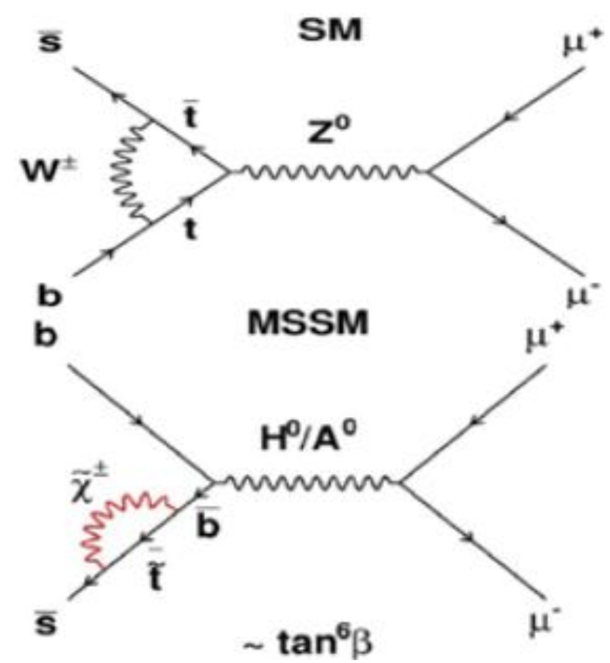
Talk by Xabier Vidal
in parallel session

- Rare decay : FCNC

- Standard Model: Helicity suppressed

  SM Br $(B_s \rightarrow \mu\mu) = (3.2 \pm 0.2) \times 10^{-9}$
  SM Br $(B \rightarrow \mu\mu) = (0.1 \pm 0.01) \times 10^{-9}$
  arXiv:1005.5310, arXiv:1012.1447
  Buras et.al , JHEP 10 (2010) 009

- Branching ratio sensitive to NP
  eg: MSSM with large tan β

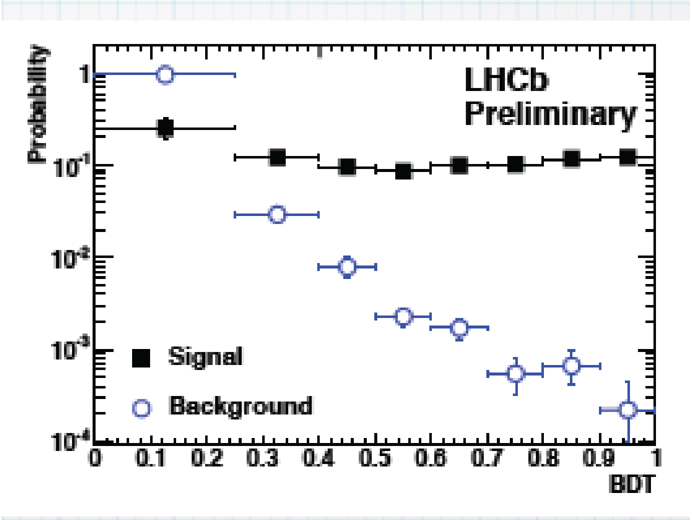


- LHCb used the 1 fb $^{-1}$ of data from 2011 to update the branching fraction limits.

Search for $B_{(s)} \rightarrow \mu^+ \mu^-$

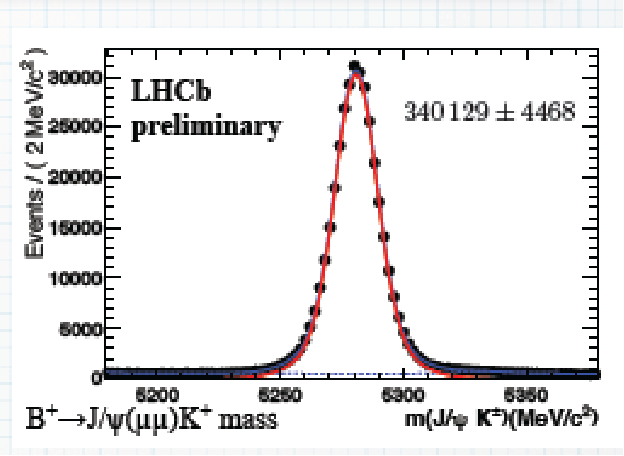
- Event Selection : BDT , verified on calibration channels $B \rightarrow h^+ h^-$ (h= K or π) in data

Signal : $B \rightarrow h^+ h^-$
Background : B_s mass sidebands



- **Branching Fraction:**
  Normalized after similar event selection in $B^+ \rightarrow J/\psi K^+$, $B_s \rightarrow J/\psi \phi$, $B \rightarrow K \pi$

$$B = B_{norm} \times \frac{\mathcal{E}_{norm}}{\mathcal{E}_{sig}} \times \frac{f_{norm}}{f_s} \times \frac{N_{sig}}{N_{norm}}$$

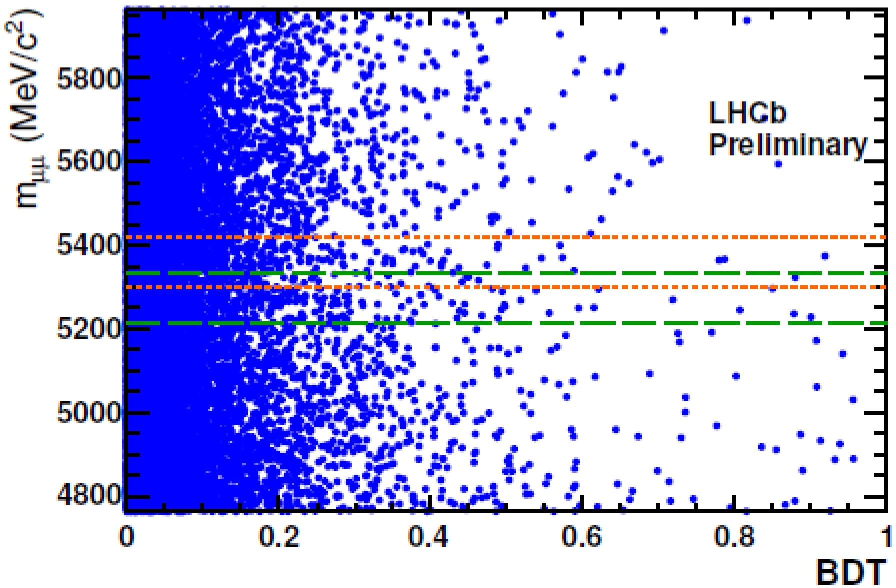


A control channel

LHCb: $f_s / f_d = 0.267^{+0.021}_{-0.020}$

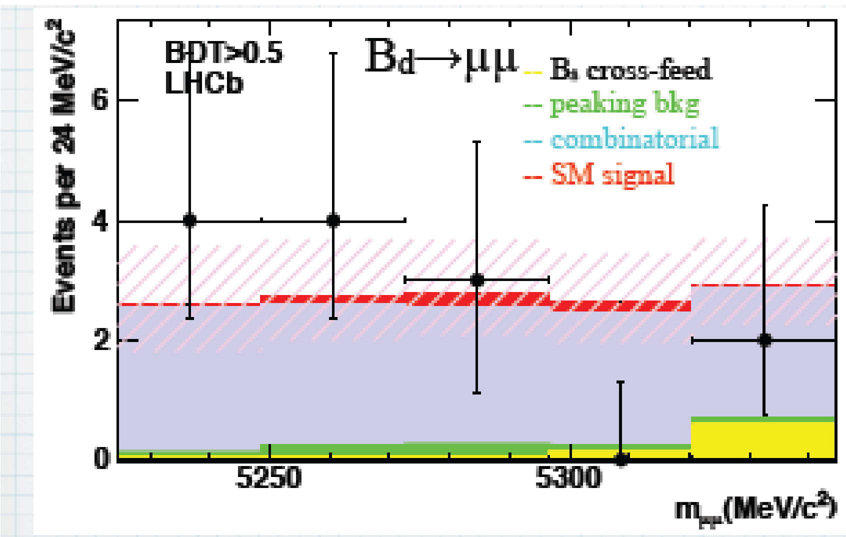
PRL 107(2011)211801

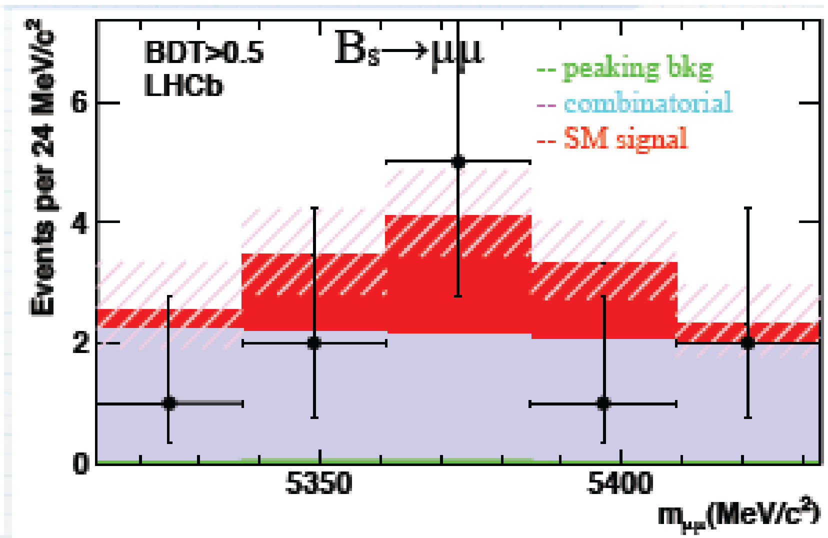
Search for B(s) → $\mu^+ \mu^-$



Branching Fraction :

- Mass vs BDT :
  8 bins in BDT and 9 bins in mass
- Estimate signal and background events in each bin using CLs method.

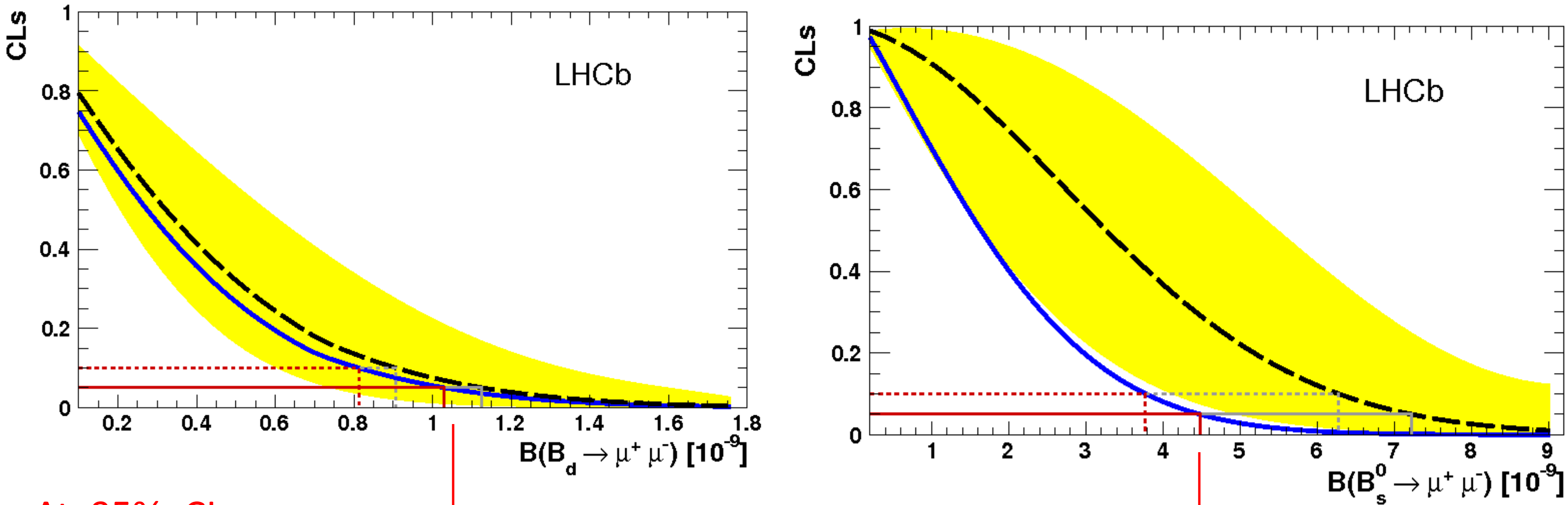




arXiv:1203.4493

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

Branching fraction:



At 95% CL

$$Br(B^0 \to \mu^+\mu^-) < 1.03\times10^{-9}$$

$$Br(B^0_s \to \mu^+\mu^-) < 4.5\times10^{-9}$$

approaching SM

95% CL upperLimit value (all X 10^{-9})	CDF	CMS	ATLAS	LHCb	SM
$Br(B^0 \to \mu^+\mu^-)$	4.6	1.8		1.03	0.1±0.01
$Br(B^0_s \to \mu^+\mu^-)$	31 13^{+9}_{-7}	7.7	22	4.5 $0.8^{+1.8}_{-1.3}$	3.2 ±0.2

Electroweak penguin decays

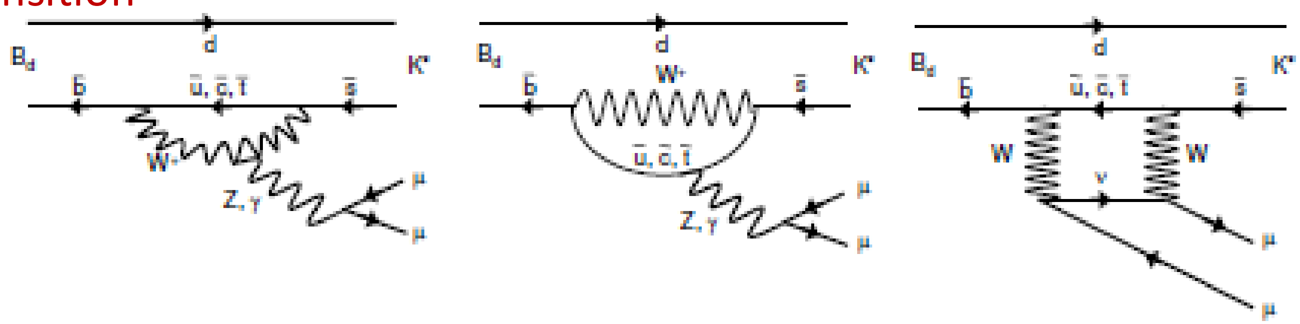
Talk by Gregory Ciezarek in parallel session

- Mediated by loop diagrams in SM and can have contributions from New Physics (NP).

$$B^0 \to K^* \mu^+ \mu^-$$

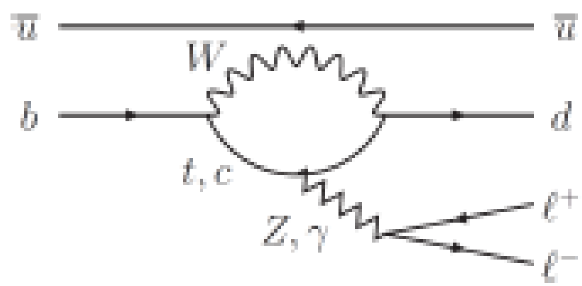
Angular analysis performed

b → s ll transition



$$B^+ \to \pi^+ \mu^+ \mu^-$$

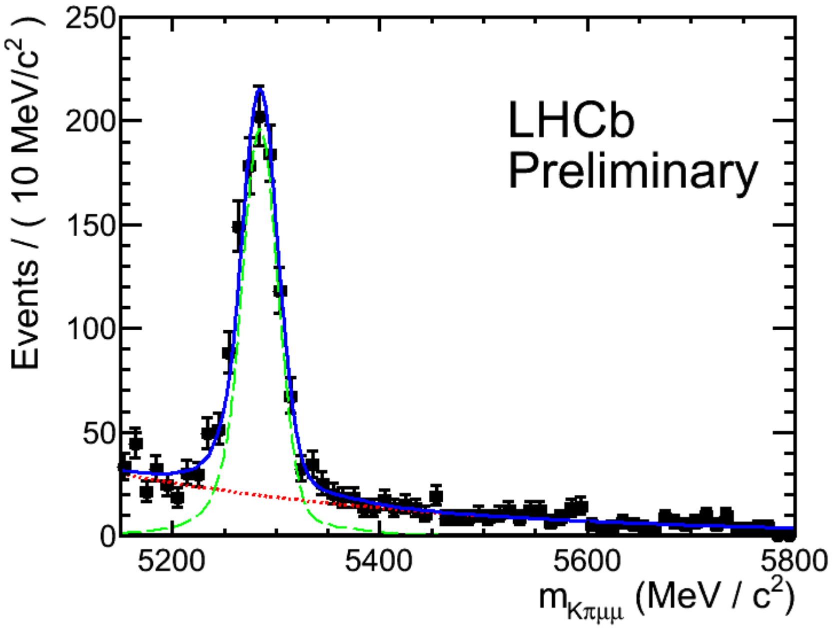
b→dll transition



$$B^0 \to K^* \mu^+ \mu^-$$

Analysis Strategy:

- Final selection : BDT trained on real data from 2010
  J/ψ K^{*0} as proxy for 'training signal' and
  upper mass side band of K^* $\mu\mu$ as background



LHCb-CONF-2012-008

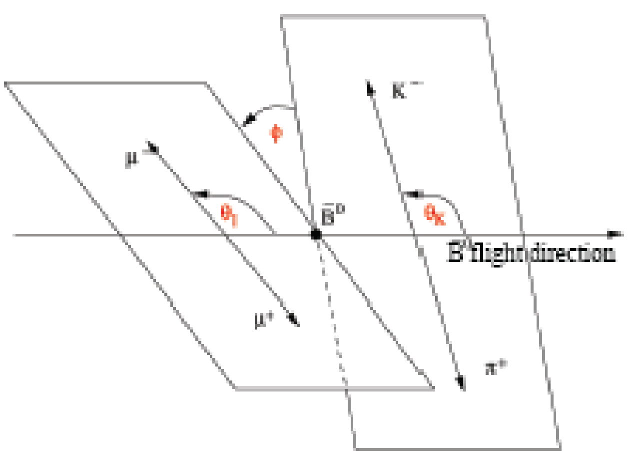
900 ± 34 events, S/B ~ 4
from 1 fb^{-1} of data in 2011 after
removing various backgrounds

$B^0 \to K^* \mu^+ \mu^-$

LHCb-CONF-2012-008
Moriond QCD conference

Differential branching fraction in terms of $q^2 = m^2_{\mu\mu}$ and θ_l , θ_k , ϕ

$$\frac{d^4\Gamma}{d\cos\theta_\ell \, d\cos\theta_K \, d\phi \, dq^2} \propto F_L \cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K) + F_L \cos^2\theta_K (2\cos^2\theta_\ell) + \frac{1}{4}(1-F_L)(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) + S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\phi + \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_\ell + A_{Im}(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\phi$$

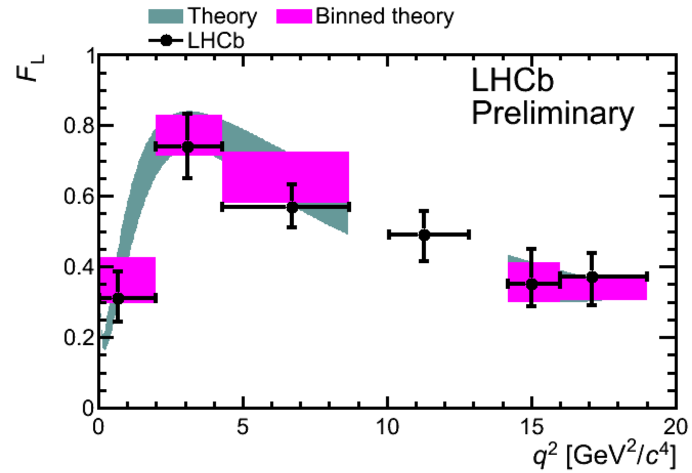


(Notations from arXiv:0811.1214)

Fit the mass ($K^+\pi^-\mu^+\mu^-$) and the angular distribution to extract observables:

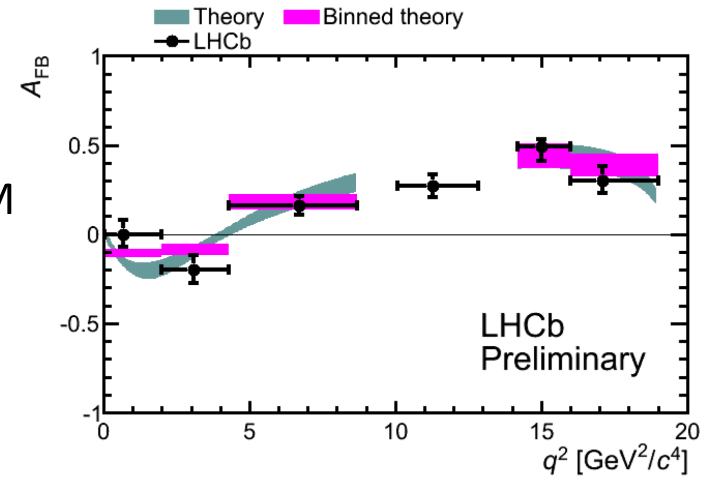
- F_L : Fraction of K^* longitudinal polarization
- A_{FB} : Forward backward asymmetry
- S_3 : A_T^2 $(1-F_L)$ with A_T = asymmetry in K^* transverse polarization
- A_{IM} : a T-odd Cp symmetry

$B^0 \to K^* \mu^+ \mu^-$

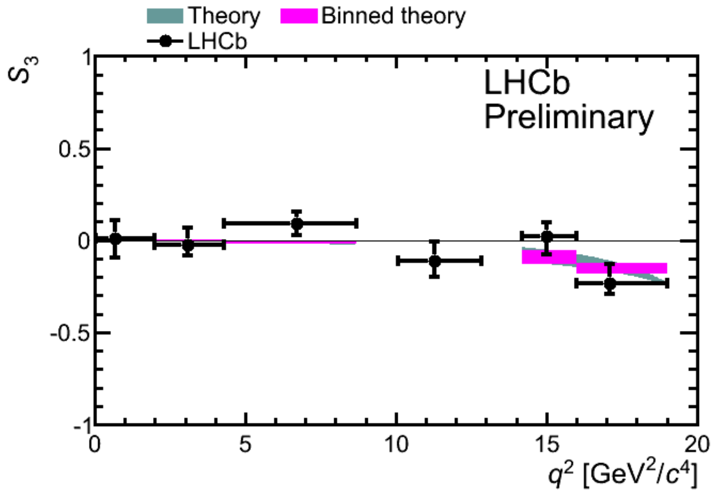


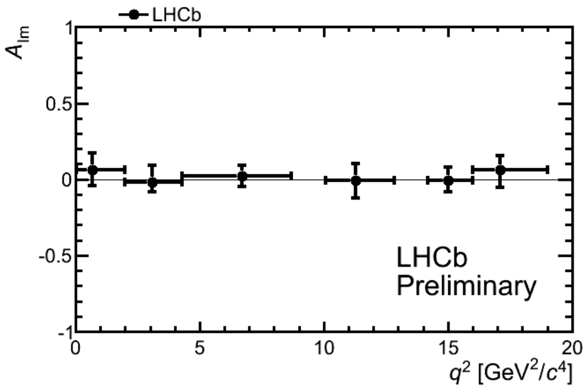
- Data in 6 bins of q^2
- Performed an unbinned max. likelihood fit to determine the observables.

- Data points at the average q^2 in each bin. Error bars include systematic errors.



- These are consistent with the prediction from SM (C.Bobeth et al. JHEP 07)





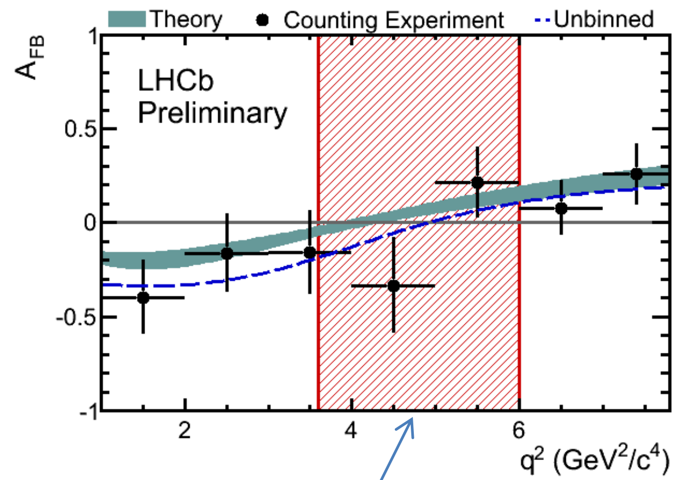
$B^0 \to K^* \mu^+ \mu^-$

- Zero crossing point of A_{FB} vs q^2

  Extracted from unbinned maximumlikelihood 2D fits to the $m_{K\pi\mu\mu}$ and q^2 distributions of B_d candidates in forward and backward going events.
  (using q^2 in the range 1→7.8 GeV^2 /c^4)

$$q_0^2 = 4.9^{1.1}_{-1.3}\,\mathrm{GeV}^2/c^4$$

- This is consistent with SM predictions : 4 - 4.3 GeV^2 /c^4
  [arXiv:1105.0376, Eur. Phys. J. C 41 (2005) 173-188, C47 (2006) 625-641]

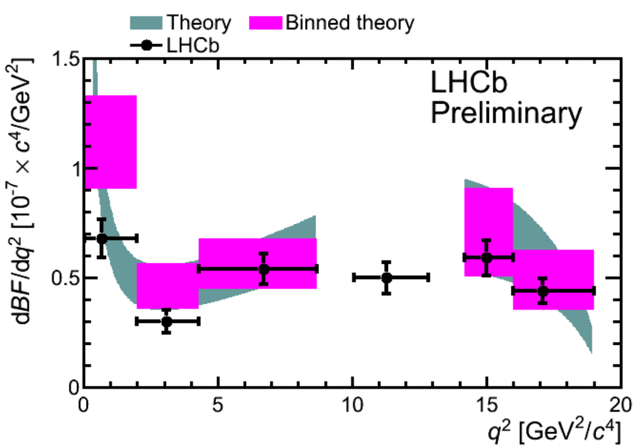


68% confidence interval in Zero crossing point from data.

LHCb-CONF-2012-089
Moriond QCD conference

- Branching fraction: normalised to

$$B^0 \to J/\psi K^*$$



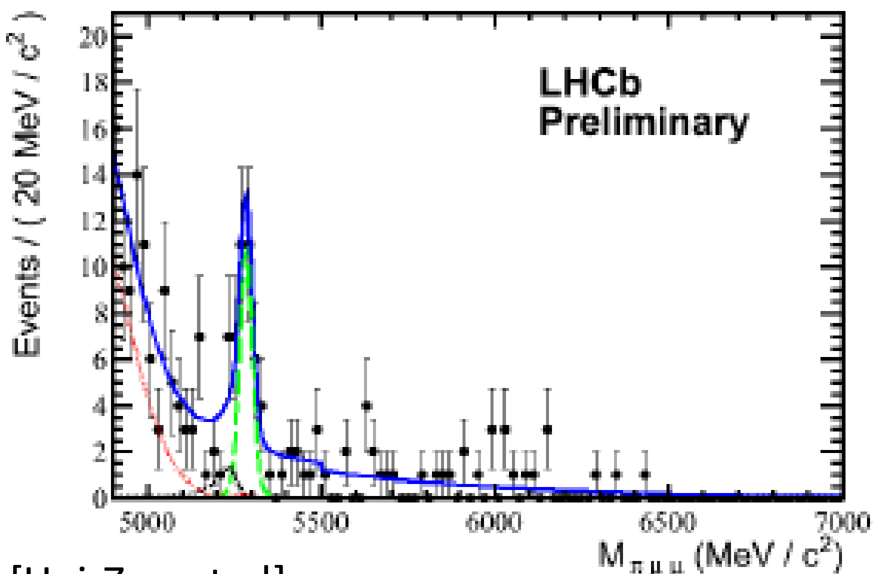
$B^+ \to \pi^+ \mu^+ \mu^-$

LHCb-CONF-2012-006
Moriond QCD Conference

- b → dll suppressed compared to b→sll by $\left| \frac{V_{td}}{V_{ts}} \right|$
- Selection used BDT calibrated on
  $B^+ \to J/\psi \pi^+$
  and $B^+ \to J/\psi K^+$
- Branching fraction (BF) normalized to $B^+ \to J/\psi K^+$

$25.3^{+6.7}_{-6.4}$ candidates of $B^+ \to \pi^+ \mu^+ \mu^-$

$$BF = (2.4 \pm 0.6(\text{stat}) \pm 0.2(\text{sys})) \times 10^{-8}$$



[Hai-Zen et.al]

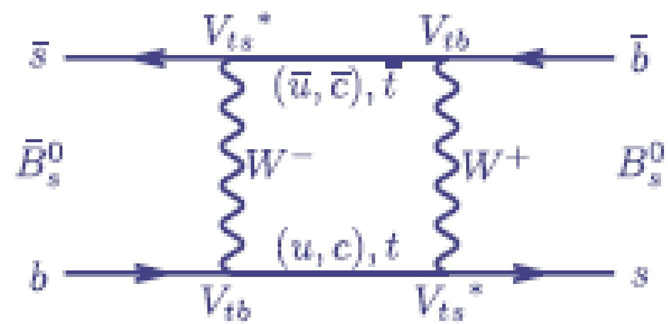
This is consistent with SM:

$$(1.96 \pm 0.21) \times 10^{-8}$$

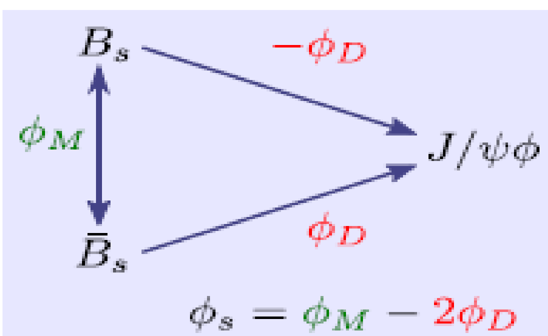
"The rarest B decay ever observed"
CERN COURIER May 2012

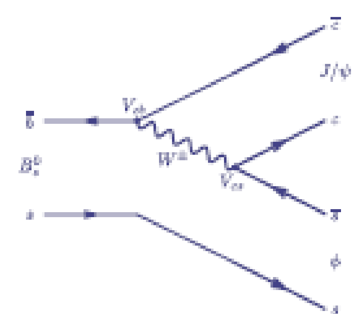
CP violation measurements

- CP violation from interference between B_s mixing and decay to the same final state.
- Recent measurements of ϕ_s from $B_s \rightarrow J/\psi\,\phi$ and $B_s \rightarrow J/\psi\,\pi\pi$ with 1 fb^{-1} data.
- Mixing phase: $\phi_M = 2\arg V_{ts} V_{tb}^* \simeq -2\beta_s$
  Sensitive to NP.



- For the decay: $\phi_D = \arg V_{cs} V_{cb}^* \simeq 0$





- In SM :

$$\varphi_s^{SM} = -2\beta_s = (-0.0363 \pm 0.0016\,)\,rad$$

PRD 84 **3** : 2011

Measurement of ϕ_s

Talk by Bilas Pal in parallel session

$B_s^0 \to J/\psi\varphi$

- Has Branching fraction 5 times that for $B_s \to J/\psi\ \pi\pi$
- But, P → V V , so final state is a mixture of CP even and CP odd (l=0,1,2)
- Three polarisation amplitudes and phases
  - $|A_0|^2, |A_{||}|^2\ \delta_0, \delta_{||}$ (CP-even)
  - $|A_\perp|^2, \delta_\perp$ (CP-odd)
- Amplitude analysis to disentangle these and extract ϕ_s.
- Non resonant $K^+ K^-$ s-wave component fraction and phase F_s , δ_s
- Decay rate is sum of 10 terms (unlike the case for $B_s \to J/\psi\ \pi\pi$)

$B_s^0 \to J/\psi\ \pi^+\pi^-$

- LHCb already measured ϕ_s from $B_s \to J/\psi$ f(980) last year from 370 pb^{-1} of data . (final state CP odd)
- A Dalitz plot analysis of $B_s \to J/\psi\ \pi\pi$ has found 775< $M(\pi^+ \pi^-)$ < 1550 MeV to be CP odd (> 97.7 % @95 % CL)

Phys. Lett. B707(2012)497

LHCb-PAPER-2012-005, arXiv:1204.5643

For both channels , one essentially measures :

$$\sin(\phi_s) \times D(\sigma_t) \times (1 - 2\omega_{tag}) \times \sin(\Delta m_s t)$$

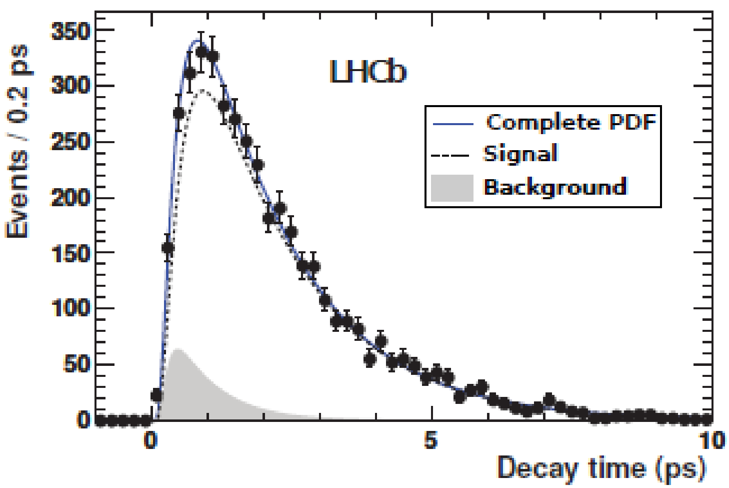
Decay time resolution

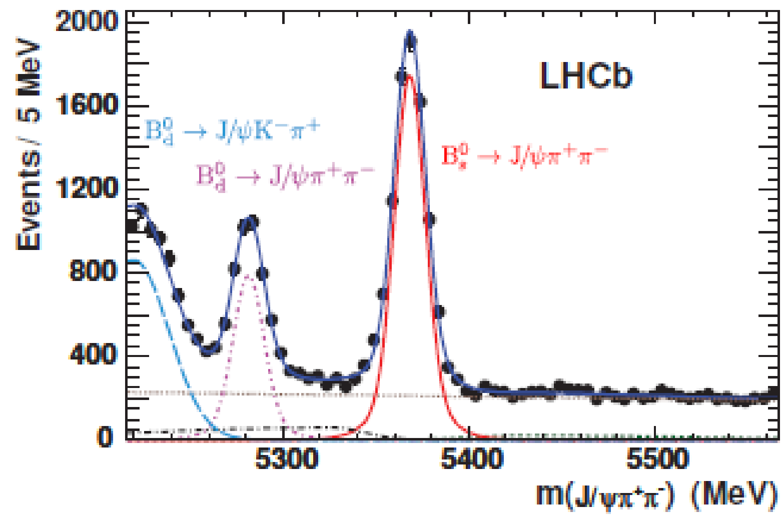
Dilution from flavour tagging

Measurement of ϕ_s

$B_s \rightarrow J/\psi\, \pi\pi$

Final selection using a BDT
yielding 7421 ± 105 signal events
At S/B ~ 4.2





- Maximum likelihood fit using the Mass and decay time

$$\phi_s = -0.019^{+0.173+0.004}_{-0.174-0.003}\ \text{rad}$$

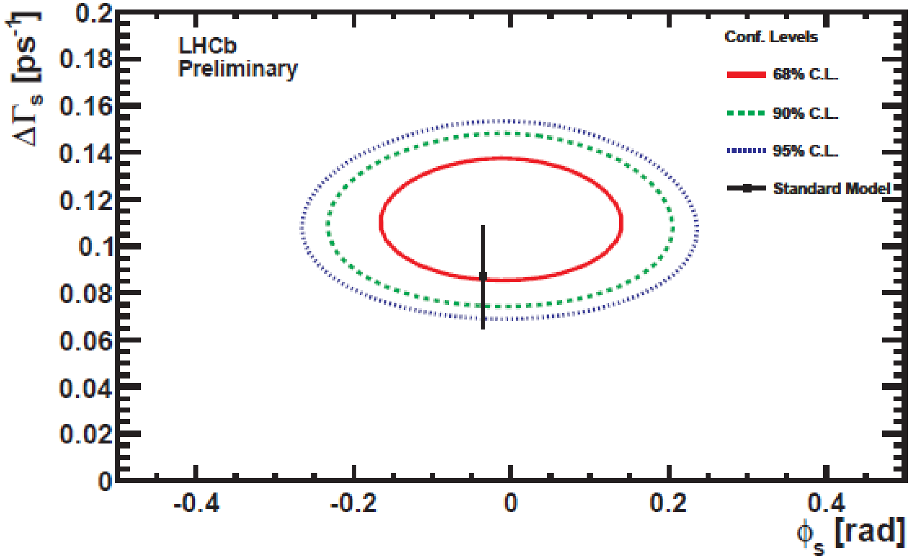
arXiv:1204.5675, submitted to PLB

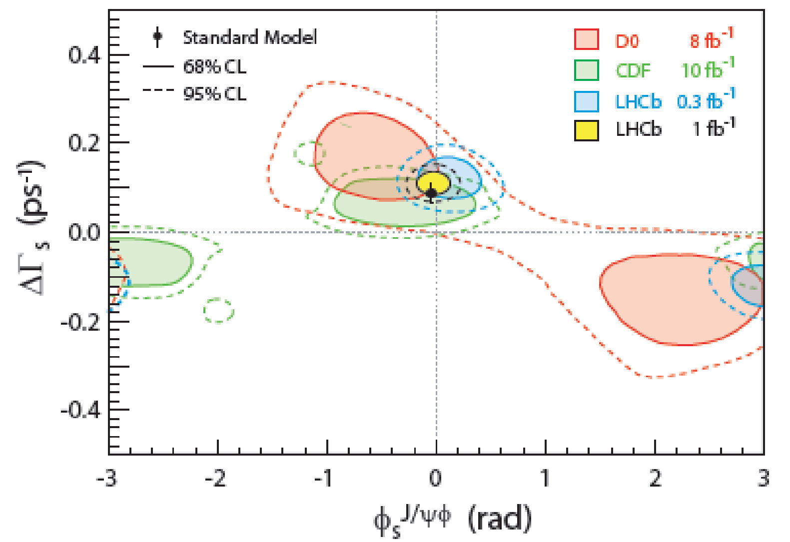
LHCb-PAPER-2012-006

Measurement of ϕ_s

$B_s \to J/\psi\, \phi$

Profile likelihood in the $\Delta\Gamma_s - \phi_s$ plane





$$\Gamma_s = 0.6580 \pm 0.0054(\text{stat.}) \pm 0.0066(\text{syst.})\ \text{ps}^{-1}$$
$$\Delta\Gamma_s = 0.116 \pm 0.018(\text{stat.}) \pm 0.006(\text{syst.})\ \text{ps}^{-1}$$
$$\phi_s = -0.001 \pm 0.101(\text{stat.}) \pm 0.027(\text{syst.})\ \text{rad}$$

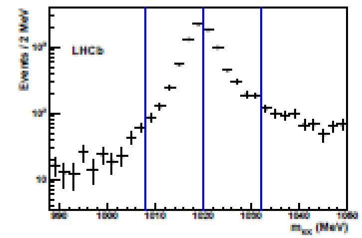
LHCb-CONF-2012-002

Simultaneous fit to both $B_s^0 \to J/\psi\pi^+\pi^-$ and $B_s^0 \to J/\psi\phi$ yields

ϕ_S = -0.002 ± 0.083 (stat) ± 0.027 (syst) rad

- *Most precise measurement of ϕ_s to date and the first 5σ observation of non-zero $\Delta\Gamma_s$*
- *ϕ_s and $\Delta\Gamma_s$ compatible with SM*

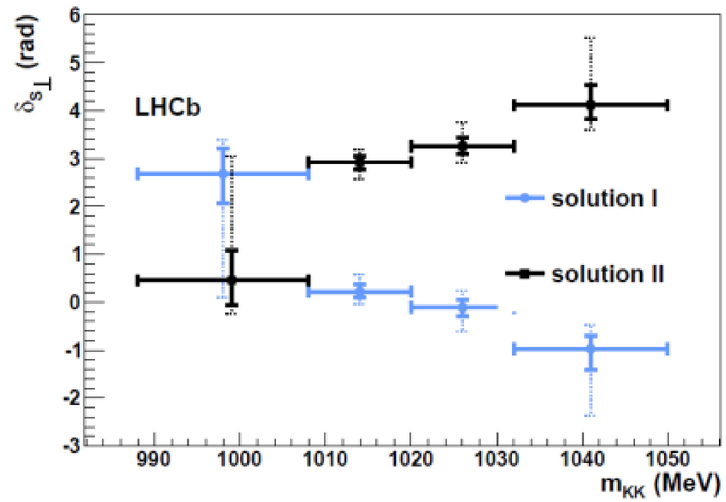
Measurement of ϕ_s



Sign of $\Delta\Gamma_s$:

Two solutions to the decay rates in $B_s \rightarrow J/\psi\ \phi$

Solution I		Solution II
$\delta_{\parallel} - \delta_0$		$\delta_0 - \delta_{\perp}$
$\delta_{\perp} - \delta_0$		$\pi + \delta_0 - \delta_{\perp}$
$\delta_s - \delta_0$	$\Leftrightarrow$	$\delta_0 - \delta_s$
ϕ_s		$\pi - \phi_s$
$\Delta\Gamma_s$		$-\Delta\Gamma_s$



- P-wave phase $(\delta_{\perp})$ increases rapidly across ϕ (1020) mass resonance, S-wave phase (δ_s) varies slowly
- Physical solution for $\delta_s - \delta_{\perp}$ decreases with m(K^+ K^-)

[arxiV:0908.3627 (hep-ph)]

- This phase difference plotted in 4 bins of M (K^+ K^-) for 0.37 fb^{-1} of data.
- It decreases for Solution 1 at 4.7 σ and is chosen.
- Heavy Bs meson lives longer

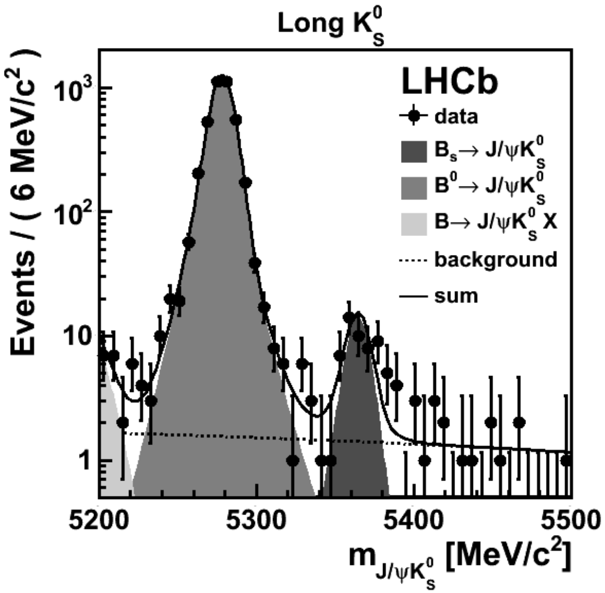
arXiV:1202.4717(hep-ex)

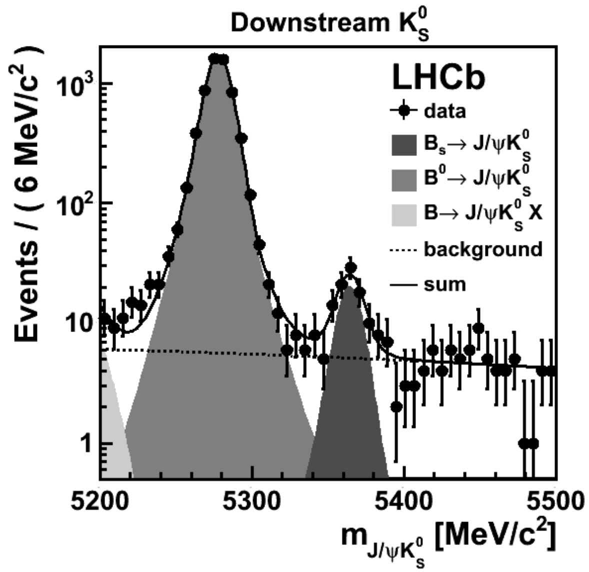
Branching Fraction of $B^0_s \rightarrow J/\psi\ K^0_s$

- Another approach to probe ϕ_s and ϕ_d
- $B^0_s \rightarrow J/\psi\ K^0_s$ is related to $B^0 \rightarrow J/\psi\ K^0_s$ though U-spin symmetry
- As a first step, ratio of branching fractions between these two channels is measured with 0.41 fb^{-1} of data from LHCb.
- Event selection : includes a multivariate selection ('Neurobayes'), trained on a part of real data for $B^0 \rightarrow J/\psi\ K^0_s$ and then used to select both channels with rest of data.

$$R_{exp} = \frac{Br(B^0_s \rightarrow J/\psi K^0_s)}{Br(B^0 \rightarrow J/\Psi K^0_s)} = \frac{N(B^0_s \rightarrow J/\psi K^0_s)}{N(B^0 \rightarrow J/\psi K^0_s)} \times \varepsilon_{geometry} \times \varepsilon_{time} \times \frac{f_d}{f_s}$$

Branching Fraction of $B^0_s \rightarrow J/\psi\ K_s$





$$R_{exp} = 0.0420 \pm 0.0049\,(\mathrm{stat}) \pm 0.0023(\mathrm{syst}) \pm 0.0033(\ f_s / f_d)$$

Using $\mathrm{Br}(B^0 \to J/\psi K^0)$ from the PDG,

$$\mathrm{Br}(B^0_s \to J/\psi K^0_s) = [1.83 \pm 0.21(\mathrm{stat}) \pm 0.10(\mathrm{syst}) \pm 0.14(f_s / f_d) \pm 0.07(\mathrm{Br}(B^0 \to J/\psi K^0))] \times 10^{-5}$$

This is compatible with, but more precise than previous measurements.

Very recent result

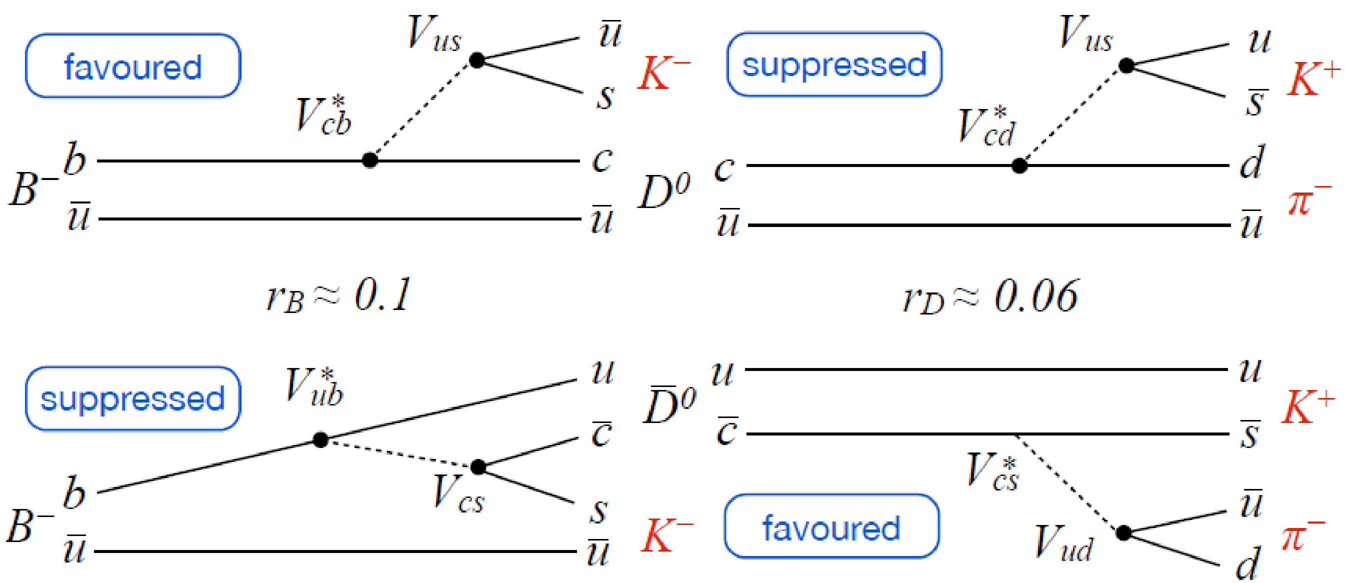
LHCb-PAPER-2011-041

CP violation in $B^+ \rightarrow DK^{\pm}$ decays

Talk by Michael Williams in parallel session

- To measure γ, b-->c and b--> u transitions of similar probability and final state.

arXiv:1203:3662v1



$$R_{CP+} = 1 + {r_B}^2 + 2r_B \cos\delta_B \cos\gamma$$

$$A_{CP+} = \frac{2r_B \sin\delta_B \sin\gamma}{1 + {r_B}^2 + 2r_B \cos\delta_B \cos\gamma}$$

$$R^{ADS} = \frac{{r_B}^2 + {r_D}^2 + 2r_B r_D \cos(\delta_B + \delta_D)\cos\gamma}{1 + (r_B r_D)^2 + 2r_B r_D \cos(\delta_B - \delta_D)\cos\gamma}$$

$$A^{ADS} = \frac{2r_B r_D \sin(\delta_B + \delta_D)\sin\gamma}{{r_B}^2 + {r_D}^2 + 2r_B r_D \cos(\delta_B + \delta_D)\cos\gamma}$$

relative amplitude:

$$\left|\frac{V_{cs} V_{ub}^*}{V_{us} V_{cb}^*}\right| f_{col} = r_B$$

weak phase difference:

$$\arg\left(\frac{V_{cs}\ V_{ub}^*}{V_{us}\ V_{cb}^*}\right) = \arg\left(-\frac{V_{ub}^*}{V_{cb}^*}\right) = \gamma$$

relative strong phase:

$$= \delta_B$$

GLW: Gronau&London, PLB 253,483(1991)
Gronau&Wyler, PLB 265,172(1991)
ADS: Atwood,Dunietz &Soni, PRL 78,3257(1997)
Atwood,Dunietz,Soni,PRD 63,036005(2001)

CP violation in $B^+ \rightarrow DK^{\pm}$ decays

GLW(CP) mode $B^- \to DK^-$ $D \to K^+K^-, \pi^+\pi^-$ (CP eigenstate)

ADS mode $B^- \to DK^-$ $D \to \pi^- K^+$

favoured+suppressed combinations

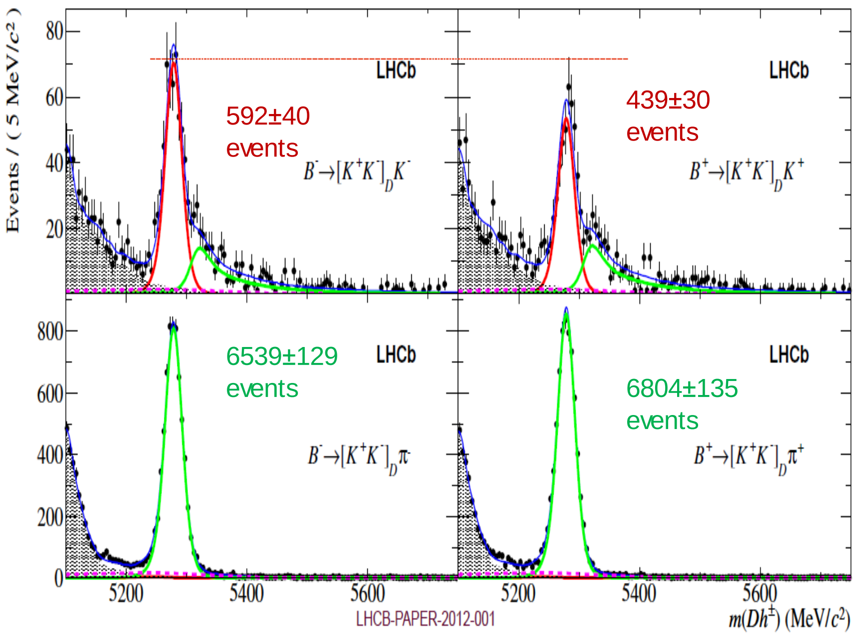
Favoured mode $B^- \to DK^-$ $D \to K^- \pi^+$

Ratios of partial widths (R) and asymmetries (A):

	CP	ADS
R:	$\dfrac{< \Gamma(B^\pm \to [\pi\pi]_D K^\pm), \Gamma(B^\pm \to [KK]_D K^\pm) >}{\Gamma(B^\pm \to [K\pi]_D K^\pm)}$	$\dfrac{\Gamma(B^\pm \to [\pi K]_D K^\pm)}{\Gamma(B^\pm \to [K\pi]_D K^\pm)}$
A:	$\dfrac{\Gamma(B^- \to D_{CP}K^-) - \Gamma(B^+ \to D_{CP}K^+)}{\Gamma(B^- \to D_{CP}K^-) + \Gamma(B^+ \to D_{CP}K^+)}$	$\dfrac{\Gamma(B^- \to D_{ADS}K^-) - \Gamma(B^+ \to D_{ADS}K^+)}{\Gamma(B^- \to D_{ADS}K^-) + \Gamma(B^+ \to D_{ADS}K^+)}$

Fit to 16 data samples (2 (B charge) x 2 (Bachelor ID) x 4 (D decays))
to get 13 observables.
Selection of events using BDT, kinematics cuts, PID cuts for K/π.

CP violation in $B^+ \to DK^\pm$ decays



Asymmetry seen in CP modes

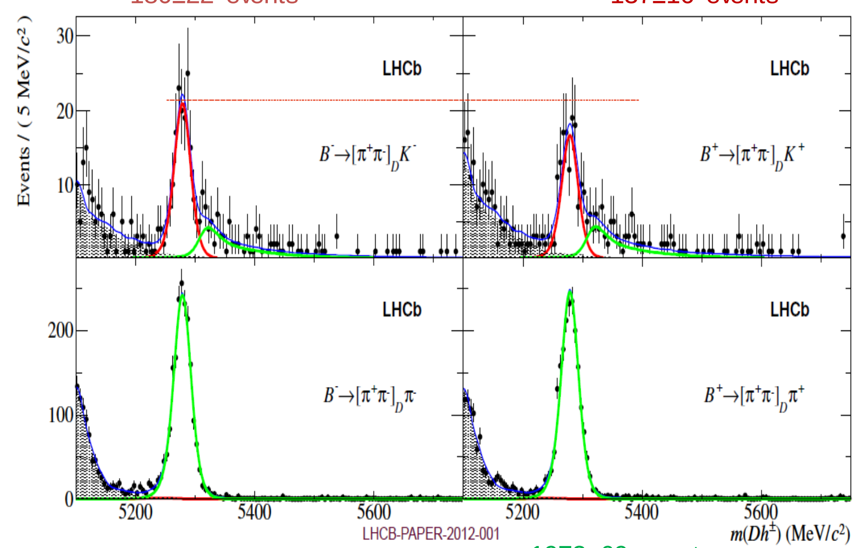
KK mode

1 fb^{-1} of data

red: B->DK

green: $B \to D\pi$

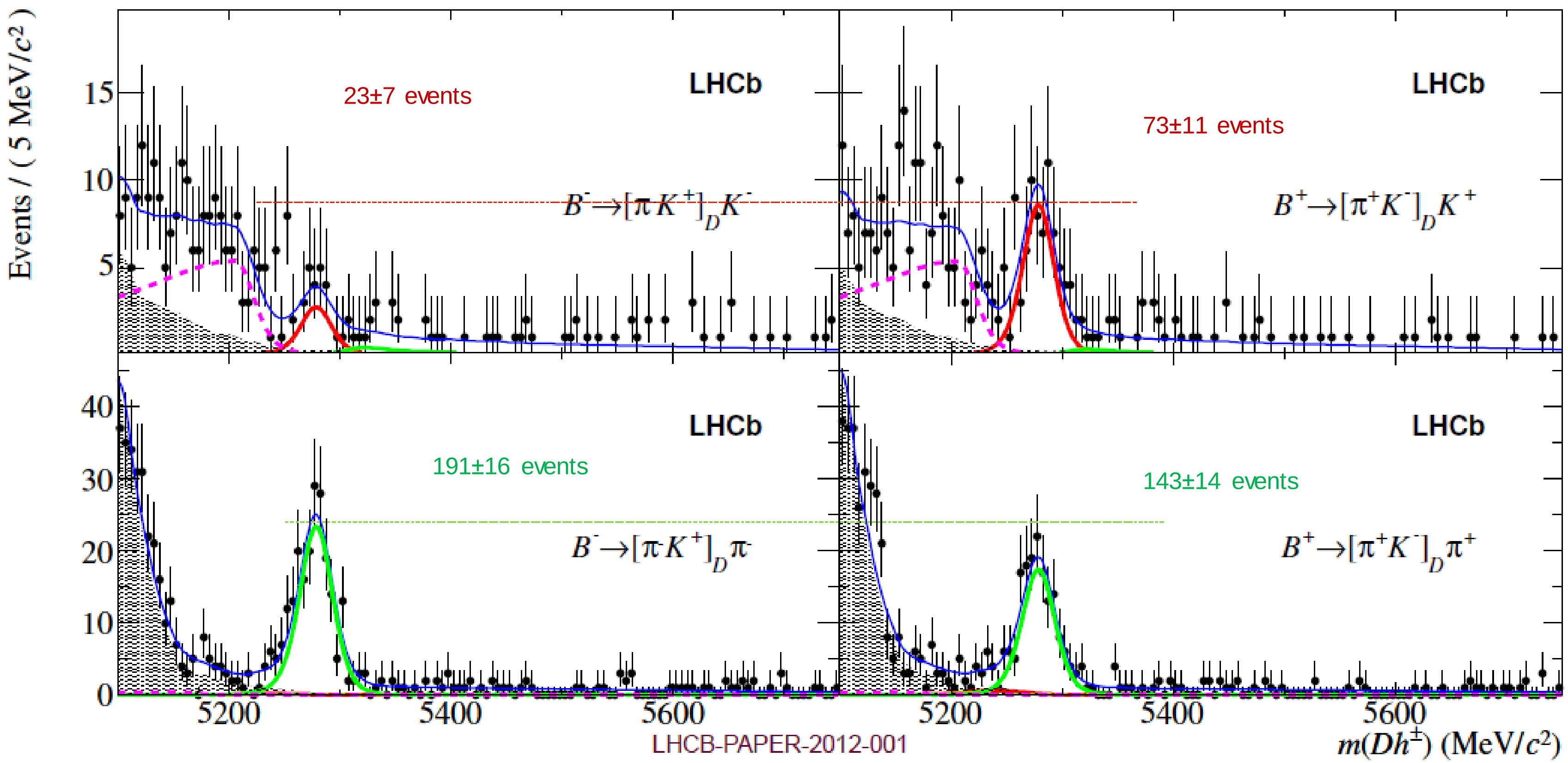
$\pi\pi$ mode



Results on R_{CP} and A_{CP} compatible with results from CDF, BABAR, Belle.
LHCb has more statistics.

CP violation in $B^+ \to DK^\pm$ decays

Asymmetry also seen in ADS modes.

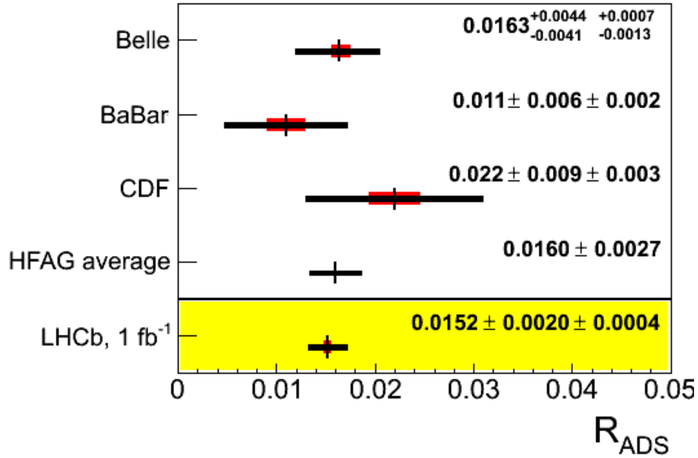


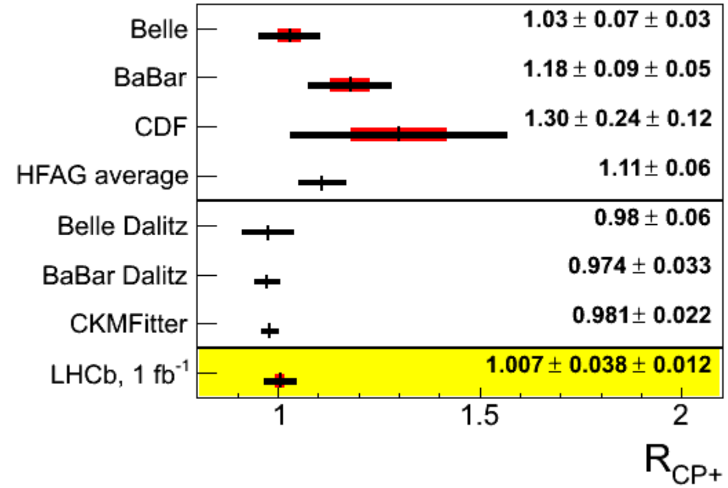
red: B->DK

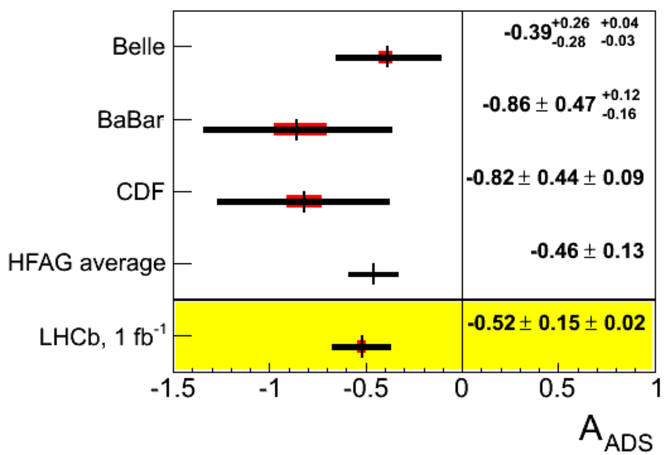
green: $B \to D\pi$

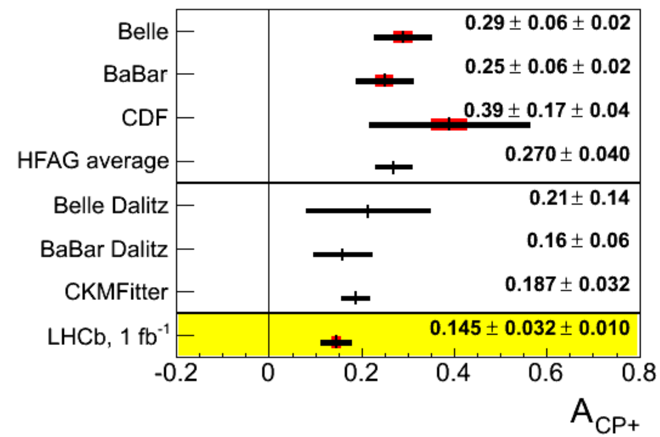
Large negative asymmetry in $B \to DK$ and a hint of positive asymmetry in $B \to D\pi$

CP violation in $B^+ \rightarrow DK^{\pm}$ decays









LHCb: arxiV:1203.3662

LHCb-PAPER-2012-001

LHCb has some of the most precise measurements on these.

CP Violation in CHARM Decays

Talk by Artur Ukleja in parallel session

Time Integrated CP Violation:

Using $D^{*\pm} \rightarrow D^0 \pi^\pm$ where $D^0 \rightarrow f$

$f = (\mathrm{KK\ or\ } \pi\pi)$ = CP eigenstate

$$A_{CP}(f) = \frac{\Gamma(D^0 \rightarrow f) - \Gamma(\overline{D}^0 \rightarrow f)}{\Gamma(D^0 \rightarrow f) + (\overline{D}^0 \rightarrow f)}$$

Single Cabibbo suppressed, Tree+Penguin

$$A_{RAW}(f) = A_{CP}(f) + A_D(f) + A_D(\pi_s) + A_P(D^{*+})$$

Detection Asymmetry of D^0 ($A_D(f)$)

Detection Asymmetry of soft π ($A_D(\pi_s)$)

Production Asymmetry ($A_P(D^{*+})$)

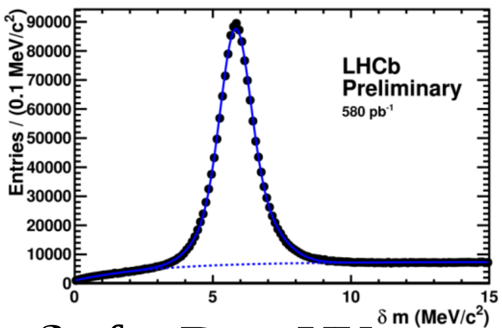
Measure the difference between the raw asymmetries into KK and ππ . All detection and production asymmetries cancel. Residual differences in decay time acceptance leads to an indirect CP component proportional to $\frac{\Delta < t >}{\tau}$

$$\Delta A_{CP} \equiv A_{CP}(K^+ K^-) - A_{CP}(\pi^+ \pi^-)$$

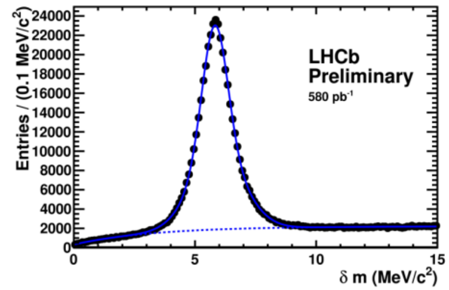
$\frac{\Delta < t >}{\tau} =$ Difference in average decay time / D^0 lifetime

CP Violation in CHARM Decays

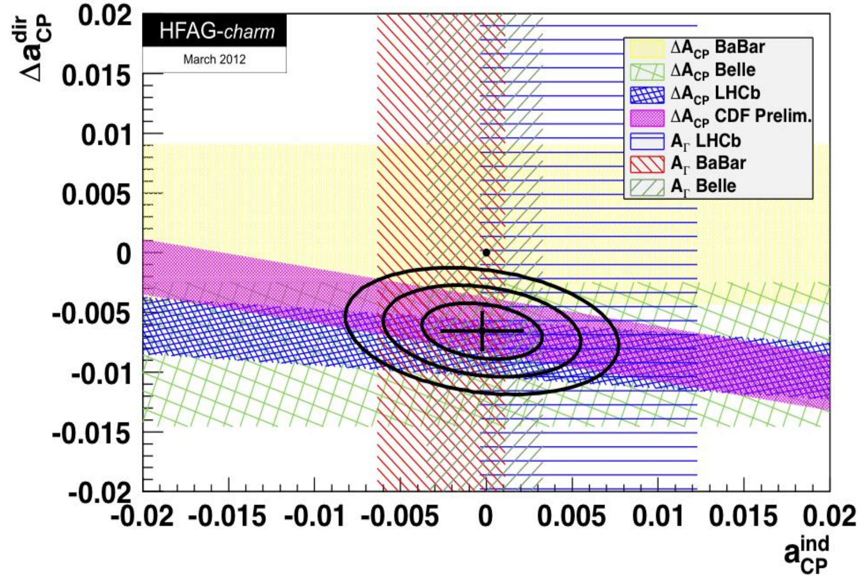
$$\delta m = m(KK\pi) - m(KK) - m(\pi)$$



δm for $D \to KK$



δm for $D \to \pi\pi$



$$\frac{\Delta < t >}{\tau} = (9.83 \pm 0.22 \pm 0.19)\%$$

So ΔA_{CP} primarily measures direct CP violation

From 0.62 fb^{-1} data,

$$\Delta A_{CP} = -0.82 \pm 0.21(stat) \pm 0.11(syst)\%$$

3.5 σ effect

PRL 108: 111602(2012)

This result is compatible with previous measurements.

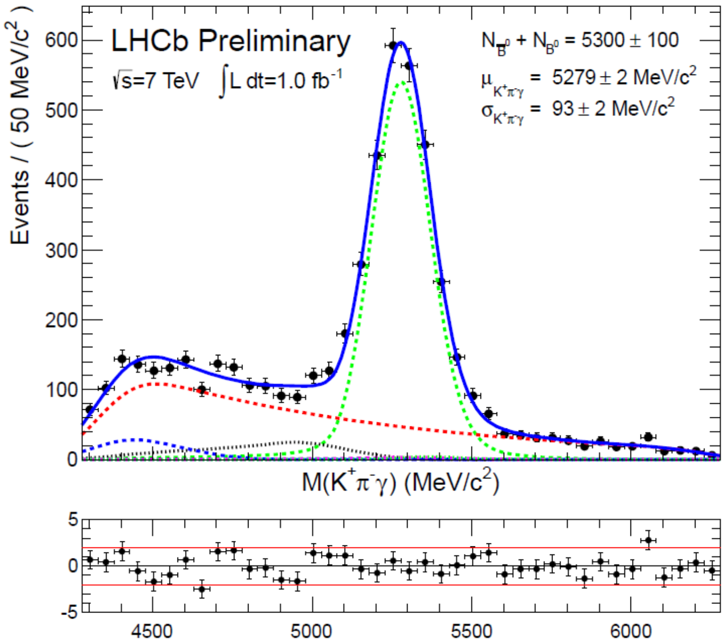
Summary and Prospects

- Excellent performance of the LHCb detector in 2011 has led to several physics results from the 1 fb^{-1} of data. LHCb has become a "flavour factory".
- LHCb has started to
  - Explore new territory in searching for NP
  - Test SM with unprecedented precision
  - Make CP violation measurements in different channels
- Excellent prospects to enhance its discovery potential.
  - 1.5 fb^{-1} at $\sqrt{s} = 8\,\mathrm{TeV}$ from 2012 data
  - > 5 fb^{-1} at $\sqrt{s} = 13\,\mathrm{TeV}$ during 2014-2017
- An active upgrade program to run at (1-2) x 10^{33} $cm^{-2}s^{-1}$ with $\sqrt{s} = 14\,\mathrm{TeV}$ from 2019, is underway.
  It would produce 5 fb^{-1} of data per year with improved trigger efficiency.
  - Full detector readout at 40 MHz and flexible software trigger

EXTRA SLIDES

CP violation in $B^0 \to K^{*0}\gamma$

NP can affect the b→s γ (FCNC)
Several exclusive modes observed in LHCb



Direct CP violation in $B^0 \to K^{*0}\gamma$

$$A_{CP}(B^0 \to K^{*0}\gamma) = 0.008 \pm 0.017 \pm 0.009$$

This is compatible with SM : (0.0061 ± 0.0043)

Keum, Matsumori, Sanda, PRD 72 (2005) 014013

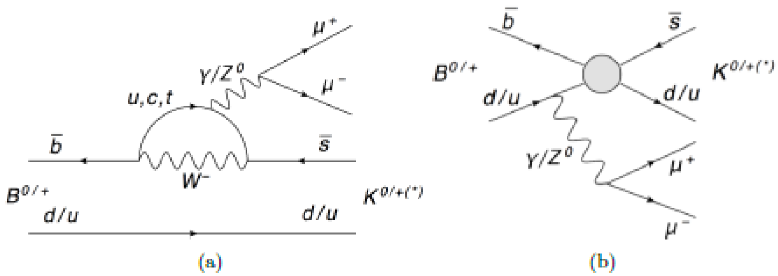
Isospin Asymmetry: $B^0 \to K^{(*)0}\mu^+\mu^-$ and $B^+ \to K^{(*)+}\mu^+\mu^-$

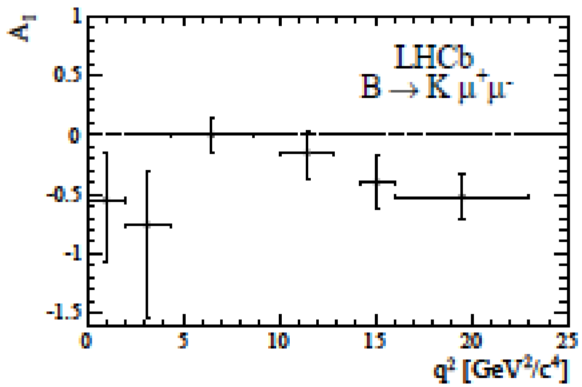
$$A_I = \frac{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) - \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) + \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}$$

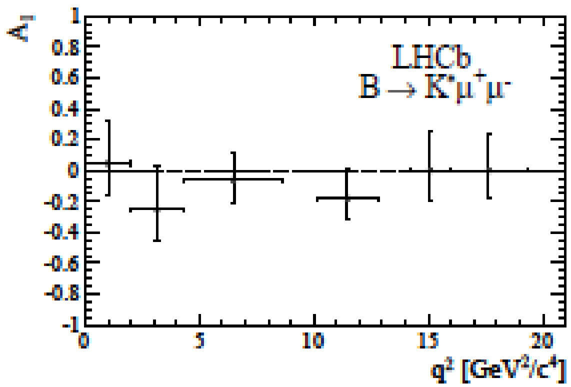
$$= \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - \frac{\tau_0}{\tau_+}\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + \frac{\tau_0}{\tau_+}\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}$$

Theory prediction : $A_I = 0$

LHCb results are consistent with previous measurements







Very recent result

LHCb-PAPER-2012-011

Negative with 3.0σ significance in $16<q^2<23$

consistent with zero

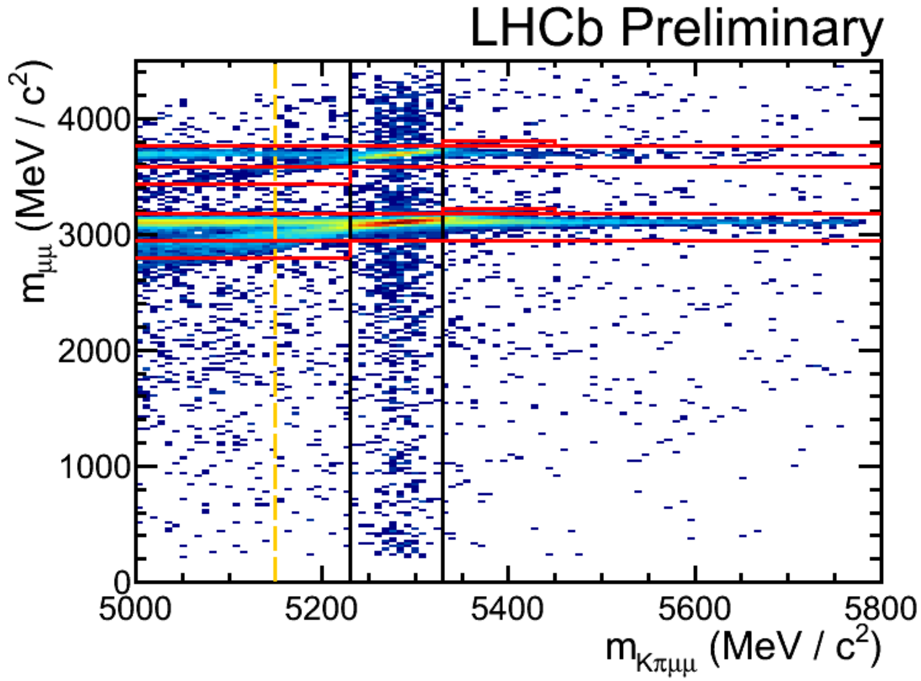
Theory: T.Feldman,J.Matias JHEP 01 (2002) 074

$B^0 \to K^* \mu^+ \mu^-$

- Final selection using a BDT trained on real data from 2010:

  $J/\psi\ K^{*0}$ as proxy for signal and

  upper side band of $K^* \mu\mu$ as background



Measurement of ϕ_s

Differential decay rates

- The differential decay rate [+ for B_s^0 and - for $\overline{B_s^0}$]

$$\frac{d^4\Gamma(B_s^0 \to J/\psi\phi)}{dtd\Omega} \propto \sum_{k=1}^{10} h_k(t) f_k(\Omega), \quad (6)$$

$$h_k(t) = N_k e^{-\Gamma_s t}\{a_k \cosh\frac{\Delta\Gamma_s t}{2} + b_k \sinh\frac{\Delta\Gamma_s t}{2} \pm c_k \cos(\Delta m_s t) \pm d_k \sin(\Delta m_s t)\} \quad (7)$$

k	$f_k(\theta,\psi,\varphi)$	N_k	a_k	b_k	c_k	d_k
1	$2\cos^2\psi\,(1-\sin^2\theta\cos^2\phi)$	$\lvert A_0(0)\rvert^2$	1	$-\cos\phi_s$	0	$\sin\phi_s$
2	$\sin^2\psi\,(1-\sin^2\theta\sin^2\phi)$	$\lvert A_\parallel(0)\rvert^2$	1	$-\cos\phi_s$	0	$\sin\phi_s$
3	$\sin^2\psi\sin^2\theta$	$\lvert A_\perp(0)\rvert^2$	1	$\cos\phi_s$	0	$-\sin\phi_s$
4	$-\sin^2\psi\sin 2\theta\sin\phi$	$\lvert A_\parallel(0)A_\perp(0)\rvert$	0	$-\cos(\delta_\perp-\delta_\parallel)\sin\phi_s$	$\sin(\delta_\perp-\delta_\parallel)$	$-\cos(\delta_\perp-\delta_\parallel)\cos\phi_s$
5	$\frac{1}{2}\sqrt{2}\sin 2\psi\sin^2\theta\sin 2\phi$	$\lvert A_0(0)A_\parallel(0)\rvert$	$\cos(\delta_\parallel-\delta_0)$	$-\cos(\delta_\parallel-\delta_0)\cos\phi_s$	0	$\cos(\delta_\parallel-\delta_0)\sin\phi_s$
6	$\frac{1}{2}\sqrt{2}\sin 2\psi\sin 2\theta\cos\phi$	$\lvert A_0(0)A_\perp(0)\rvert$	0	$-\cos(\delta_\perp-\delta_0)\sin\phi_s$	$\sin(\delta_\perp-\delta_0)$	$-\cos(\delta_\perp-\delta_0)\cos\phi_s$
7	$\frac{2}{3}(1-\sin^2\theta\cos^2\phi)$	$\lvert A_S(0)\rvert^2$	1	$\cos\phi_s$	0	$-\sin\phi_s$
8	$\frac{1}{3}\sqrt{6}\sin\psi\sin^2\theta\sin 2\phi$	$\lvert A_S(0)A_\parallel(0)\rvert$	0	$-\sin(\delta_\parallel-\delta_S)\sin\phi_s$	$\cos(\delta_\parallel-\delta_S)$	$-\sin(\delta_\parallel-\delta_S)\cos\phi_s$
9	$\frac{1}{3}\sqrt{6}\sin\psi\sin 2\theta\cos\phi$	$\lvert A_S(0)A_\perp(0)\rvert$	$\sin(\delta_\perp-\delta_S)$	$\sin(\delta_\perp-\delta_S)\cos\phi_s$	0	$-\sin(\delta_\perp-\delta_S)\sin\phi_s$
10	$\frac{4}{3}\sqrt{3}\cos\psi(1-\sin^2\theta\cos^2\phi)$	$\lvert A_S(0)A_0(0)\rvert$	0	$-\sin(\delta_0-\delta_S)\sin\phi_s$	$\cos(\delta_0-\delta_S)$	$-\sin(\delta_0-\delta_S)\cos\phi_s$

only 7th term presents in $J/\psi\pi^+\pi^-$ analysis.

$B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ decay rates

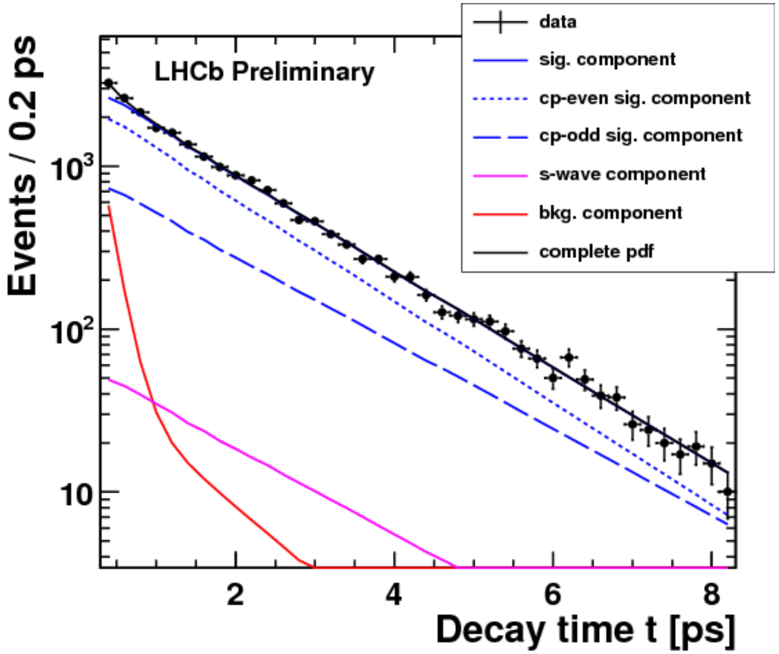
$$\Gamma\left(B_s^0 \rightarrow J/\psi f_{odd}\right) = \frac{\mathcal{N}}{2} e^{-\Gamma_s t}\left\{ e^{\Delta\Gamma_s t/2}(1 + \cos\phi_s) + e^{-\Delta\Gamma_s t/2}(1 - \cos\phi_s) - \sin\phi_s \sin(\Delta m_s t)\right\}$$

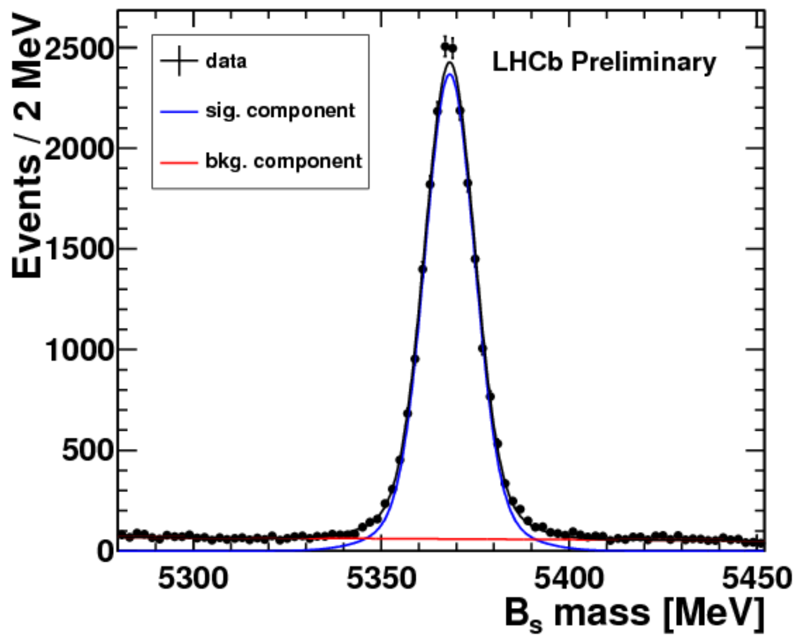
$$\Gamma\left(\overline{B}_s^0 \rightarrow J/\psi f_{odd}\right) = \frac{\mathcal{N}}{2} e^{-\Gamma_s t}\left\{ e^{\Delta\Gamma_s t/2}(1 + \cos\phi_s) + e^{-\Delta\Gamma_s t/2}(1 - \cos\phi_s) + \sin\phi_s \sin(\Delta m_s t)\right\}$$

Measurement of ϕ_s

$B_s \rightarrow J/\psi\ \phi$

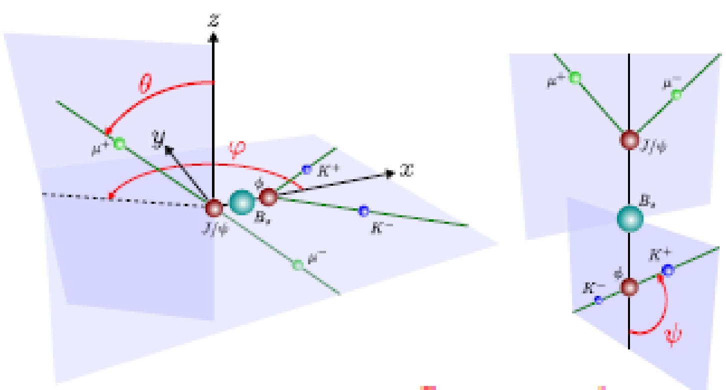
- Rectangular cut selection yielding ~ 21299 signal candidates with very little background.





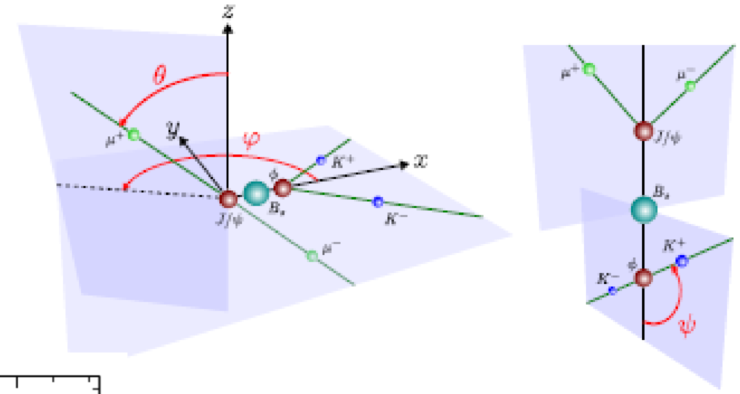
Max likelihood fit to mass, decay time and the angles.

- s-wave fraction:
  $F_S = (2.2 \pm 1.2 \pm 0.7)\%$



Using transversity basis: θ, φ, ψ

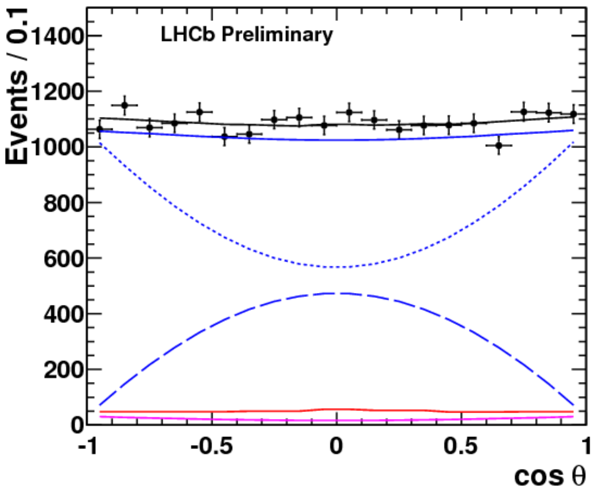
Measurement of ϕ_s

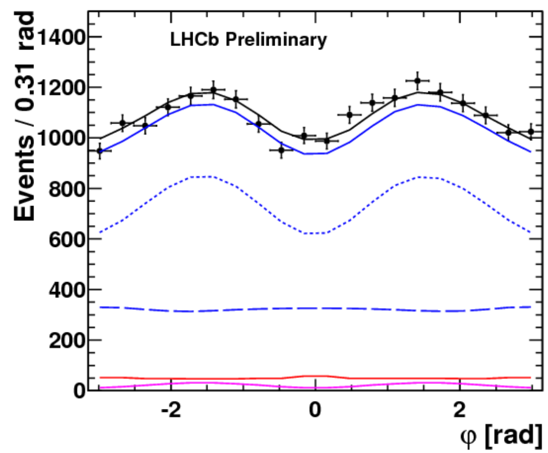


$B_s \to J/\psi\ \phi$

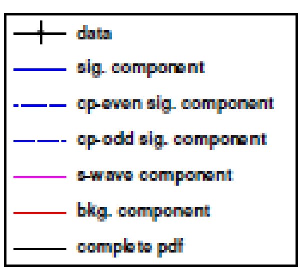
For the angular analysis,
using transversity basis:

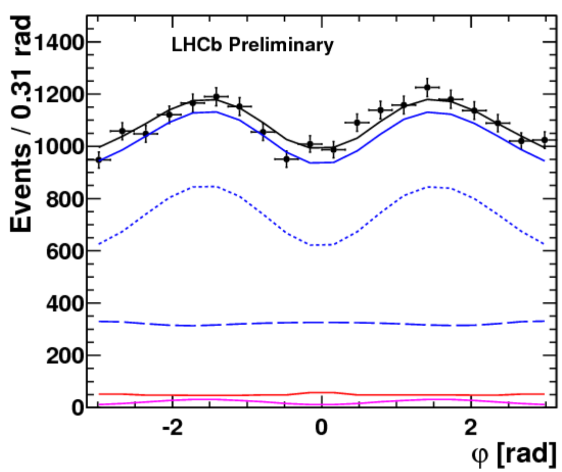
θ, φ, ψ





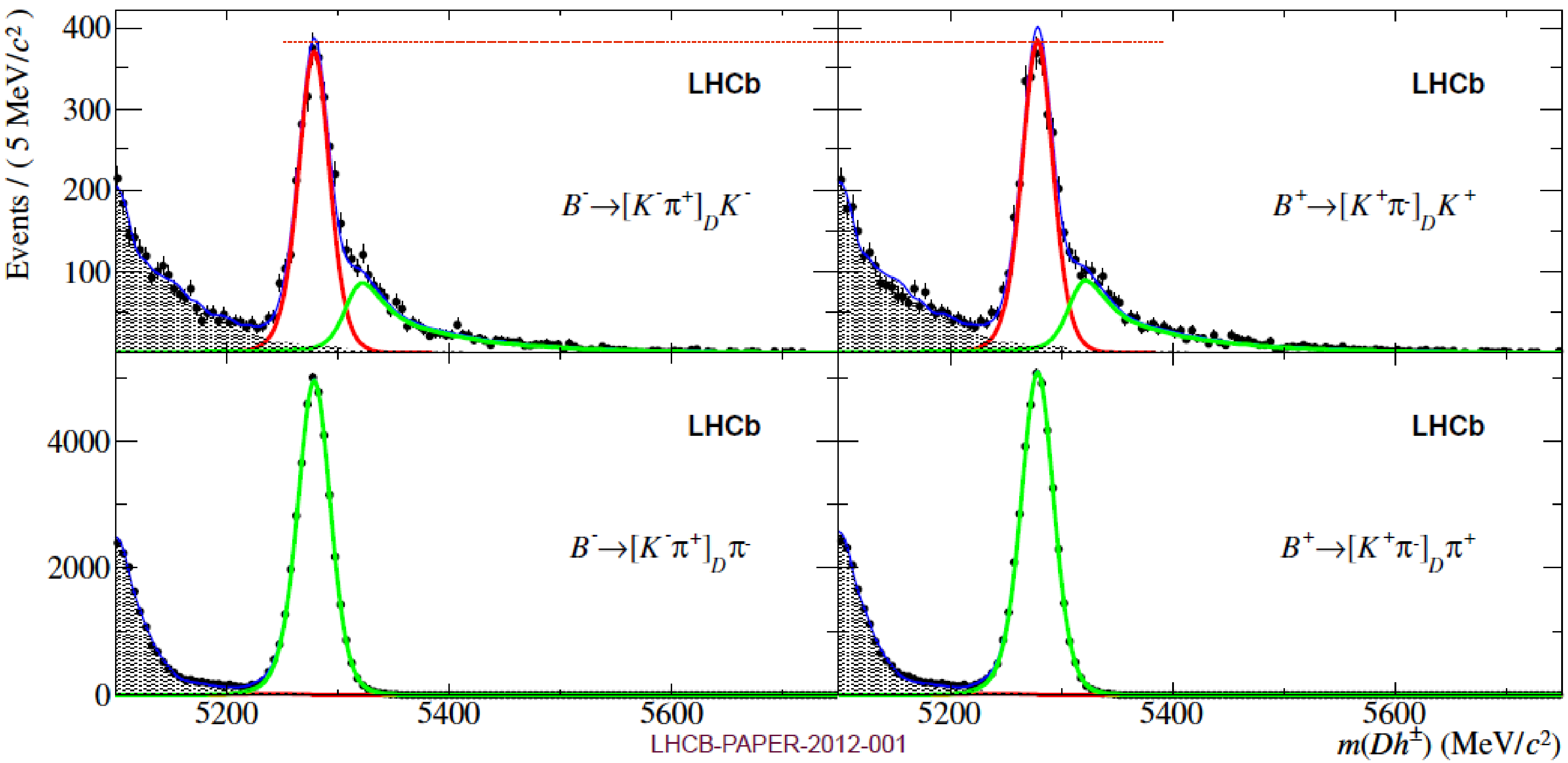
Maximum likelihood
fit to mass, decay time
and the angle distributions.





CP violation in $B^+ \rightarrow DK^\pm$ decays

Favoured Mode :



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