RECENT RESULTS FROM THE LHCb EXPERIMENT

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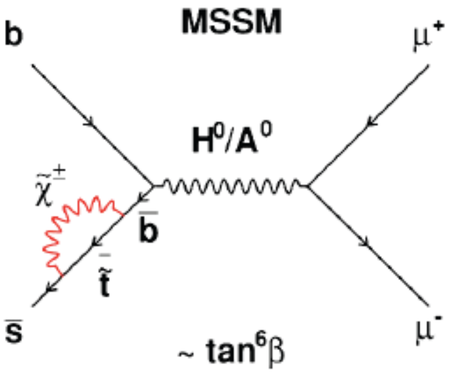
on behalf of the LHCb Collaboration

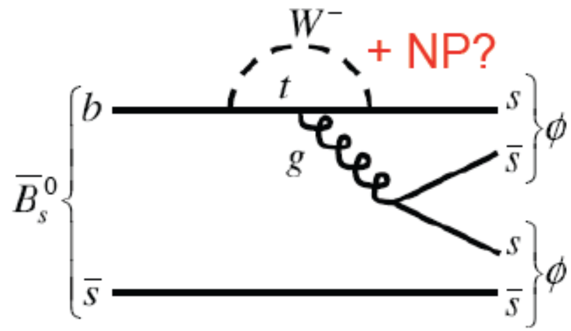
Outline of talk:

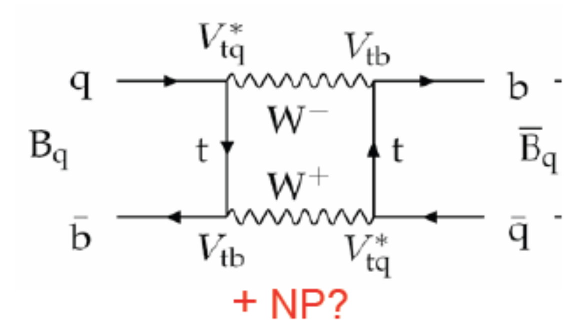
- Flavour physics at 8 TeV pp
- $B_s \rightarrow \mu\mu$, $b \rightarrow s\mu\mu$ and rare decays
- Mixing and CPV in b-quark
- Mixing and CPV in charm

LHCb Physics Program

Search for New Physics (NP) which may appear in CP violation or in rare decays mediated by new particles at high mass scale – via their effects in loop diagrams (e.g.: compare CKM quantities determined in tree and loop process)







Approach complementary to direct searches in ATLAS and CMS: once New Physics discovery will be made, its non trival flavour structure has to be determined

- CPV B_s oscillation phase ϕ_s , asymmetries (a_{sl})
  CKM angle γ in tree and loop mediated decays
  Mixing and CP Asymmetries in charm decays

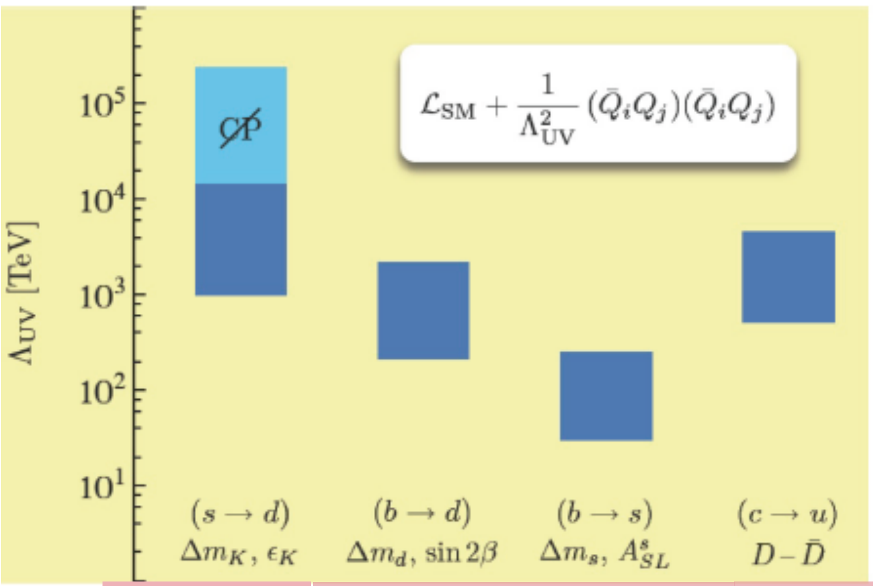
- Rare decays Helicity structure in $B_d \rightarrow K^* \mu\mu$, $B_s \rightarrow \phi\gamma$
  FCNC in loops ($B_{s,d} \rightarrow \mu\mu$, $D \rightarrow \mu\mu$)

\+ b and c production studies, spectroscopy, forward electro-weak physics, exotica, etc ...

LHC : Direct versus indirect searches

Any extension of Standard Model found in DIRECT SEARCHES must comply with a non-trivial flavor structure: Flavor is a key ingredient of any BSM theory

The absence of FCNC already now sets strong constraints on the multi TeV-scale physics (higher than those found in direct searches so far, even forseeable at LHC)

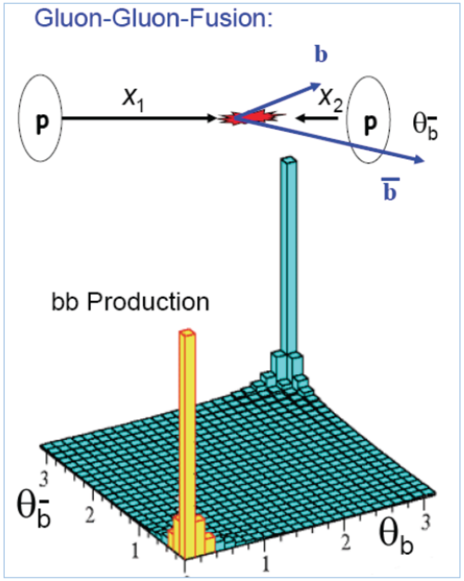


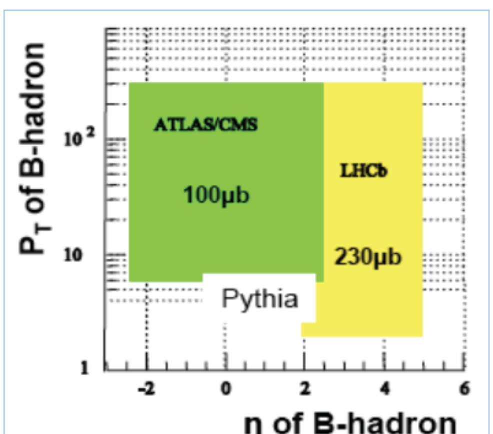
CP violation in K system	Oscillations and CPV in B_d system	Oscillations and CPV in B_s system	Oscillations in D system

G. Isidori
arXiv:1302.0661

This technique has been used since a long time in particle physics with great sucess

b-quark production at LHCb





- Cross section predictions (PYTHIA8)
  $\sigma_{inelastic}$ ~ 70 -80 mb
  σ_{bb} ~ 500 μb [14 TeV]

  $\sigma_{measured}$ at 7 TeV ~ 280 μb
  (~ 75 μb in LHCb acceptance) PLB 694 (2010) 209.

- All b-hadrons species produced at LHC
  (B^{+-}, B^0, B_s, B_c, Λ_b ...)

- Operated since end of 2011 at 4 10^{32} cm^{-2} s^{-1}
  (design luminosity was × 2 lower)
  pileup with 50 ns bunch spacing < μ > ~ 1.7

- ~ 3 KHz of $b\bar{b}$ events in LHCb [7 TeV]

LHCb acceptance $2 < \eta < 5$

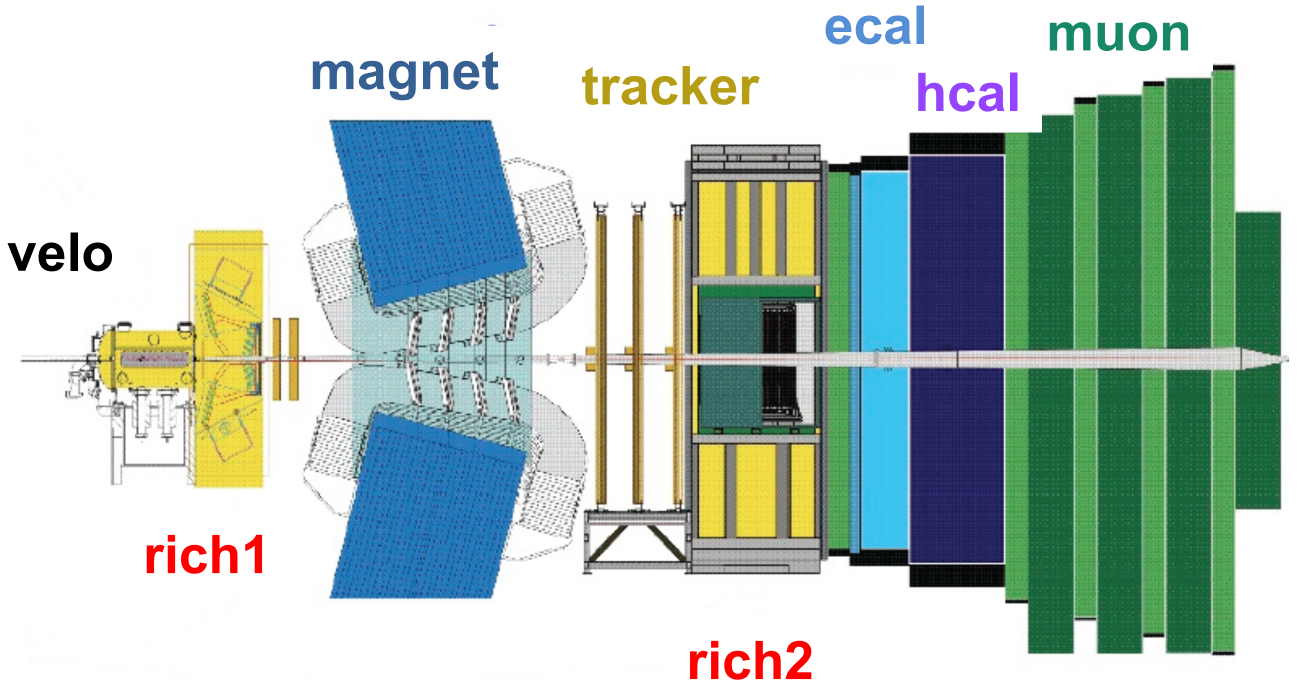
ATLAS and CMS: $|\eta| < 2.5$

The LHCb apparatus at 8 TeV pp collisions

Brasil, China, France, Germany, Ireland, Italy, Netherlands, Pakistan, Poland, Romania, Russia, Spain, Switzerland, UK, Ukraine, US, CERN

~ 60 institutes
~ 750 members

> 100 papers



VELO: 21 (R+φ) silicon station
- Movable: 7 mm when stable beams

RICH1: C_4F_{10} + AEROGEL
- π/K separation for 2<p<60 GeV

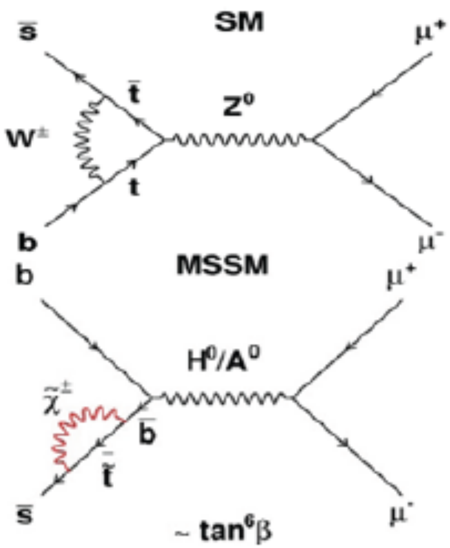
Tracking: Si + straw tubes + 4Tm
- Δp/p=0.45%

RICH2: CF_4
- π/K separation for 20<p<100 GeV

CALO
- ECAL lead+scintillation tiles
- HCAL: iron+scintillation tiles

MUON MWPC+GEM: π/μ separation

First observation of $B_s \rightarrow \mu^+\mu^-$ decay



Predicted to be very rare in SM

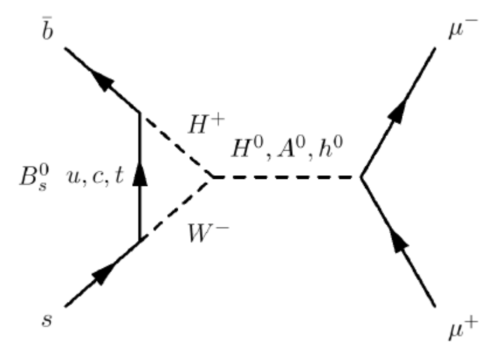
Precise prediction in SM:

- $BR(B_s \rightarrow \mu\mu) = 3.5 \pm 0.2\ 10^{-9}$
- $BR(B_d \rightarrow \mu\mu) = 1.1 \pm 0.2\ 10^{-10}$

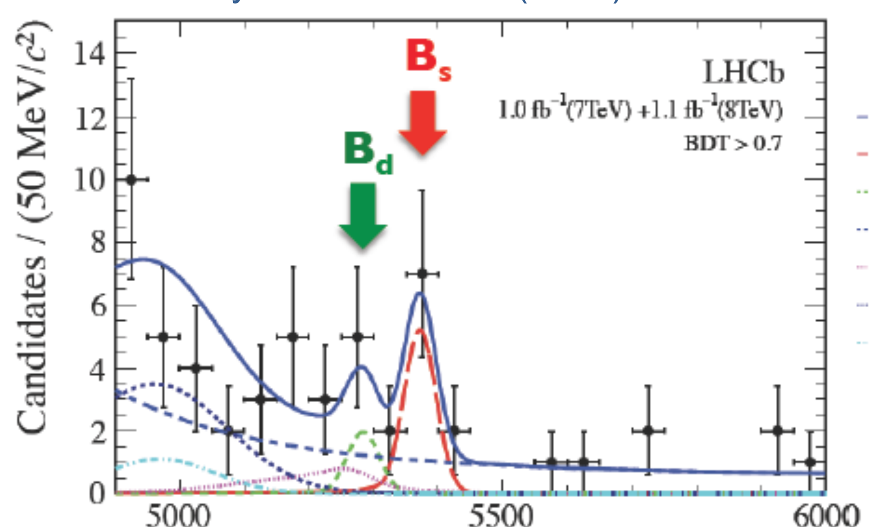
$$\mathcal{B}_{MSSM}(B_q \rightarrow l^+l^-) \propto \frac{M_b^2 M_t^2 \tan^6\beta}{M_A^2}$$

"Golden channel" for New Physics effects

- absence of tree-level FCNC
- helicity suppressed
- CKM suppressed



Phys. Rev. Lett.110 (2013) 021801



With 2011+ part of 2012 data (2.1 fb^{-1}) LHCb has got the first evidence of $B_s \rightarrow \mu\mu$ decay at ~ 3.5σ

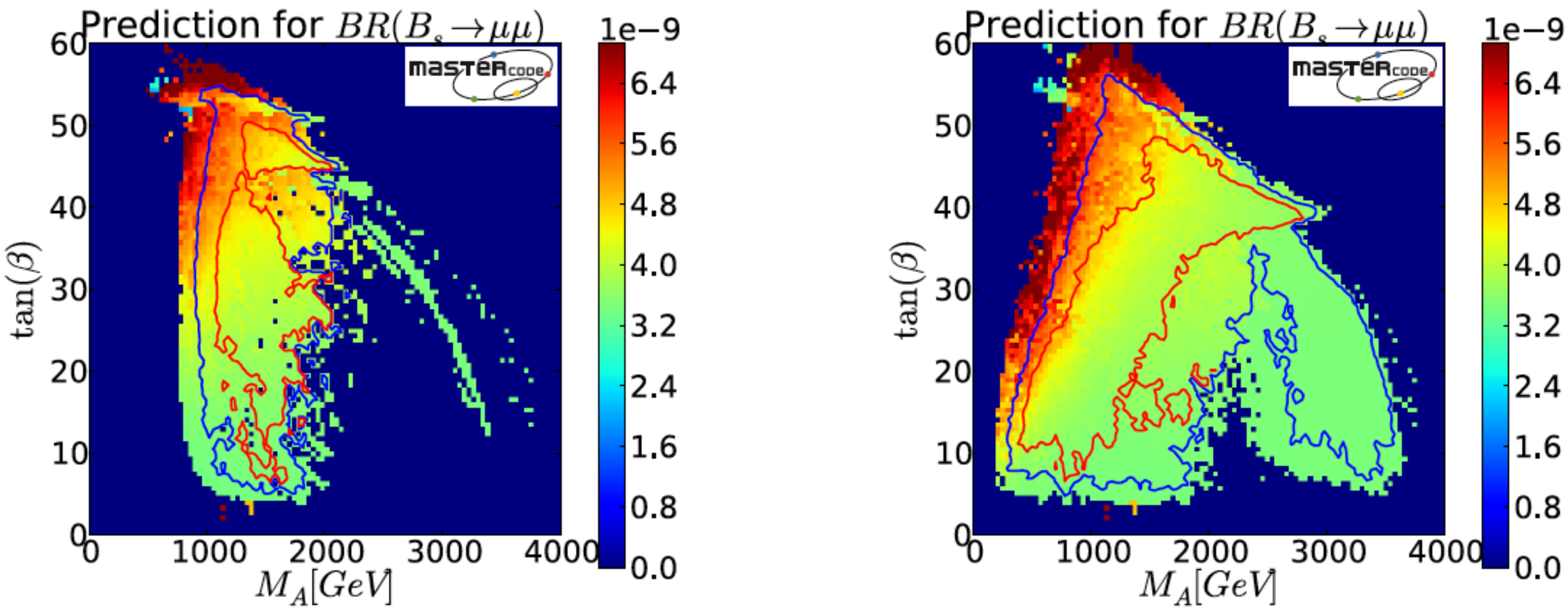
$$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$$

in agreement with SM
"background only" p value ~ 5 10^{-4}
Also best limit on $B_d \rightarrow \mu\mu$

$$\mathcal{B}(B_d^0 \rightarrow \mu^+\mu^-) < 9.4 \times 10^{-10}$$

B → $\mu^+\mu^-$ constraining Supersymmetry

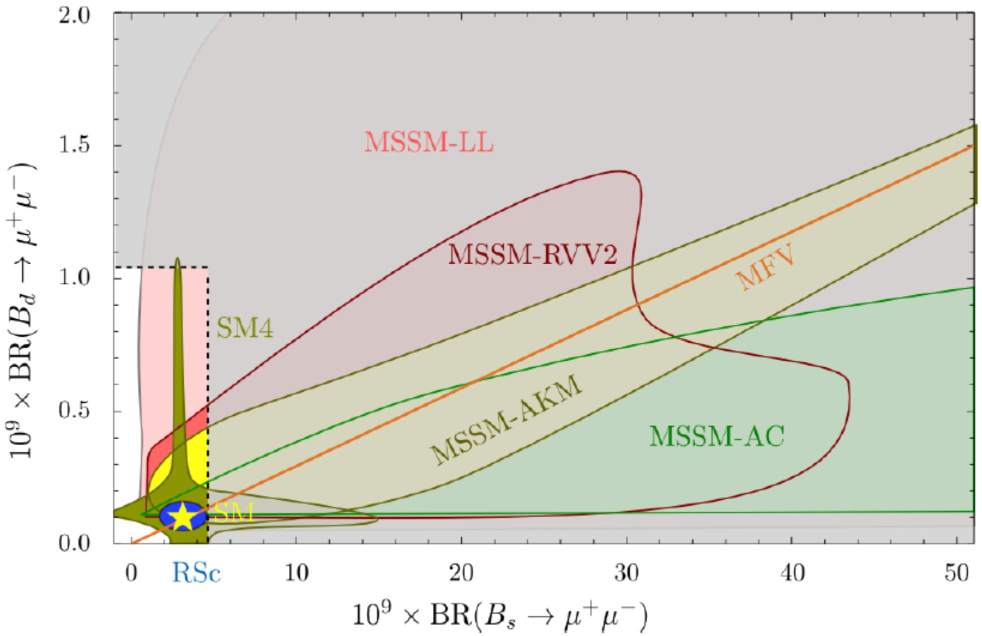
BR(B_s → $\mu^+\mu^-$) sets strong bounds on tanβ, at least in CMSSM, and reduces the phase space of Supersymmetry, complementary to direct searches. Higgs mass of 125 GeV included, as well as other electroweak and XENON100 data. Some scenarios of new Physics are removed. SUSY now confronted.

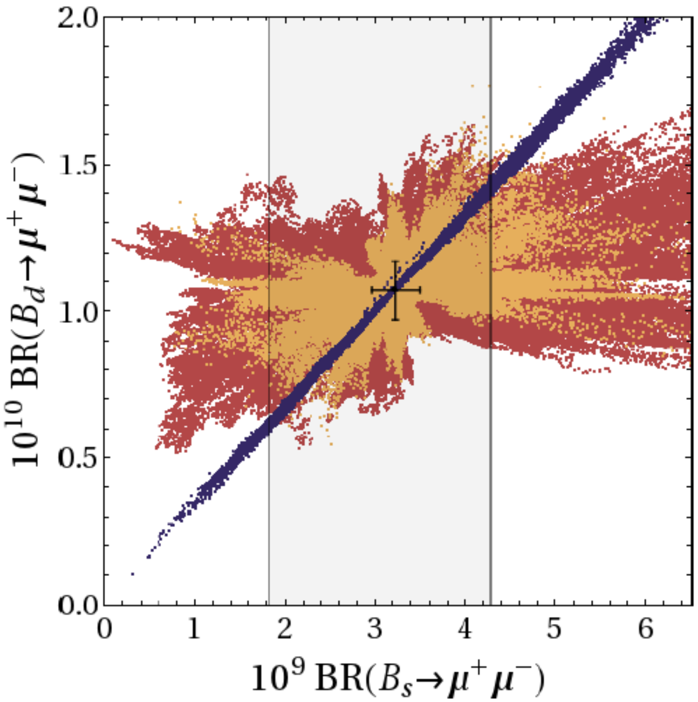


BR predictions in the CMSSM and in the CMSSM with non-universal Higgs masses NUHM1 (right). Allowed region regions of parameter space at 68% and 98% CL

O. Buchmueller et al., Eur. Phys. J. C 72 (2012) 2243 [arXiv:1207.7315]

B → $\mu^+\mu^-$ constraining SUSY and compositeness





Large tanβ with **light pseudoscalar Higgs** in CMSSM is strongly **disfavored**.
Now in the regime where more "natural" O(50%) NP effects can be probed

Straub arXiv:1302.4651
Analysis of several models with partial compositeness

Now vital to measure:

- **BR(B_s → $\mu^+\mu^-$) down to theory uncertainty (a few x 10^{-10})**
- BR(B_d → $\mu^+\mu^-$) to test "golden" relation between SM and MFV, distinguish between NP models

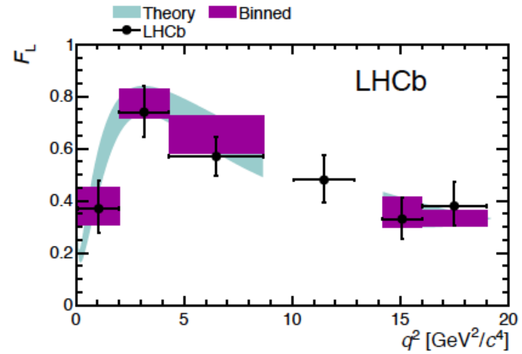
$$\frac{BR(B_s \to \mu^+\mu^-)}{BR(B_d \to \mu^+\mu^-)} \approx \frac{f_{B_s}^2}{f_{B_d}^2}\frac{\tau_{B_s}}{\tau_{B_d}}\frac{|V_{ts}|^2}{|V_{td}|^2} \approx 32$$

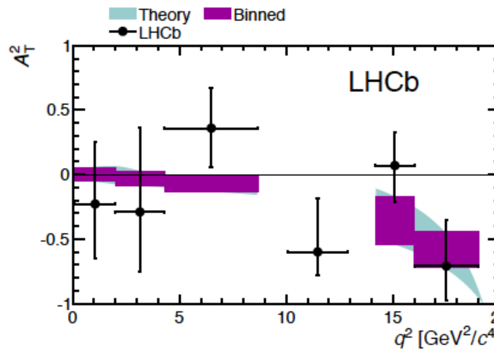
The rare decay $B \to K^* \mu^+\mu^-$

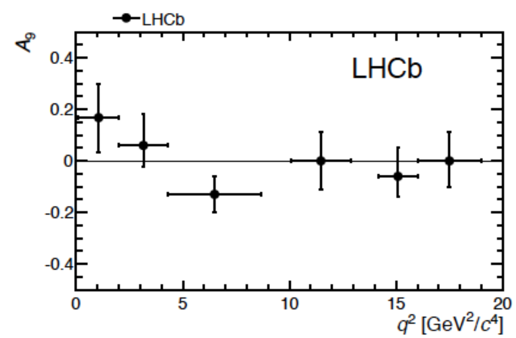
CERN-PAPER-2013-019 arXiv: 1304.6325

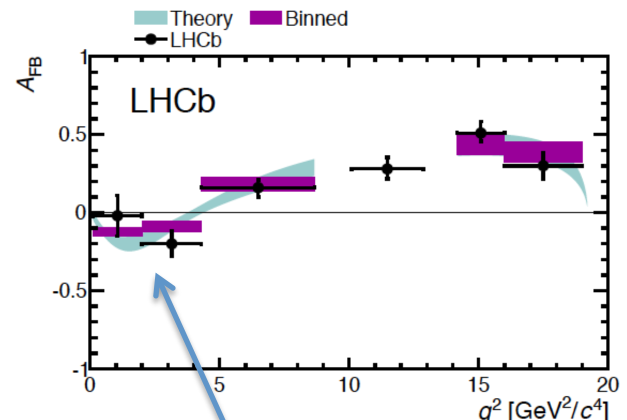
Angular analysis in $B \to K^{*0}(K^+\pi^-)\mu^+\mu^-$ sensitive to right-handed currents

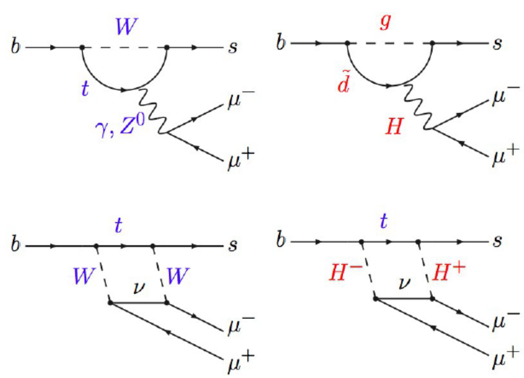
In the Standard Model, A_{FB} flips sign at a well defined q^2 point, no hadronic uncertainties : $q_0^2 = 4.36 \pm 0.33\ \mathrm{GeV}^2/c^4$











A_9 asymmetry : null test of CP violation in RH currents

$q_0^2 = 4.9 \pm 0.9\ \mathrm{GeV}^2$

Zero crossing point q_0^2 very sensitive to Flavour Blind MSSM models arXiv:0811.1214

Good agreement with SM predictions found

CDF, Belle, BaBar, ATLAS, CMS existing measurements not shown

$B \to K^{0(*)/+(*)} \mu^+\mu^-$ isospin asymmetries A_I

JHEP 07 (2012) 133

Definition A_I :

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

puzzling non-zero value 4.4σ

$A_I \approx 0$ in the SM ; sizeable (10%) deviations possible in only low q^2 (<1)
T. Feldman, J. Matias [JHEP 01(2002) 074]

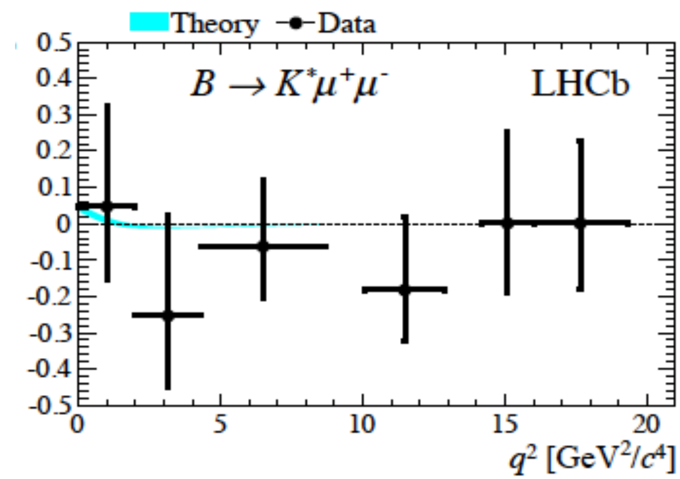
Branching ratios are reported:

BR ($B \to K^0 \mu^+\mu^-$) = $(0.31 \pm 0.08) \times 10^{-6}$

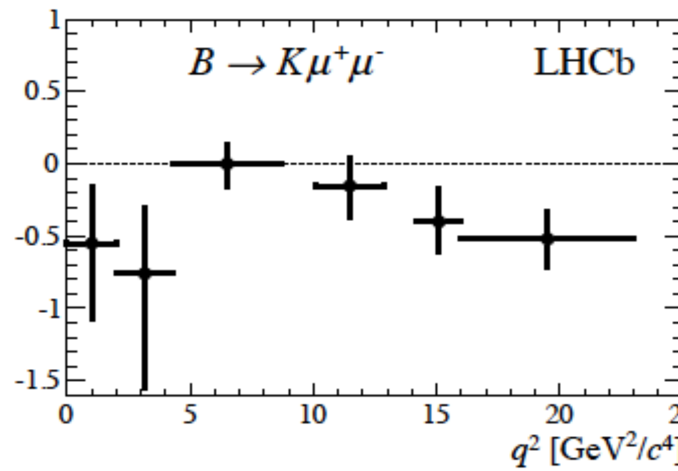
BR ($B^+ \to K^{*+} \mu^+\mu^-$) = $(1.16 \pm 0.19) \times 10^{-6}$

Previous measurements on A_I exist:
PRL 102 (2008) 091803 BaBar
PRL 103 (2009) 171801 Belle
consistent with LHCb data.

LHCb q^2-integrated measurements :



$A_I(B \to K^*\mu\mu)$:

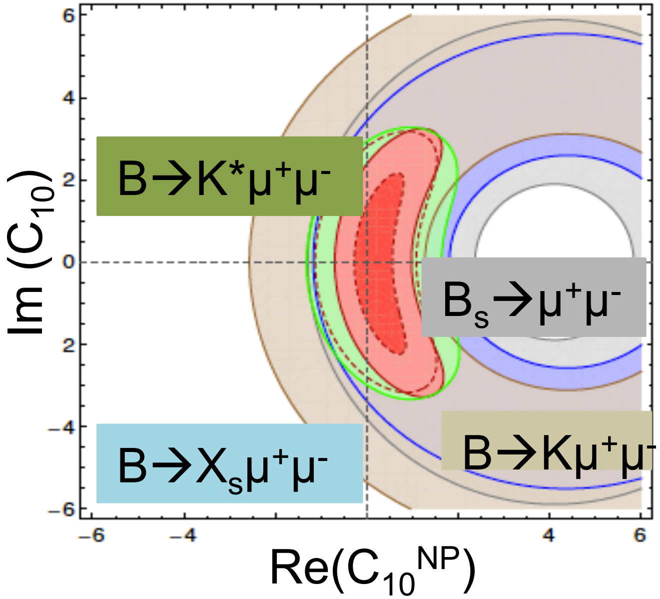


Combined leptonic and semileptonic B decays

arXiv:1206.0273

Constraints on new physics

Measurements of $B \to \mu\mu$, $B \to K^{*}\mu\mu$, $B \to X_s ll$, $b \to s\gamma$ set limits on the mass scale of non-SM contributions



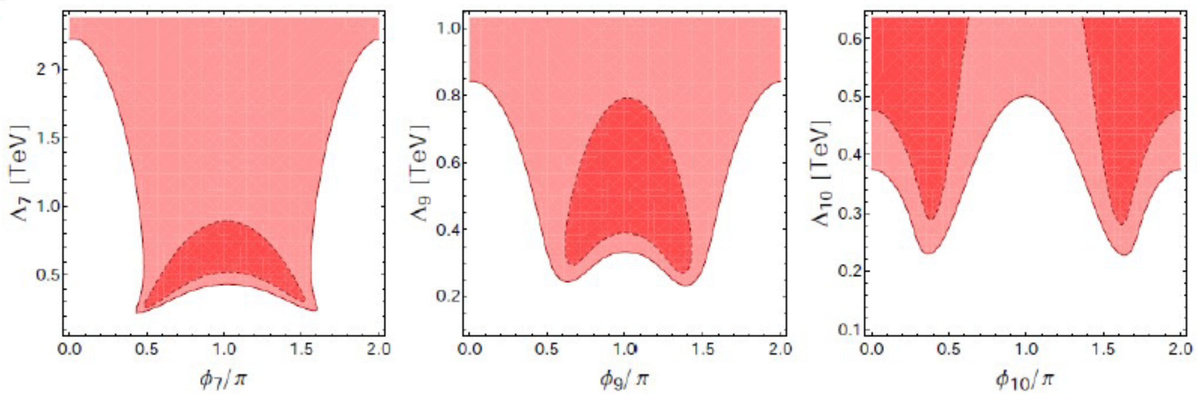
$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \sum (C_i O_i + C'_i O'_i) + h.c.$$

Effective Hamiltonian relevant for $b \to s\gamma$ and $b \to s l^{+} l^{-}$

~ loop level CKM-like flavour violation

$$L = L_{SM} - \sum_{j=7,9,10} \frac{V_{tb} V_{ts}^{*}}{16\pi^2} \frac{e^{i\phi_i}}{\Lambda_j^2} O_j$$

Almannshofer, Paradisi, Straub
JHEP 04 (2012) 008 + updates



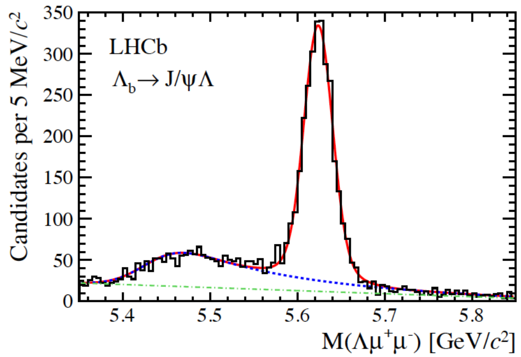
$$O_{10} = (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu \gamma_5 l) \quad O_9 = (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu l) \quad O_7 = \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu} P_R b)(F^{\mu\nu})$$

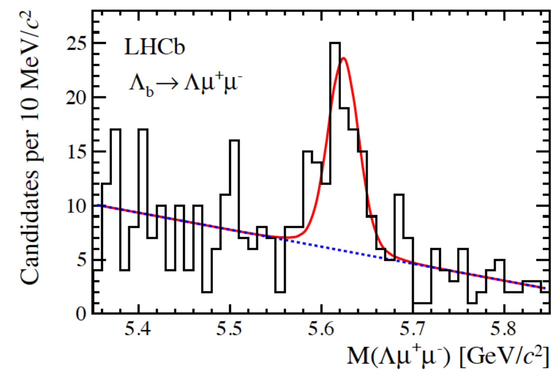
Nothing with SM type flavour couplings below O(400 GeV)

The rare decay $\Lambda_b \to \Lambda\mu^+\mu^-$

LHCb-PAPER-2013-025 arXiv: 1306.2577

- In the Standard Model, electroweak penguin sensitive to new Physics operators. Numerous predictions exist (see arXiv 1306.2577)
- poor experimental constraints on Λ_b hadronic form factors





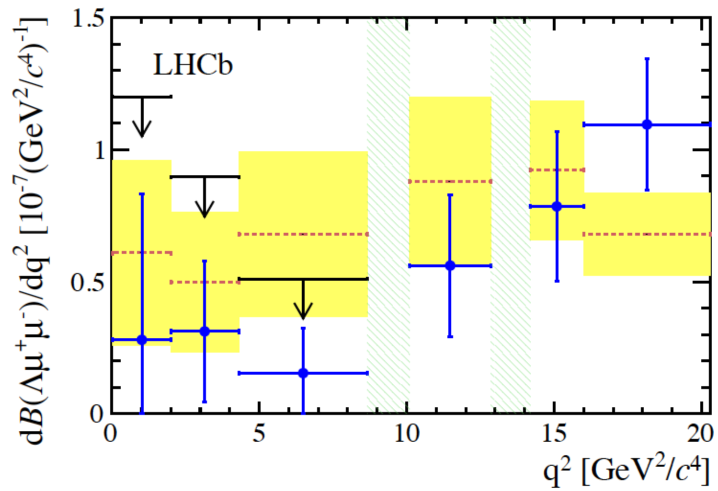
Originally observed by CDF :
BR ($\Lambda_b \to \Lambda\mu^+\mu^-$) = 1.73±0.42±0.55) x 10^{-6}
[PRL 107 (2011) 201802]

BR ($\Lambda_b \to \Lambda\ \mu\mu$) =
(0.96 ± 0.16 (stat) ± 0.13 (syst) ± 0.21 (norm)) x 10^{-6}

Differential branching fraction is measured as function of $q^2(\mu^+\mu^-)$

Normalization mode $\Lambda_b \to J/\psi\Lambda$ (2680±64 decays in LHCb, 1.0 fb^{-1})

Good agreement with SM within errors

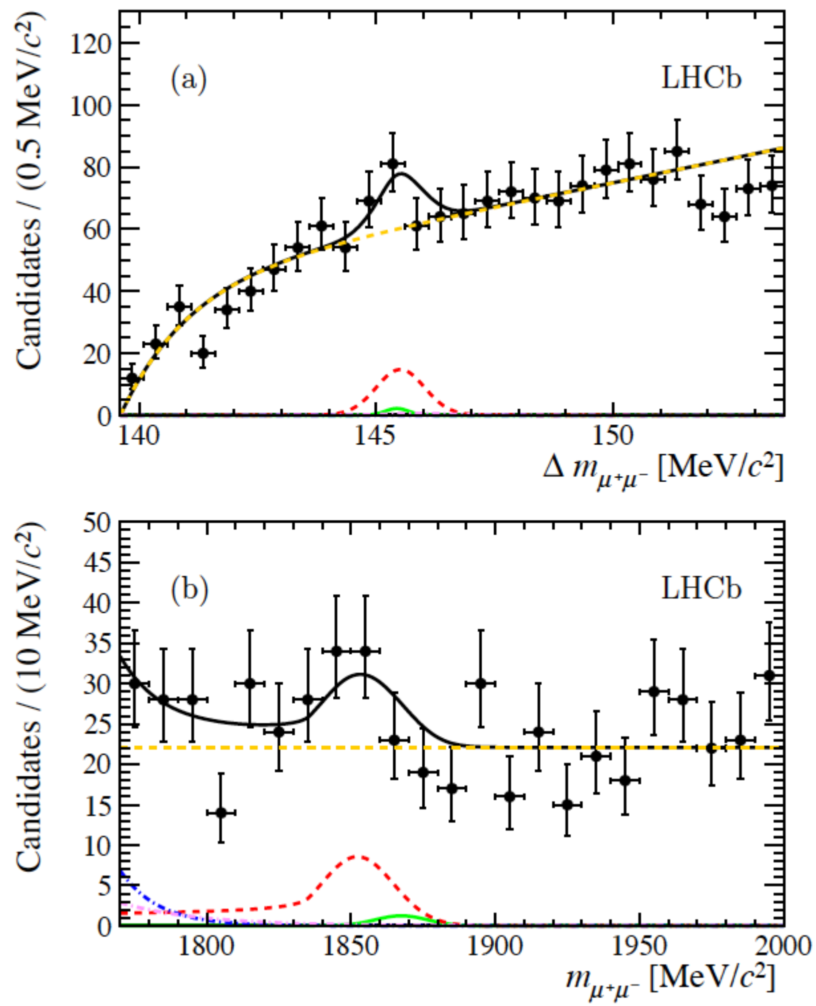


The rare decay $D^0 \to \mu^+\mu^-$

LHCb-PAPER-2013-013 arXiv: 1305.5059

- FCNC in $D^0 \to \mu\mu$ meson decays are extra suppressed in the SM, due to the absence of a high-mass down-type quark
- Short distance perturbative contribution is 6×10^{-11}, determined by known $BR(D^0 \to \gamma\gamma)$
- Current upper limit from Belle : $BR(D^0 \to \mu\mu) < 1.4 \times 10^{-7}$ (90% CL)

Models beyond the SM include R-parity violation, and Randall-Sundrum warped extra dimensions, with predictions ~ 10^{-10}



D^{*+} triggers are used from direct production in pp collisions, yielding 6201 ± 88 $D^{*+} \to D^0(\pi^+\pi^-)\pi^+$ normalization events [0.9 fb^{-1}]

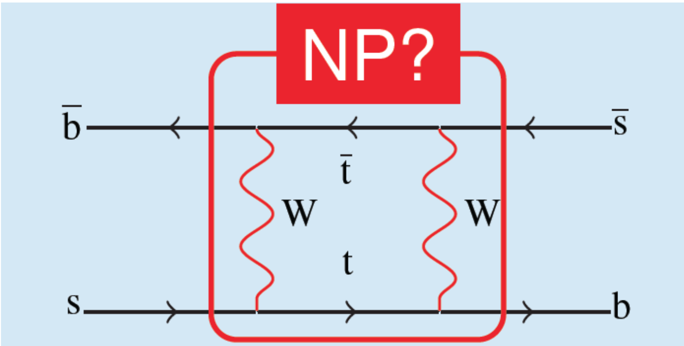
Peaking background from $D^0(\pi^+\pi^-)\pi^+$ misid.
Combinatorial background from (b,c) semileptonic decays.
No excess is observed, upper limit given:

$BR(D^0 \to \mu+\mu-) < 6.2 \times 10^{-9}$ at 90% CL

Factor > 20 improvement to current measurements

Probes for New Physics in B_s mixing

M_{12} mixing matrix sensitive to NP



- CPV in mixing $a^s_{fs} = |\Gamma_{12}/M_{12}| \sin\varphi_{12}$, $\varphi_{12} = \arg(-M_{12}/\Gamma_{12})$
- Mass difference: $\Delta m = m_H - m_L \approx 2|M_{12}|$
- Decay width difference: $\Delta\Gamma = \Gamma_H - \Gamma_L \approx 2|\Gamma_{12}| \cos\varphi_{12}$
- Phase difference between $B \to f$ and $B \to \bar{B} \to f$ (f: CP eigenstate), causing time-dependent CP violation

$$i\frac{d}{dt}\begin{pmatrix} |B_s(t)\rangle \\ |\bar{B}_s(t)\rangle \end{pmatrix} = \left(\begin{bmatrix} M_{11} & M_{12} \\ M_{12}^* & M_{11} \end{bmatrix} - \frac{i}{2}\begin{bmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma_{11} \end{bmatrix} \right) \begin{pmatrix} |B_s(t)\rangle \\ |\bar{B}_s(t)\rangle \end{pmatrix}$$

Golden channel: $B_s \to J/\psi\, (\mu^+\mu^-)\phi(K^+K^-)$ Decay amplitude A interferes with mixing

$\Phi_s = -\arg(\lambda)$ $\lambda = p/q\, (\bar{A}/A)$ Theoretically clean tree contribution

SM : $\Phi_s \approx 2\,\beta_s = -0.036 \pm 0.002$ (rad) sensitive to NP in B_s mixing
[J. Charles et al. PRD 84 (2011) 033005 , A. Lenz, U. Nierste arXiv: 1102.4274]

precise SM prediction from global fit ignoring penguin contribution.

Measurement of the mixing phase ϕ_s

Angular analysis from $B_s \rightarrow J/\psi(\mu\mu)\Phi(K^+K^-)$
K^+K^- P-wave: 0 (CP-even), || (CP-even), ⊥ (CP-odd)
Small S-wave amplitude: S (CP-odd)

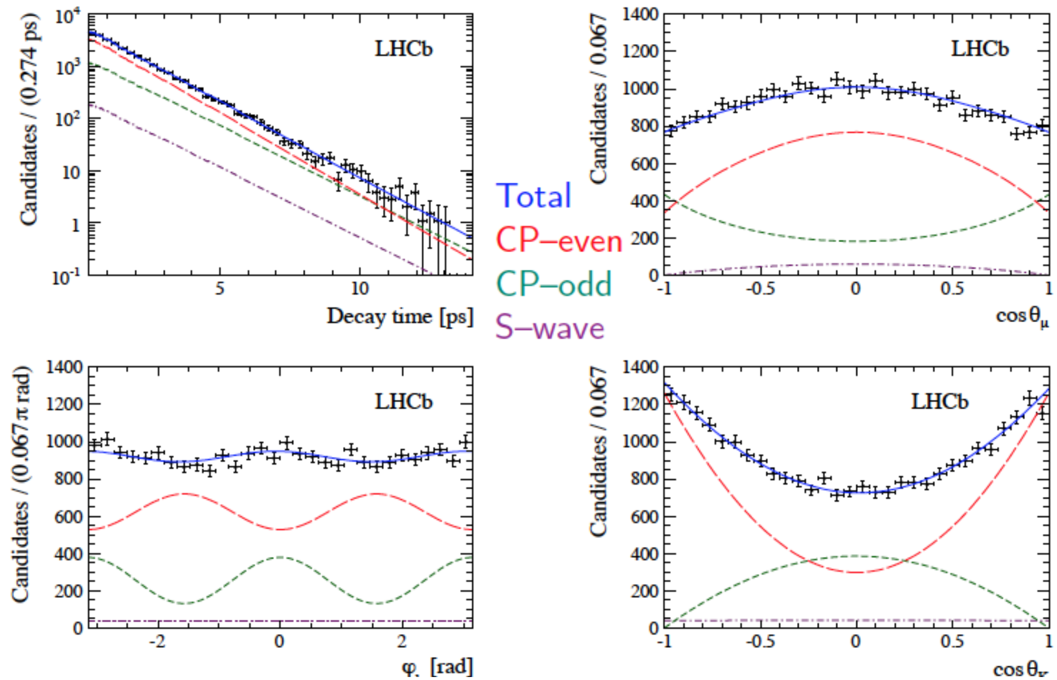
$$\frac{d\Gamma}{d\Omega} = \sum_i K_i(t) f_i(t) \quad \Omega = (\theta_\mu, \theta_K, \phi)$$

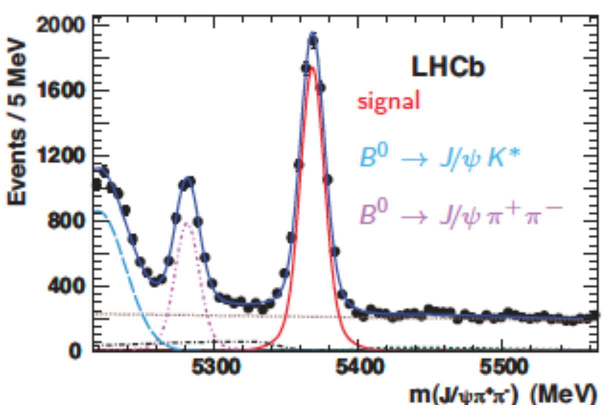
K_i (t) time-dependent operators:
Re $A_k^*(t)A_l(t)$, Im $A_k^*(t)A_l(t)$

Pure CP-odd analysis from $B_s \rightarrow J/\psi(\mu\mu)f_0(\pi^+\pi^-)$
No angular analysis needed

PRD 86 (2012) 052006

Γ_s and $\Delta\Gamma_s$ constrained to the result from $B_s \rightarrow J/\psi\, K^+K^-$



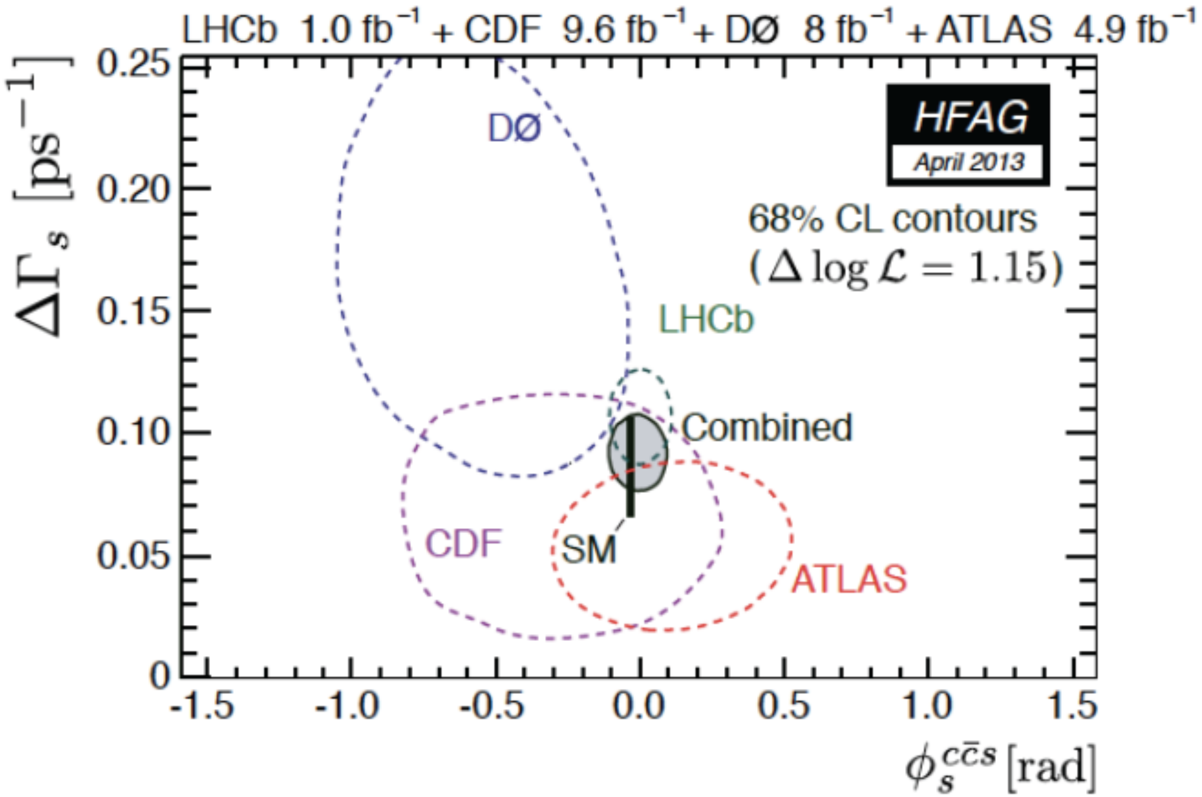


Combined fit of $B_s \rightarrow J/\psi\, K^+K^-$ and $B_s \rightarrow J/\psi\, \pi^+\pi^-$:

$$\phi_s^{c\bar{c}s} = 0.01 \pm 0.07 \pm 0.01 \text{ rad}$$

$$\Delta\Gamma_s = 0.106 \pm 0.011 \pm 0.007 \text{ ps}^{-1}$$

ϕ_s and $\Delta\Gamma_s$ comparison with other experiments

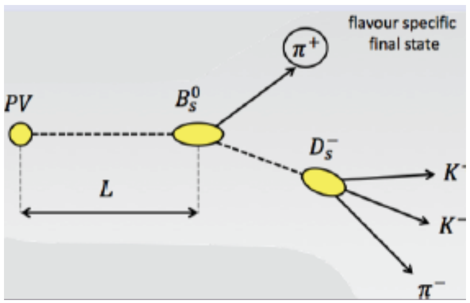


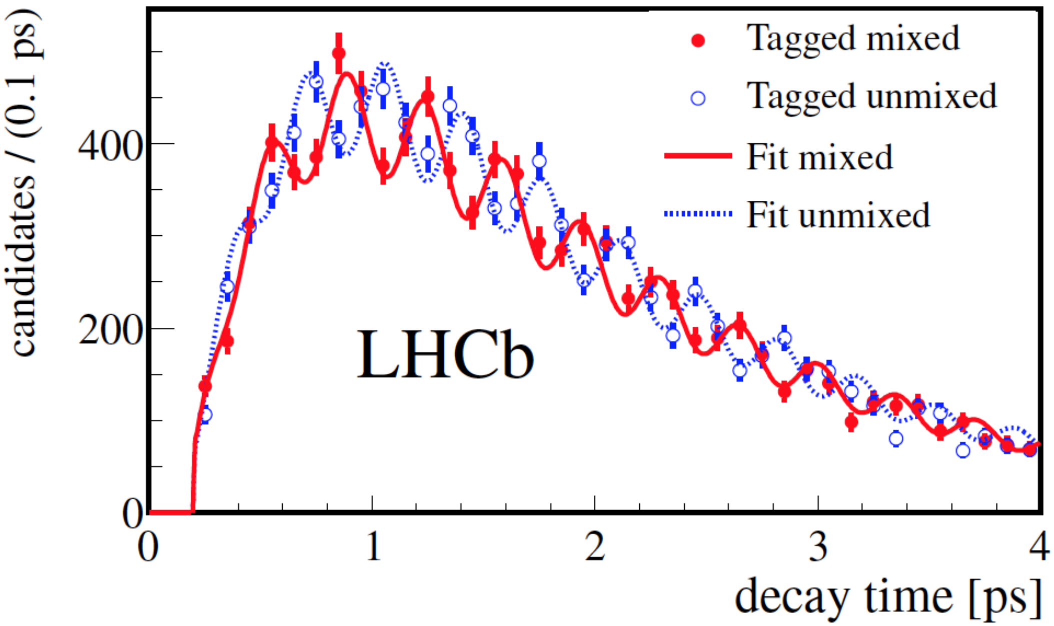
LHCb measurement is dominating world average. No big new Physics effect is observed. Precision improvement crucial to further test of the SM

Precision measurement of $B_s - \bar{B}_s$ oscillation frequency

$B_s \rightarrow D_s^- \pi^+$
time dependent, flavour tagged analysis
D_s^- decaying into 5 different
final states ($\phi\pi$, $KK\pi$, $K\pi\pi$, $\pi\pi\pi$)

Very clear oscillation pattern
B_s meson changes flavour ~ 9 times
($x = \Delta m_s/\Gamma_s = 26.9$)





Time resolution ~ 44 fs
Sizeble reduction of systematics:
decay length and momentum scale

NJP 15 (2013) 053021 arXiv: 1304.4741

Consistent with :
World average [PDG, PRD 86 (2012) 010001]
$\Delta m_s = 17.69 \pm 0.08\ ps^{-1}$
SM expectation [A. Lenz U. Nierste, arXiv: 1102.4274]
$\Delta m_s = 17.3 \pm 2.6\ ps^{-1}$
Need better precision on hadronic parameters
from latice QCD

Most precise measurement to date
$\Delta m_s = 17.768 \pm 0.023$ (stat) $\pm$ 0.006 (syst) ps^{-1}

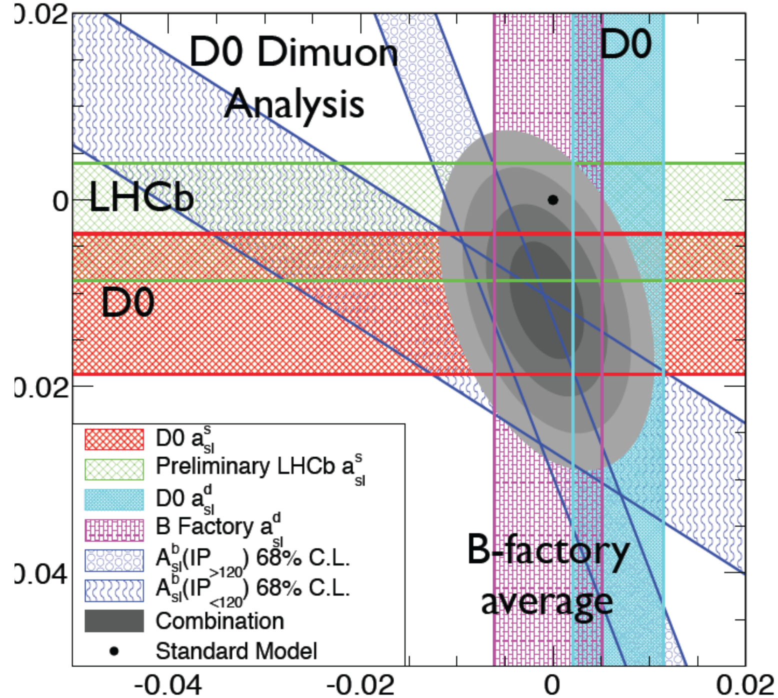
Semileptonic CP-asymmetry

LHCb-CONF-2012-022

D0 measured like-sign dimuon asymmetry:

$$a_{sl}^{b} = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}} \approx 0.6 a_{sl}^{d} + 0.4 a_{sl}^{s}$$

and observed anomalous asymmetry:
a^b_{sl}= (- 0.787 ± 0.172 ± 0.093) x 10^{-2}



About 40K for each charge

LHCb pp collisions are not CP-symmetric as pp are. However LHCb can measure the time integrated CP asymmetry:

$$a_{sl}^{s} = \frac{\Gamma(B_s^0 \to D_s^- \mu^+) - \Gamma(\bar{B}_s^0 \to D_s^+ \mu^-)}{\Gamma(B_s^0 \to D_s^- \mu^+) + \Gamma(\bar{B}_s^0 \to D_s^+ \mu^-)} \approx 1 - \left|\frac{q}{p}\right|^2$$

- Leading systematics associated with efficiency ratio $\varepsilon(D_s^- \mu^+)/\varepsilon(D_s^+ \mu^-)$, from calibration samples

LHCb obtains : a^s_{sl}= (- 0.24 ± 0.54 ± 0.33) x 10^{-2}

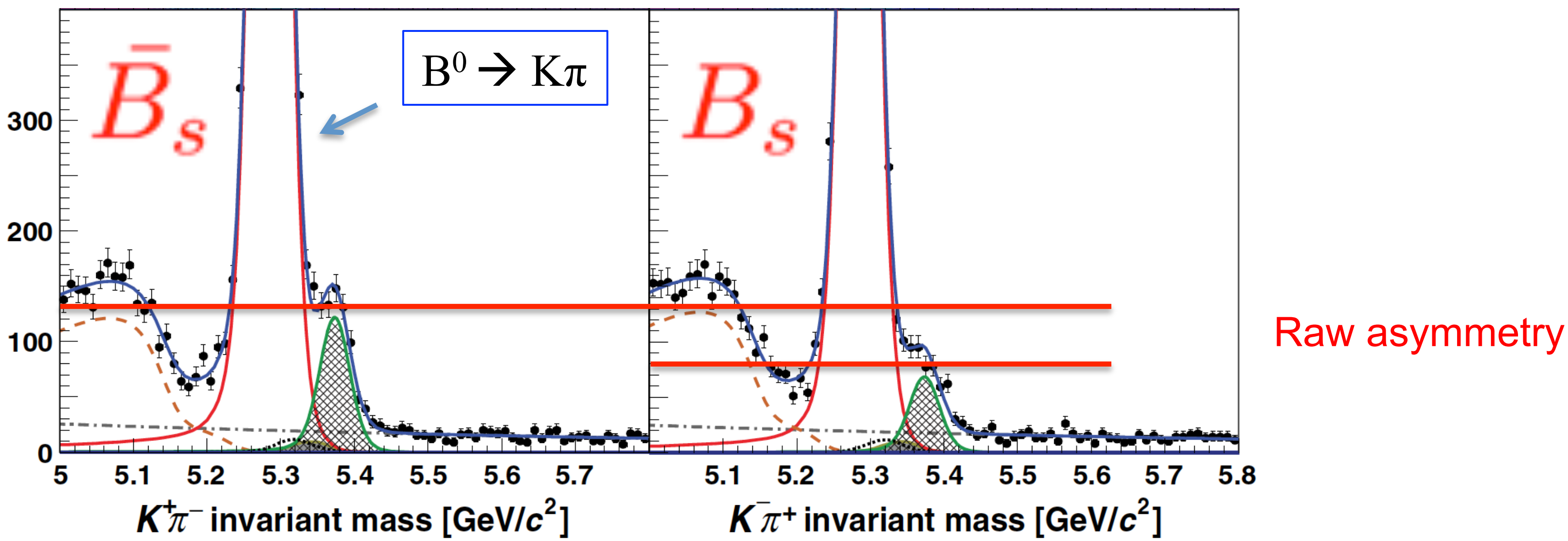
Standard Model prediction : a^s_{sl}= (1.9 ± 0.3) x 10^{-3} A. Lenz arXiv205:1444

First observation of CPV in B_s decays

PRL 110, 221601 (2013)

Study of charmless B decays (interesting as they are penguin dominated)
Goal: obtain γ from time dependent analysis and compare with γ from tree

First 5σ observation of CP violation in $B_s \to K\pi$ decays (thanks to RICH PID capabilities)



After corrected for production and detector asymmetries (small: ~ 1%)

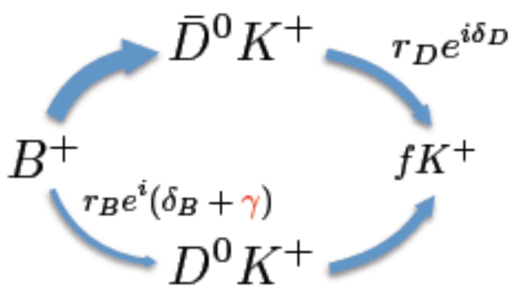
$A_{CP} = 0.27 \pm 0.04 \pm 0.01$ ($1 fb^{-1}$ sample)

B_s is the 4th particle known to show direct CP violation after $K^0_{[1964]}$, $B^0_{[2000]}$, $B^\pm_{[2006]}$

CKM γ angle measurement

$$\gamma = \arg\left[- V_{ud}V^{*}_{ub} / (V_{cd}V^{*}_{cb})\right]$$

The angle γ is the least known variable of the CKM unitarity triangle

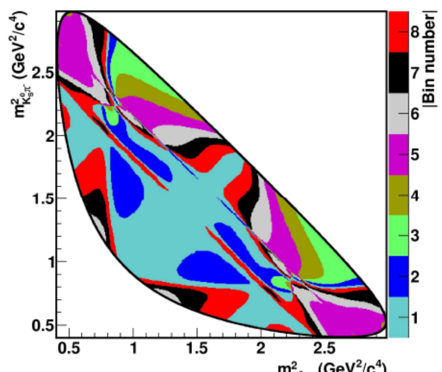


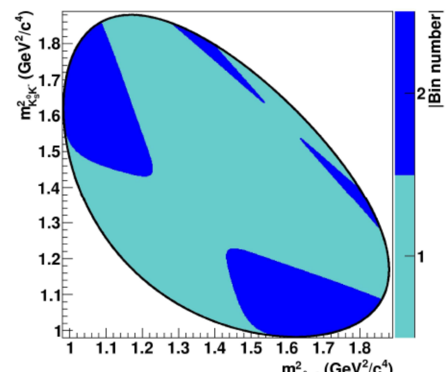
Strong phase varies over the 3-body phase space. It has been measured by CLEOc with quantum-correlated D^0-$\bar{D}^0$ data :

Phys. Rev. D82 (2010) 112006

Giri, Grossman, Soffer and Zupan (GGSZ) deals with self conjugate 3-body final states f = D :
D → K_s ππ and K_sKK

Phys. Rev. D68 (2003) 054018





$$N^{+}_{\pm i} = h_{B^+}[K_{\mp i} + (x_+^2 + y_+^2)K_{\pm i} + 2\sqrt{K_i K_{-i}}(x_+ c_{\pm i} \mp y_+ s_{\pm i})]$$
$$N^{-}_{\pm i} = h_{B^-}[K_{\pm i} + (x_-^2 + y_-^2)K_{\mp i} + 2\sqrt{K_i K_{-i}}(x_- c_{\pm i} \pm y_- s_{\pm i})]$$

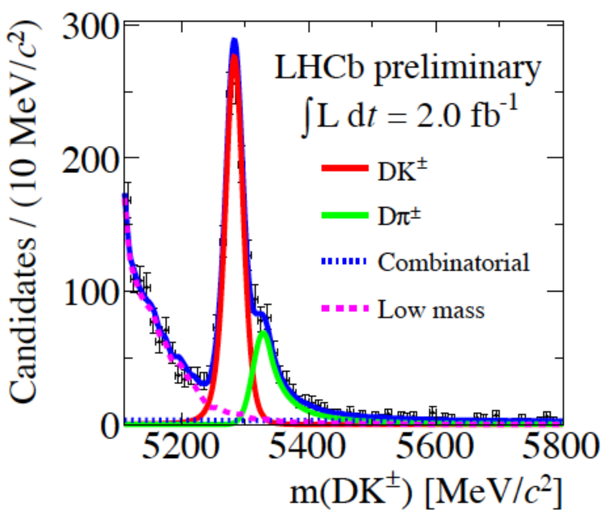
$x_\pm = r_B \cos(\delta_B \pm \gamma)$ $y_\pm = r_B \sin(\delta_B \pm \gamma)$

$c_i = \cos(\Delta\delta_D)$

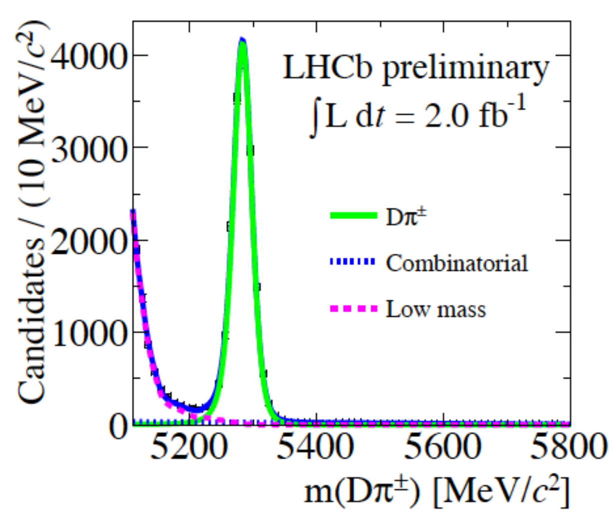
LHCb-CONF-2013-004

Excellent signal/noise after constrained fit,
multivariate selection (BDT)
and PID requirements in RICH detector :

$B^{\pm} \rightarrow (K^0_s\pi^+\pi^-)_D K^{\pm}$

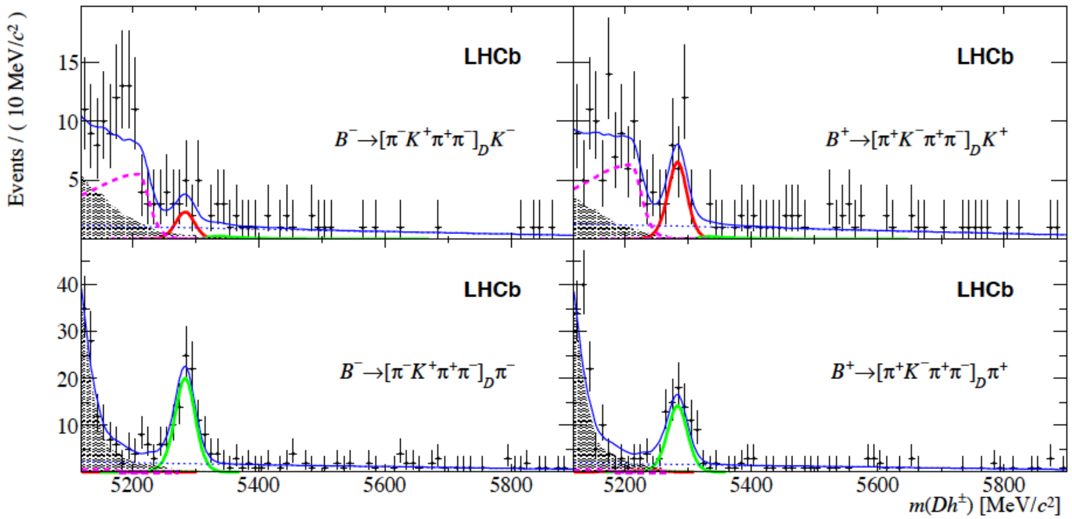


$B^{\pm} \rightarrow (K^0_s\pi^+\pi^-)_D \pi^{\pm}$



First observation of suppressed ADS modes

First observation of $B^+ \rightarrow [\pi^+ K^- \pi^+ \pi^-]_D K^+$ (5.7σ)
and $B^+ \rightarrow [\pi^+ K^- \pi^+ \pi^-]_D \pi^+$ (10σ)
ADS suppressed modes [$1 fb^{-1}$ data]



Measurement of the suppressed-to-favoured $B^{\pm} \rightarrow DK^{\pm}$ amplitude ratio : $r_B^K = 0.097 \pm 0.011$. Other observables also measured relating the partial widths of $B^{\pm} \rightarrow Dh^{\pm}$, essential to improve a combined determination of γ from all $B^{\pm} \rightarrow DK^{\pm}$ modes.

LHCb-PAPER-2012-055

New LHCb measurement of CKM γ angle

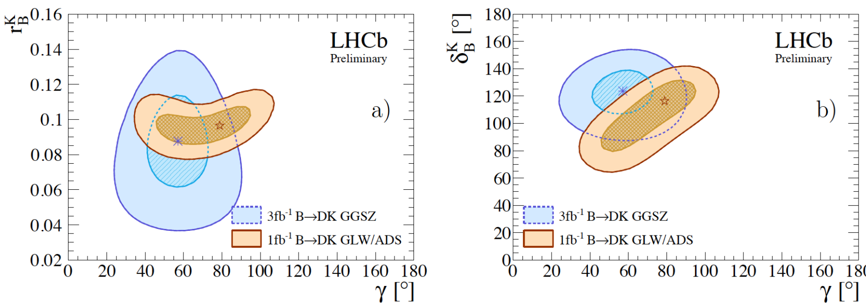
LHCb-CONF-2013-006

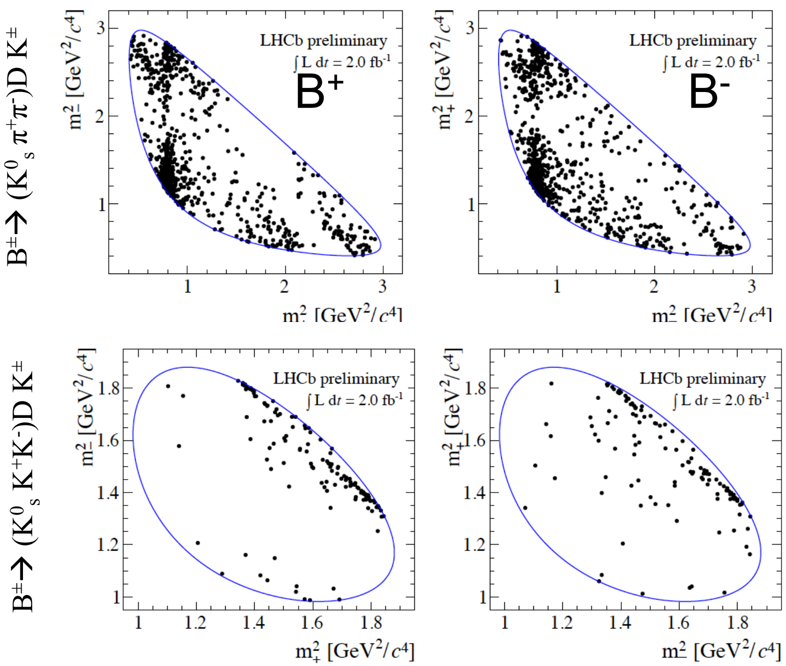
Update of GGSZ analysis with 3 fb^{-1} at Beauty 2013. New combination with earlier LHCb data from GLW/ADS (1 fb^{-1}) brings a significant decrease of the error :

$$\gamma = (67 \pm 12)^o$$

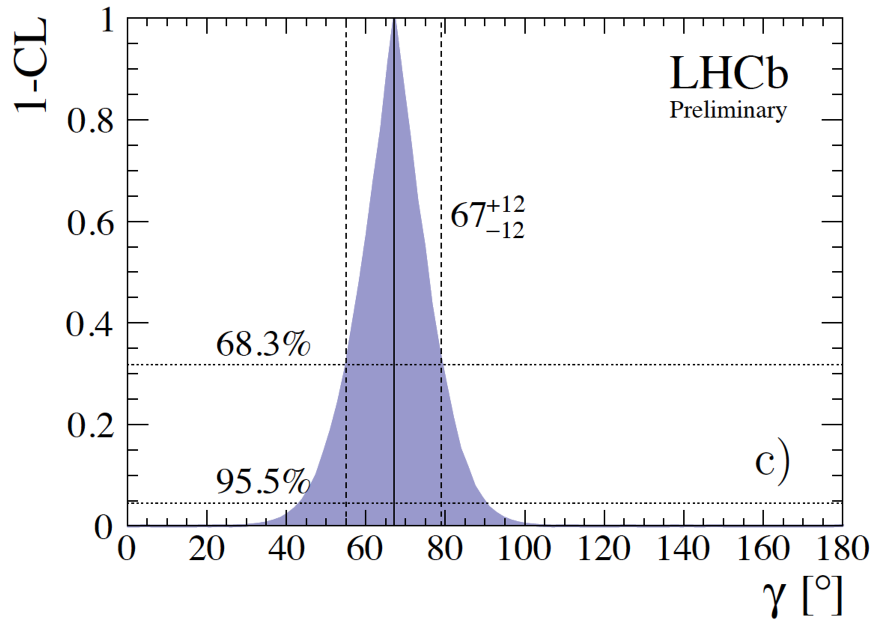
LHCb now world's most precise

Combined result :





B → DK combination :



Future on γ angle measurement

More to come in the next years on γ determination :

- Update analysis to full dataset, all modes (3 fb^{-1})
- Until 2018 : collect up to 10 fb^{-1}
- γ from loops induced processes
- Prospects for the LHCb upgrade (~ 50 fb^{-1}) [**arXiv: 1208.3355**] :
  γ combined uncertainty **$\delta\gamma \sim O(1^o)$**

Mixing and CP violation in charm

- CP violation in charm is an important piece of the Standard Model, and it is usually seen as a portal to new Physics
- The discovery of non-zero $O(10^{-2})$ charm mixing and signals of CPV drew a great deal of attention to the field
- SM predictions are actually difficult due to long-distance processes, and a strong theory activity has taken place, both within and beyond the SM. CP-asymmetries would be as large as $O(10^{-2})$

D^0 mixing from prompt $D^{*+} \rightarrow D^0 \pi^+_s$

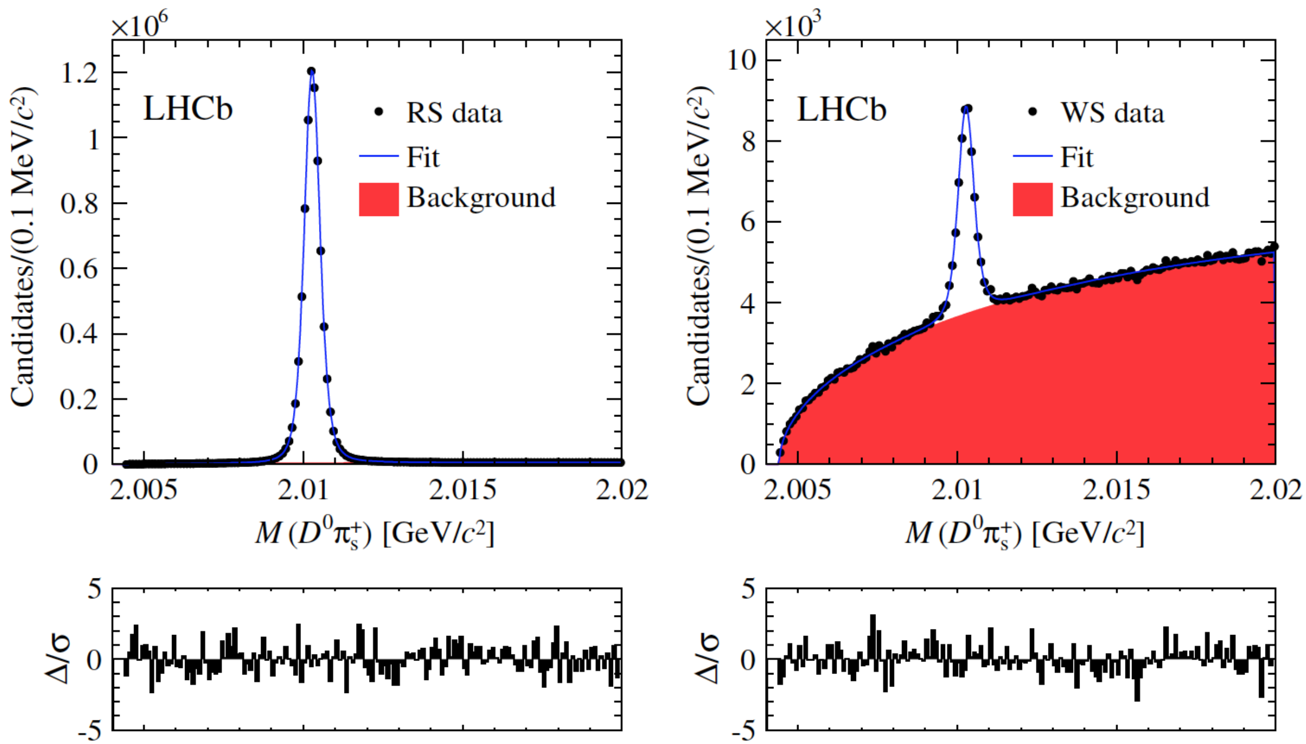
Based on ratio of wrong-sign to right-sign decay rates:

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

PRL 110 (2013) 101802

$D^{*+} \rightarrow D^0 (K^- \pi^+) \pi^+_s$, $D^{*+} \rightarrow D^0 (K^+ \pi^-) \pi^+_s$ where pion charge tags D flavor

(8.4×10^6 decays) (3.6×10^4 decays)



D^0 mixing from prompt $D^{*+} \rightarrow D^0 \pi^+_s$

LHCb [**1.0 fb-1 (2011)**]

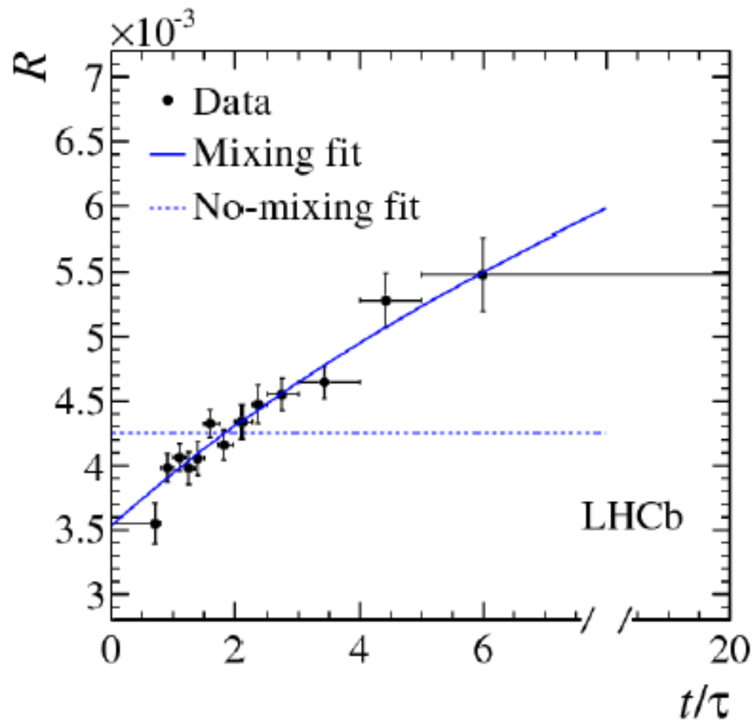
Phys. Rev. Lett. 110,101802 (2013)

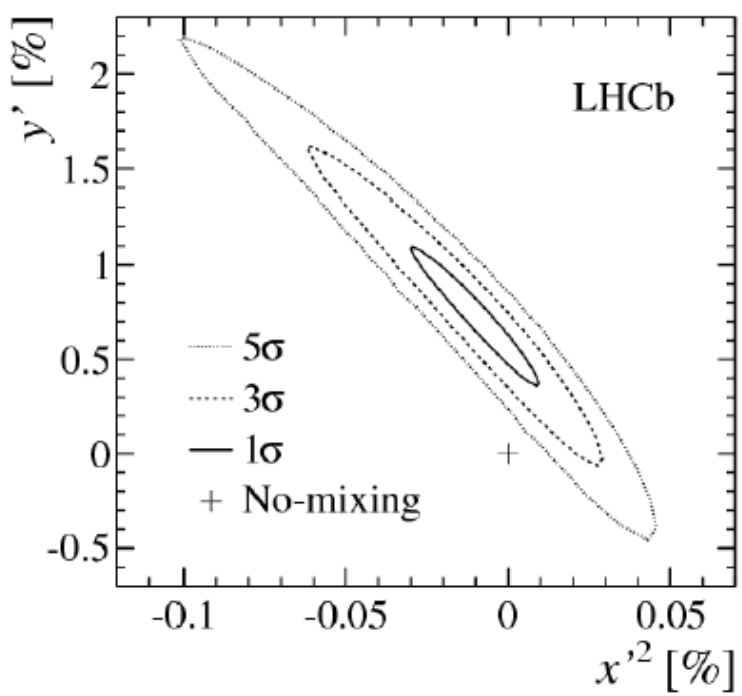
$x'^2 = (-0.9 \pm 1.3) \times 10^{-4}$

$y'^2 = (7.2 \pm 2.4) \times 10^{-3}$

$R_D = (3.52 \pm 0.15\ (stat. + sys.)) \times 10^{-3}$

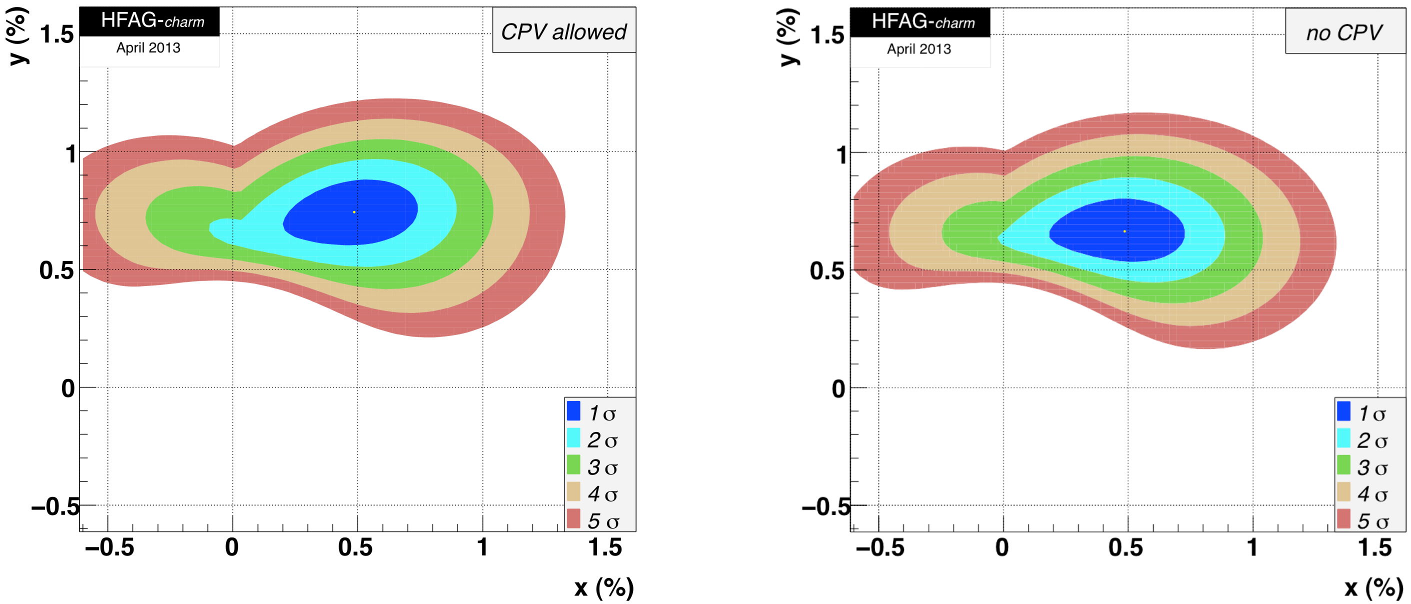
Result excludes the no-mixing hypothesis at 9.1σ





D^0- $\bar{D}^0$ oscillations - new HFAG averages

http://www.slac.stanford.edu/xorg/hfag/charm



$$\langle x \rangle = (0.49^{+0.17}_{-0.18})\% \qquad \langle y \rangle = (0.66 \pm 0.09)\%$$

$$\langle x \rangle = (0.49^{+0.17}_{-0.18})\% \qquad \langle y \rangle = (0.74 \pm 0.09)\%$$

Mixing parameters rotated by strong phase difference
between CF and DCS : $x' = x\cos(\delta) + y\sin(\delta)$ $\quad y' = y\cos(\delta) - x\sin(\delta)$

ΔA_{CP} from $D^0 \rightarrow h^+h^-$ decays

Time dependent asymmetry for D^0 decays to a CP eigenstate :

$$A_{CP}(f;t) = \frac{\Gamma(D^0(t)\to f) - \Gamma(\bar{D}^0(t)\to f)}{\Gamma(D^0(t)\to f) + \Gamma(\bar{D}^0(t)\to f)} = a_{CP}^{dir}(f) + \frac{t}{\tau} a_{CP}^{ind}$$

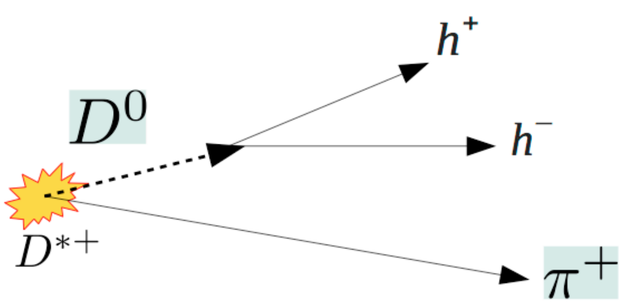
- Measure ΔA_{CP} between $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$ decays
- Assume equal decay time acceptance for K^+K^- and $\pi^+\pi^-$
- Two datasets:
  - Prompt: $D^{*+} \rightarrow (D^0 \rightarrow h^+h^-)\, \pi^+_{soft}$ **Update**
  - Secondary: $B \rightarrow (D^0 \rightarrow h^+h^-)\, \mu\, X$ **New result**

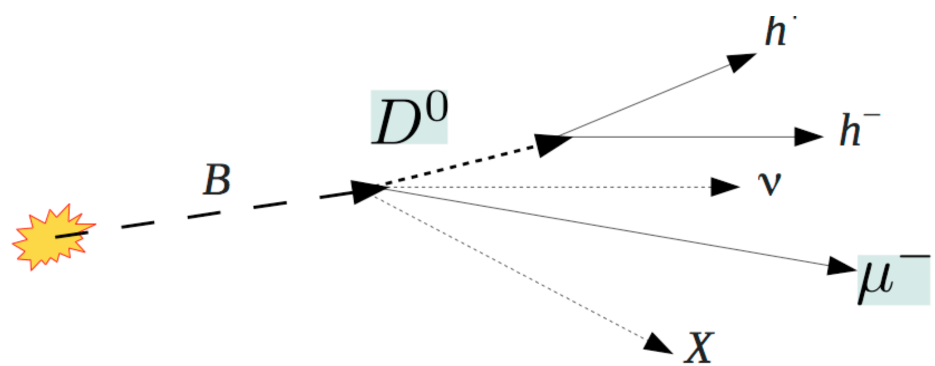
Little overlap between them (statistics and systematics)

- In both cases assume:

$$\Delta A_{CP} = A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+) = \left[a_{CP}^{dir}(K^-K^+) - a_{CP}^{dir}(\pi^-\pi^+)\right] + \frac{\Delta\langle t\rangle}{\tau_D} a_{CP}^{ind} \approx A_{raw}(K^-K^+) - A_{raw}(\pi^-\pi^+)$$

- Insensitive to indirect CP violation $\rightarrow$ universal to both final states



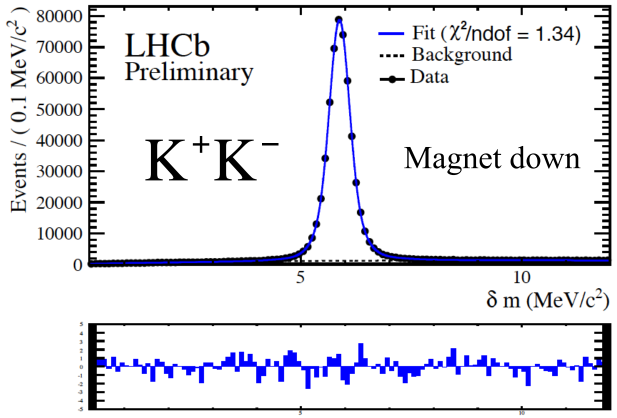


ΔA_{CP} from prompt $D^{*+} \to D^0 \pi^+_s$

Raw asymmetry given by:

- $A_{raw}(t) = A_{CP}(t) + A_D(t) + A_D(\pi_s^+) + A_P(D^{*+})$
- To first order $A_D(f)=0$ with f=self-conjugate and $A_D(\pi_s^+)$, and $A_P(D^{*+})$ depend on D^{*+} kinematics
- Events weighted to match kinematics of KK and $\pi\pi$
- Soft pion and D^0 constrained to primary vertex
- Yields obtained from fits to $\delta m = m(D^*) - m(D) - m(\pi^+)$

$$\Delta A_{CP} = \left[a_{CP}^{dir}(K^-K^+) - a_{CP}^{dir}(\pi^-\pi^+)\right] + \frac{\Delta\langle t\rangle}{\tau_D}$$



Previous result from LHCb

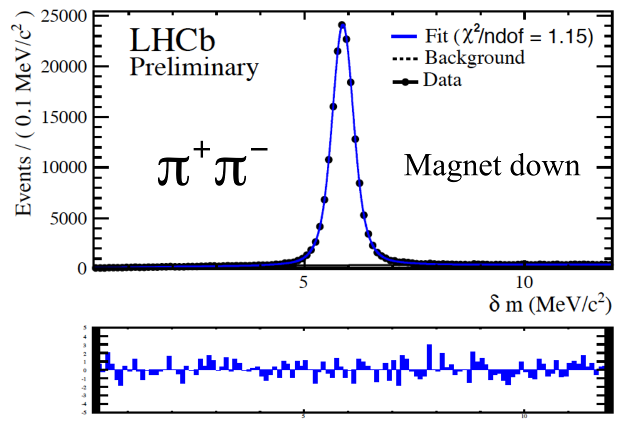
ΔA_{CP} = (-0.82 ± 0.21 (stat) ± 0.11 (syst))%

Phys. Rev. Lett. 108 (2012) 111602

Triggered a great deal of interest

Update of CPV at LHCb :

now includes full 1.0 fb^{-1} from 2011



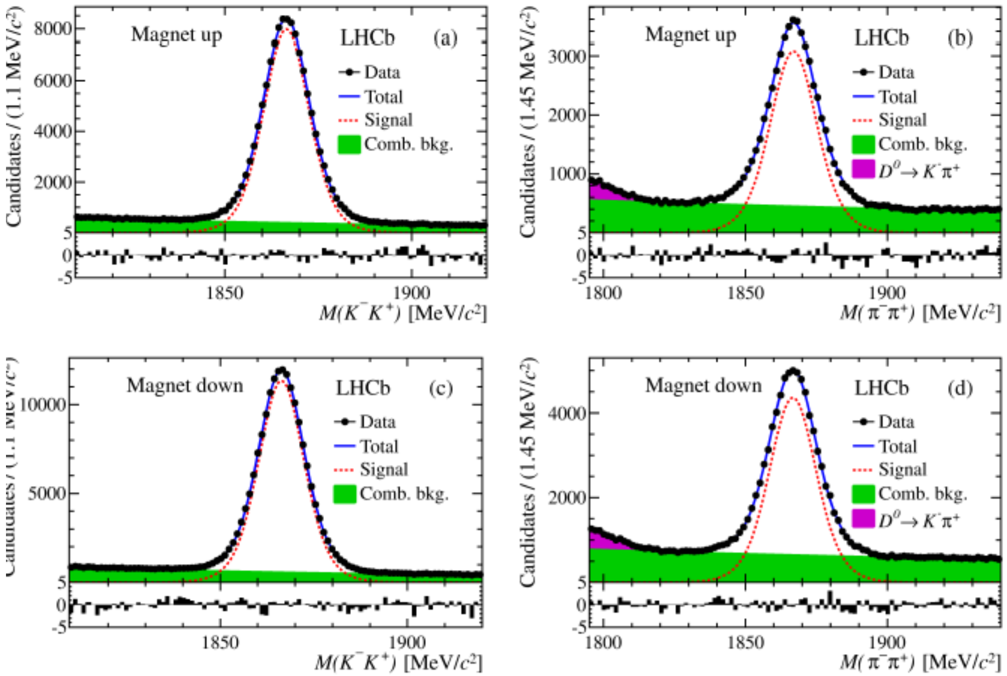
LHCb-CONF-2013-003

ΔA_{CP} = -0.34 ± 0.15 (stat) ± 0.10 (syst) %

consistent with previous measurements but does not confirm the evidence of CPV previously reported.
2012 data set (2 fb^{-1}) currently being analysed

ΔA_{CP} in D → h^+h^- from B→$D^0\mu X$

Flavour of D tagged from charge of muon



LHCb-PAPER-2013-003
submitted to Phys. Lett. B

LHCb [1.0 fb^{-1} (2011)] ΔA_{CP} =
(+0.49 ± 0.30 (stat) ± 0.14 (syst))%

It does not confirm the direct CPV observed in other analyses

- Raw asymmetry can be approximated to $A_{raw} = A_{CP} + A^{\mu}_{D} + A^{B}_{P}$
- A^{B}_{P} is the b/$\bar{b}$ production asymmetry, independent of the final state particles
- Re-weight D^0 (p_T, η) distributions to account for differences in A^{μ}_{D} between the ππ and KK final states

ΔA_{CP} from $D^0 \rightarrow h^+h^-$ decays

Prompt: ΔA_{CP} = (-0.34 ± 0.15 (stat) ± 0.10 (syst))%

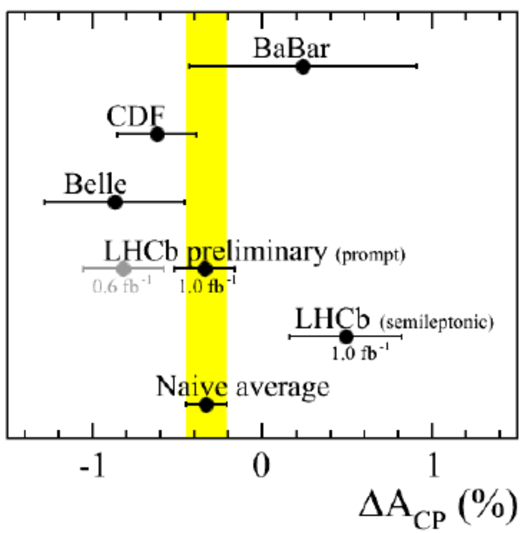
Secondary: ΔA_{CP} = (+0.49 ± 0.30 (stat) ± 0.14 (syst))%

Both consistent with no *CP* violation hypothesis

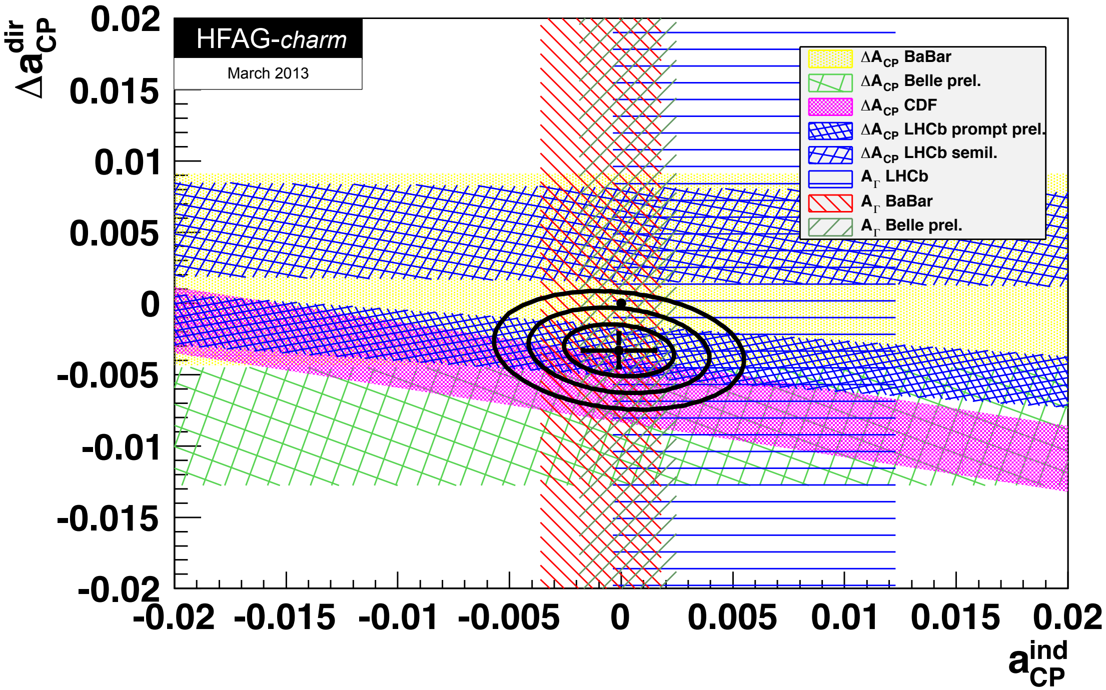
LHCb-PAPER-2013-003

ΔA^{dir}_{CP} = (-0.329 ± 0.121)%

ΔA^{ind}_{CP} = (-0.010 ± 0.162)%



Agreement with no CPV hypothesis – CL = 2.1 x 10^{-2}



World average: ΔA^{dir}_{CP} = (-0.329 ± 0.121)%

[Heavy Flavour Averaging Group]

Summary

- Interest in precision flavour measurements is stronger than ever

- A few interesting anomalies , but agreement with SM is so far excellent
  → large NP contributions O(SM) ruled out in many cases

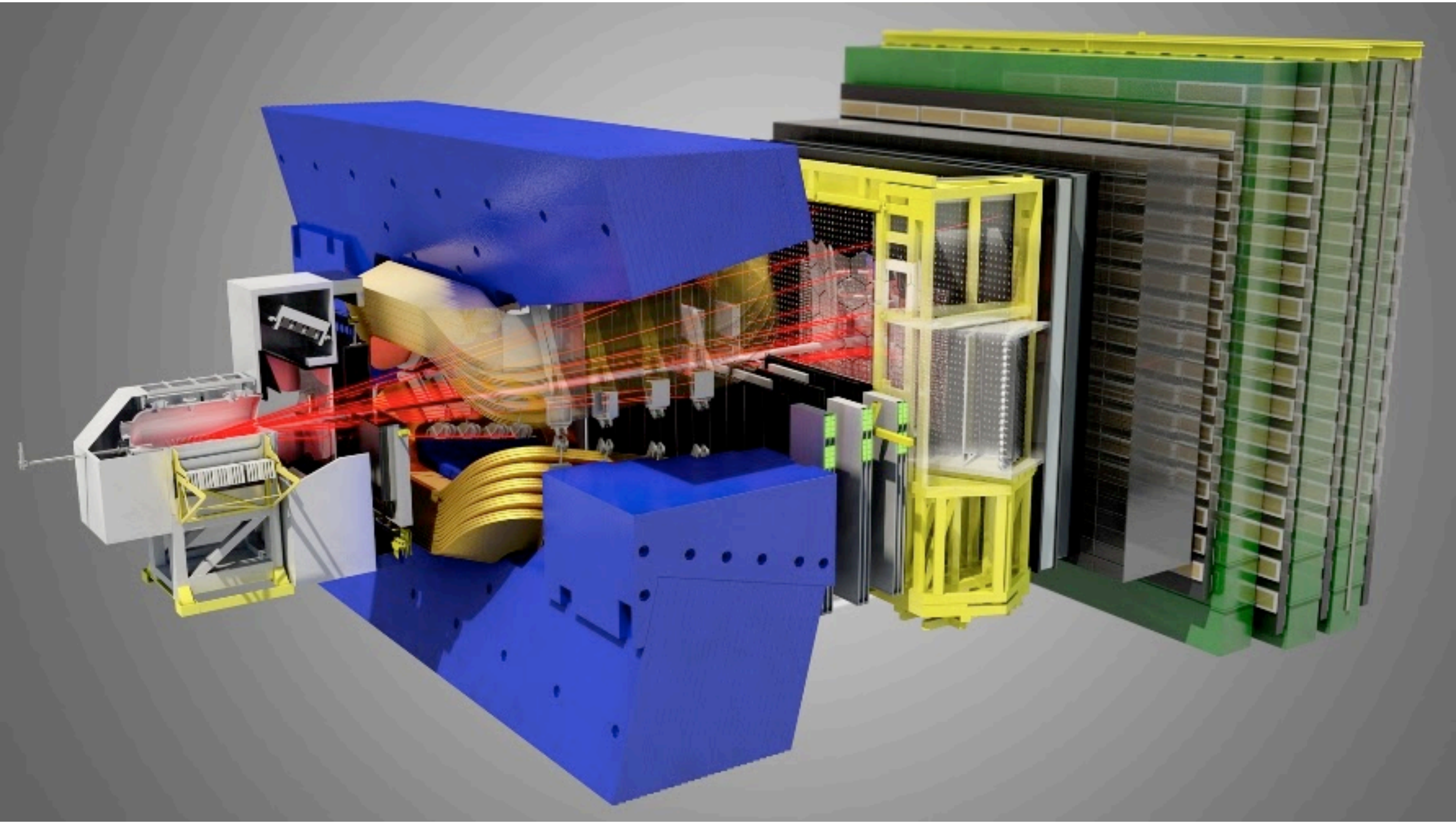
- New Physics can be found by precision measurements of the coupling of the new Higgs scalar, or by precision measurements in the flavour sector. Both just equally worth.

- The search has just started at LHCb with 1+2 fb^{-1} at 7-8 TeV

- **LHCb upgrade** (starting 2019) plans to collect ~ 50 fb^{-1} with two times $b\bar{b}$ cross-section. By 2022 **ATLAS / CMS** plan to collect ~ 300 fb^{-1} and **Belle II** plans for ~ 50 ab^{-1}

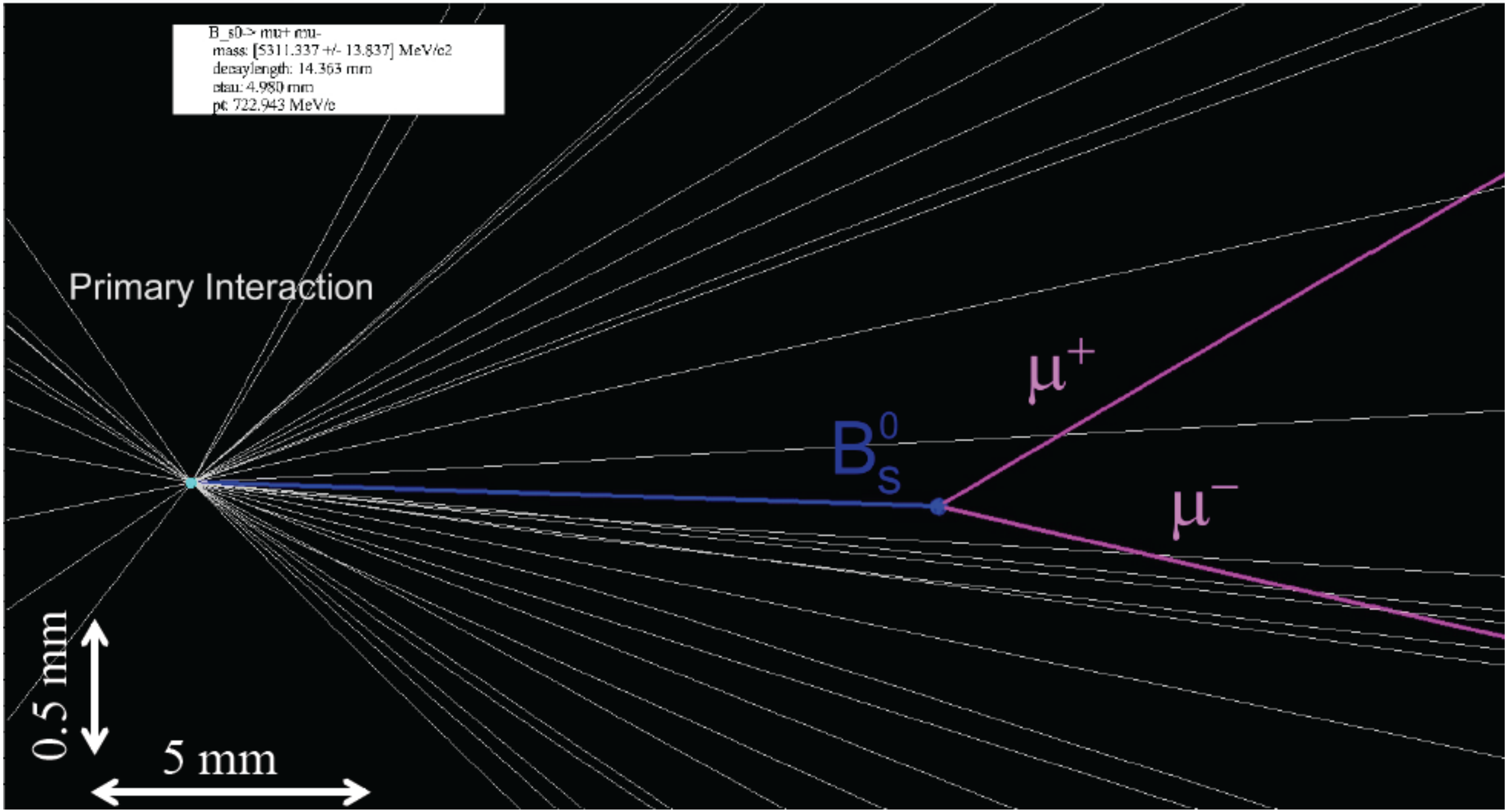
The scale of new Physics may well be unveiled by then

THE END



BACKUP

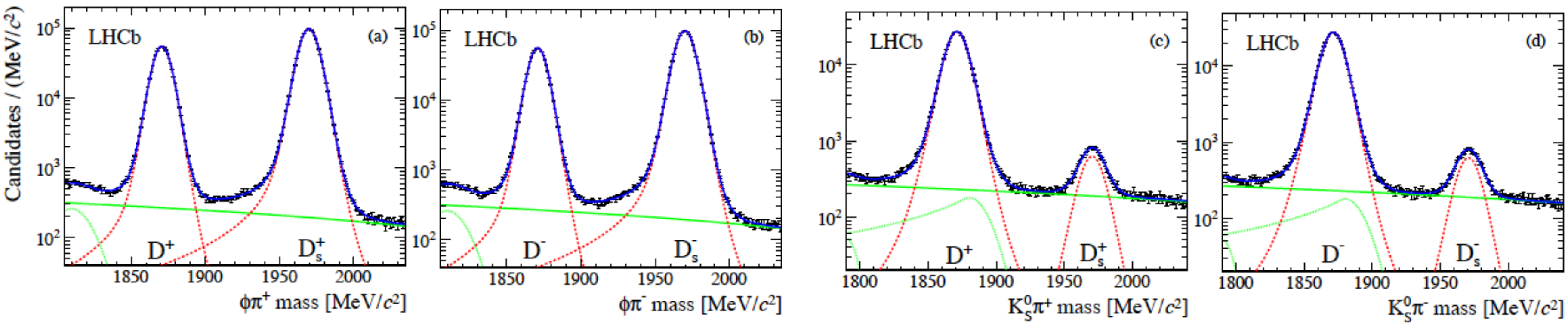
$B_s \rightarrow \mu^+\mu^-$ event



CPV in $D^+ \to \phi\pi^+$ and $D^+_s \to K^0_s \pi^+$

Measure ΔA_{CP} from difference in A_{raw} between $D^+ \to \phi\pi^+$ and $D^+_s \to K^0_s \pi^+$

Also extract ΔA_{CP} from SCS $D^+_s \to K^0_s \pi^+$ and CF $D^+ \to \phi\pi^+$



Assume CPV in D^+ from CF/DCS interference negligible

Small effect of CPV in K^0_s decay in $A_{CP}(K^0/K^0)$

$$A_{CP}(D^+ \to \phi\pi^+) = A_{raw}(D^+ \to \phi\pi^+) - A_{raw}(D^+ \to K_s\pi^+) + A_{CP}(K^0/\bar{K}^0)$$
$$A_{CP}(D_s^+ \to K_s\pi^+) = A_{raw}(D_s^+ \to K_s\pi^+) - A_{raw}(D_s^+ \to \phi\pi^+) + A_{CP}(K^0/\bar{K}^0)$$

$$A_{CP}(D^+ \to K_s\pi^+) \approx A_{CP}(D_s^+ \to \phi\pi^+) \approx 0$$

LHCb [1.0 fb^{-1} (2011)]

$A_{CP}(D^+ \to \phi\pi^+) = [\,-0.04 \pm 0.14\,(stat) \pm 0.13\,(syst)\,] \times 10^{-2}$

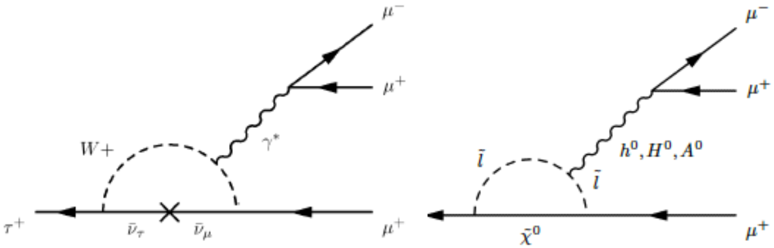
$A_{CP}(D^+ \to K_s\pi^+) = [\,0.61 \pm 0.83\,(stat) \pm 0.13\,(syst)\,] \times 10^{-2}$

arXiv: 1303.4906 (2013)

Lepton Flavour Violation in $\tau^\pm \rightarrow \mu^+\mu^-\mu^\pm$

LHCb-PAPER-2013-014

LFV decay $\tau \rightarrow \mu\mu\mu$
In SM only allowed via neutrino oscillations with **BR ~ 10^{-54}** . Some New Physics models predict significant enhancement :
BR ~ $10^{-10} - 10^{-8}$



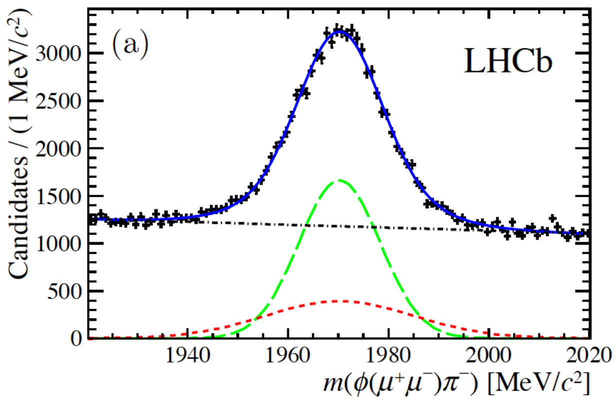
So far only measurements at e^+e^- colliders:
BR ($\tau^\pm \rightarrow \mu^+\mu^-\mu^\pm$) < 2.1 x 10^{-8} (90% CL)
Belle with 782 fb^{-1} [PLB 687 (2010) 3]

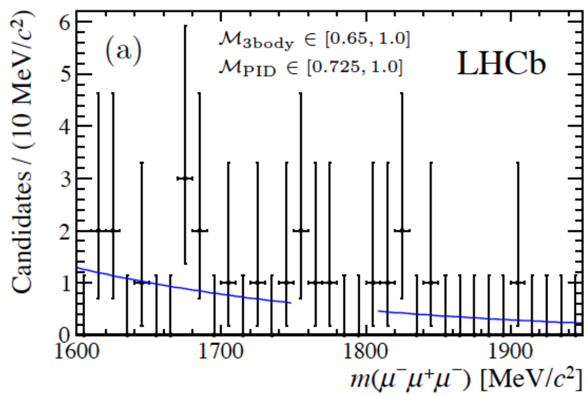
Large τ production cross section at LHC:
~ 80 μb (25% in LHCb acceptance)

~ 10^{11} τ decays/y in LHCb (from $D_s \rightarrow \tau\nu_\mu$)
Normalisation to $D_s \rightarrow \phi(\mu\mu)\pi$

BR < 8.0 x 10^{-8} (90% CL)
LHCb: 1.0 fb^{-1}

Proof of principle for a hadron collider:
Good prospects for future

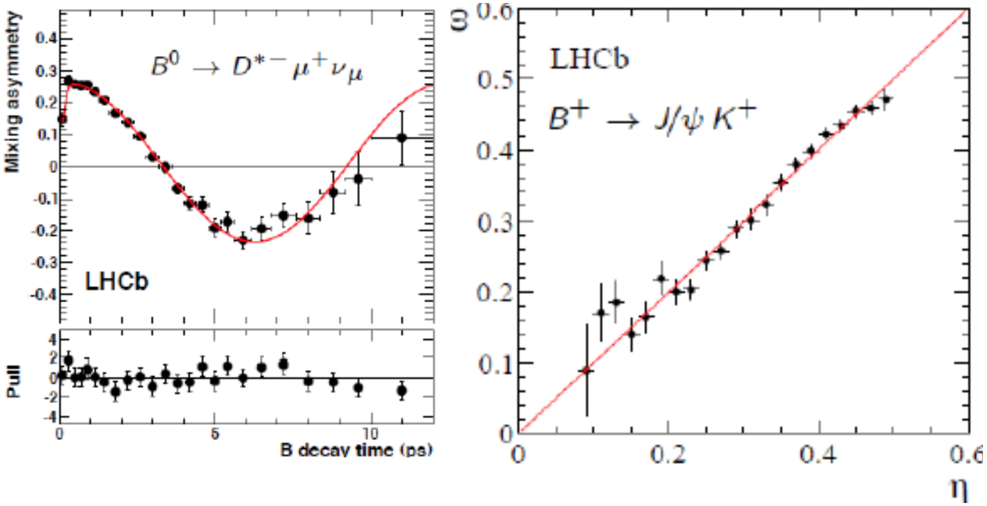




B-flavour tagging at LHCb

Opposite side tagging (OS) calibrated on data :

- Fit time evolution in flavour specific $B \rightarrow D^{*-} \mu^+ \nu \mu$
- Count miss-tagged events in self tagging $B^+ \rightarrow J/\psi K^+$

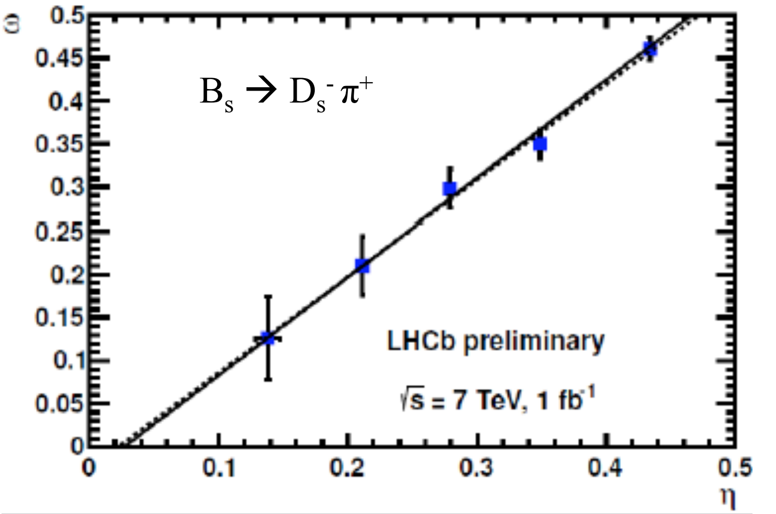


EPJC 72 (2012) arXiv: 1202.4979

Same side tagging (SS) optimized on MC and calibrated on data :

- Fit time evolution in $B_s \rightarrow D_s^- \pi^+$

algorithm	$\varepsilon (1-2\omega)^2$ [%]
SSK	0.89 ± 0.17
OS	2.29 ± 0.06
OS + SSK	3.13 ± 0.12



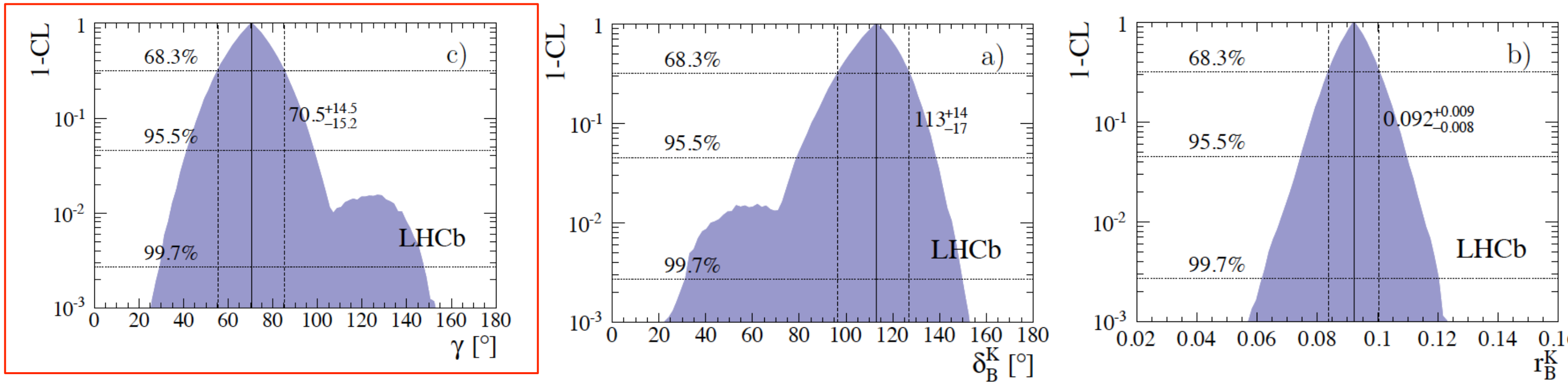
LHCb-CONF-2012-033

CKM γ angle measurement by LHCb

Submitted to Phys. Lett. B - arXiv:1305.2050

Several results were published with the 1 fb^{-1} of the 2011 LHCb data and gathered into a single paper (22 γ-related observables):

- **(Two-body GLW/ADS)** : B → Dh, D→ hh [**Phys. Lett. B712 (2012) 203**]
- **(Four-body ADS)** : B → Dh, D→ Kπππ [**LHCb-PAPER-2012-055; arXiv:1303.4646**]
- **(GGSZ)** : B → Dh, D→ $K_s$hh [**Phys. Lett. B718 (2012) 43**]



Precision achieved from B → DK combinations :

$\gamma = 70^{+14.9}_{-15.2})^o$ at 68% CL

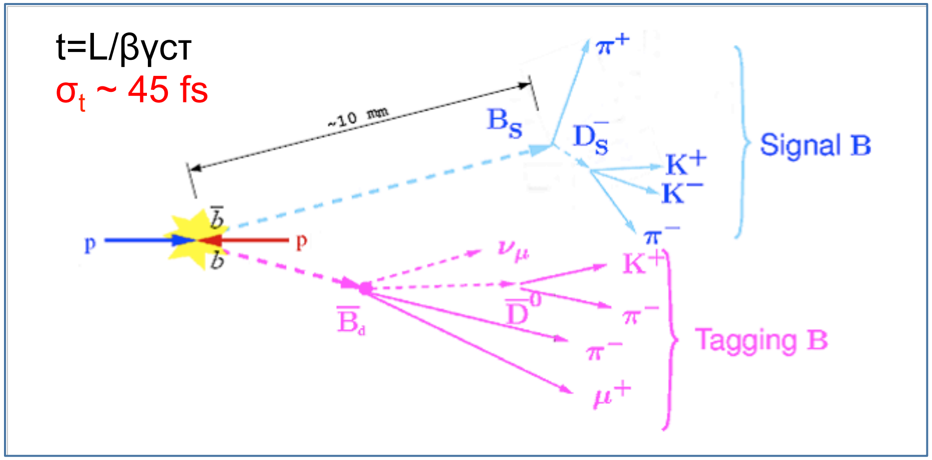
For comparison :

Belle : $\gamma = 68^{+15}_{-14})^o$

BaBar : $\gamma = 69^{+17}_{-16})^o$

Detached vertices

B meson decays topology



Excellent vertex resolution:
to resolve B_s oscillation
Background reduction:
Very good mass resolution
Good particle identification (K/π/μ)
High statistics:
Efficient trigger for hadronic
and leptonic states

B decays with *μμ*	$\varepsilon_{(L0 \times HLT)}$ ~ 70-90 %
B decays with *hadrons*	$\varepsilon_{(L0 \times HLT)}$ ~ 20-50 %
Charm decays	$\varepsilon_{(L0 \times HLT)}$ ~ 10-20 %

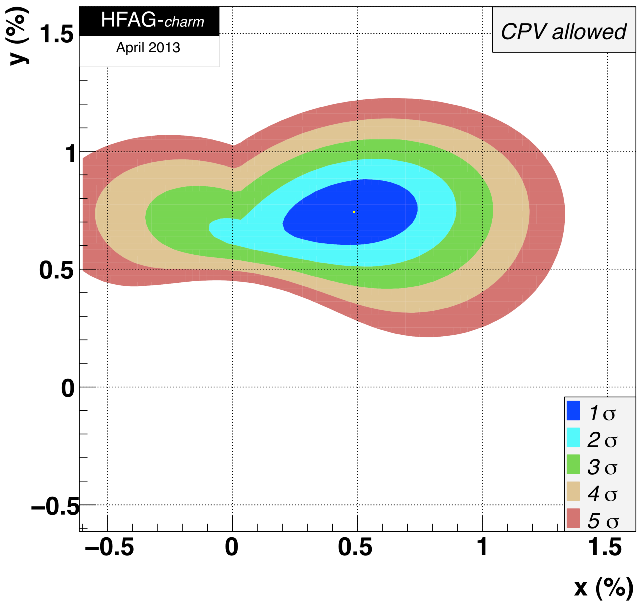
(trigger efficiencies for off-line selected events)

At L0 trigger level (7 TeV)
min bias : cc : bb
250 : 20 : 1

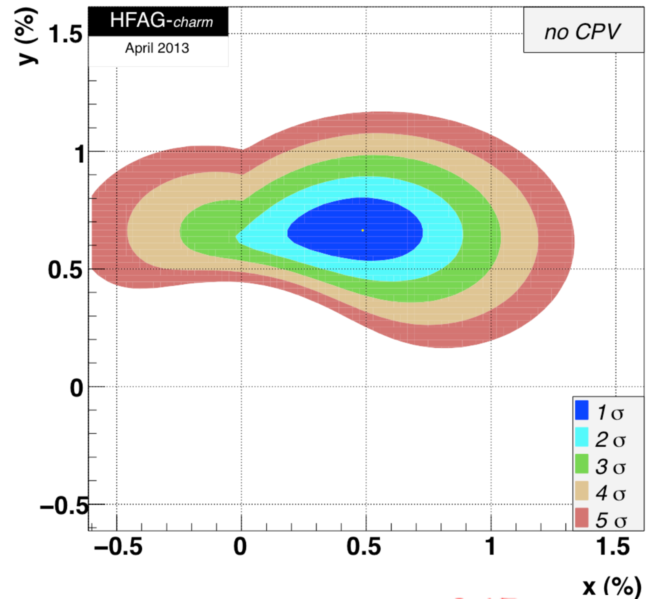
σ_{cc} ~ 6 mb
(~ 1.7 mb in LHCb acceptance):
LHCb is a charm factory !

D^0- $\bar{D}^0$ oscillations - new HFAG averages

http://www.slac.stanford.edu/xorg/hfag/charm



$$\langle x \rangle = (0.49^{+0.17}_{-0.18})\%$$
$$\langle y \rangle = (0.66 \pm 0.09)\%$$



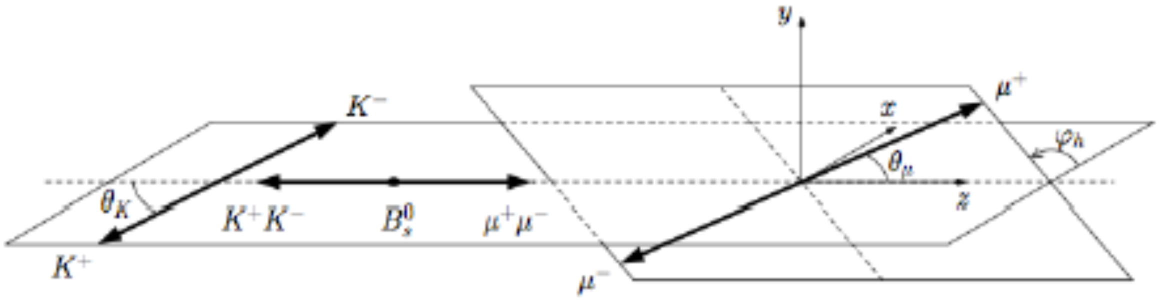
$$\langle x \rangle = (0.49^{+0.17}_{-0.18})\%$$
$$\langle y \rangle = (0.74 \pm 0.09)\%$$

Latest results on "WS"
$D^0 \rightarrow K\pi$ decay

Exp.	$R_D(10^{-3})$	$y'(10^{-3})$	$x'^2(10^{-3})$
LHCb	3.52 ± 0.15	7.2 ± 2.4	-0.09 ± 0.13
Belle	3.64 ± 0.17	$0.6^{+4.0}_{-3.9}$	$0.18^{+0.21}_{-0.23}$
BaBar	3.03 ± 0.19	9.7 ± 5.4	-0.22 ± 0.37
CDF	3.51 ± 0.35	4.3 ± 4.3	0.08 ± 0.18

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

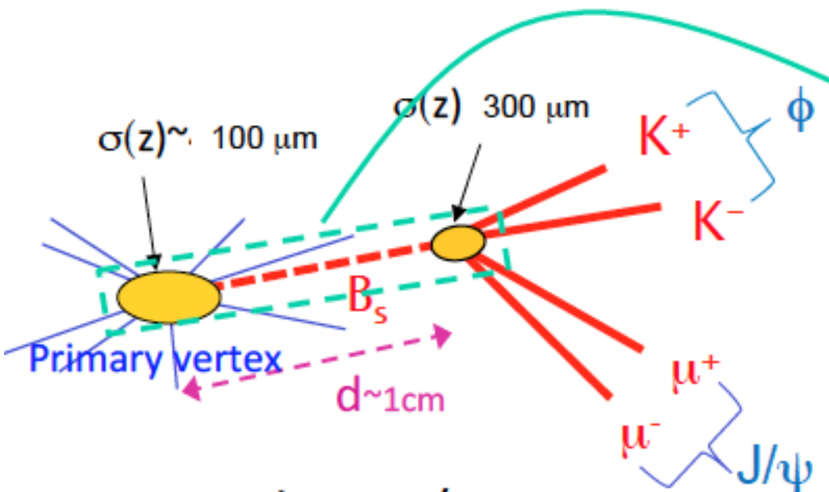
Angular analysis to statiscally separate CP eigenstates
K^+K^- in P wave: 0 (CP even), || (CP-even), perp (CP-odd)

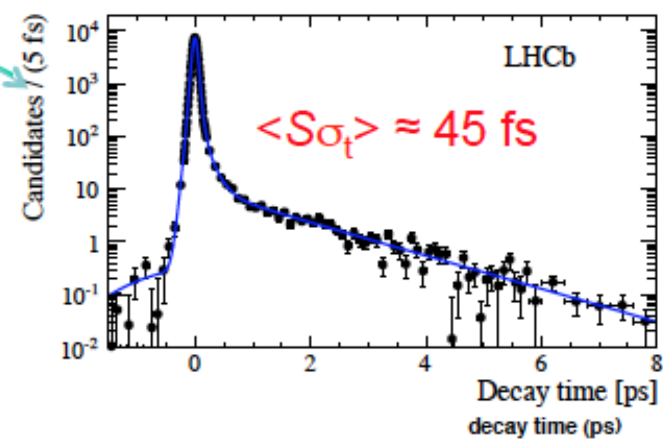


Physics parameters :
ϕ_s, $\Delta\Gamma_s$, Γ_s, Δm_s,$|\lambda|$, $|A_0|^2$, $|A_{perp}|^2$,$\delta_{||}$, δ_{perp} ,
S wave parameters

$B_s \rightarrow J/\psi(\mu\mu)\ \phi(KK)$

Calibration with prompt events





$t = d \times m_B/p_B$

c.f. oscillation period ~ 350 fs