Searching for new physics with the LHCb Experiment

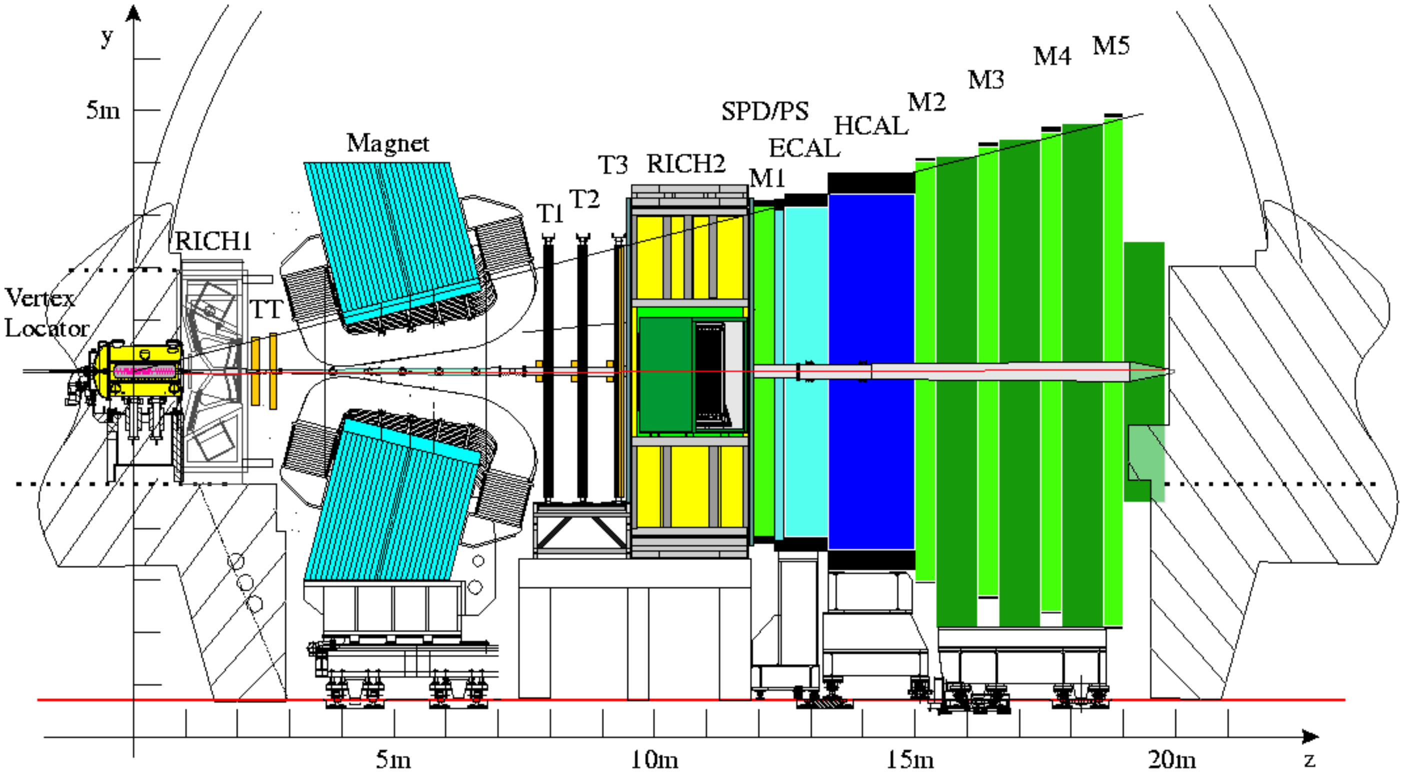
Mitesh Patel (Imperial College London)

NExT Meeting, 14th Mar 2012

Imperial College London

Introduction

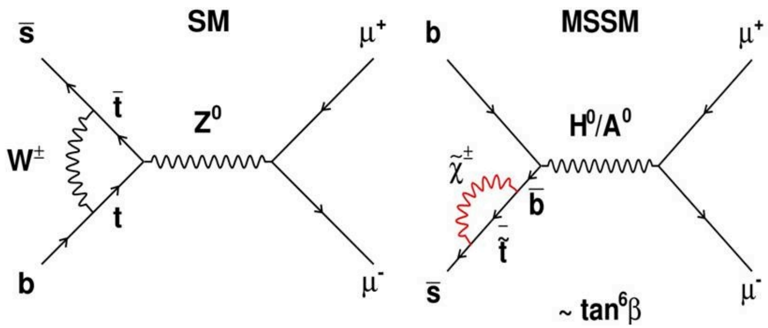
- The LHCb experiment is designed to look for new physics in heavy flavour decays



- During 2011 the experiment collected $1.1 fb^{-1}$ of integrated luminosity ($\sim 1/5^{th}$ of integrated luminosity of ATLAS,CMS)

The decays $B_d \to \mu^+\mu^-$ and $B_s \to \mu^+\mu^-$

- The branching ratios of the decays $B_d \to \mu^+\mu^-$ and $B_s \to \mu^+\mu^-$ allow the parameters of any extended Higgs sector to be probed



- The decays are doubly suppressed in the SM
  - FCNC
  - Helicity suppression

  However, rates well calculable – in the SM,

  $B(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$ **$B(B_d \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$**

  [*Buras et al., arXiv:1007.5291*]

- Sensitive to NP contributions in the scalar/pseudo-scalar sector:

$$(c_{S,P}^{MSSM})^2 \propto \left(\frac{m_b m_\mu \tan^3\beta}{M_A^2} \right)^2$$ MSSM, large tanβ approximation

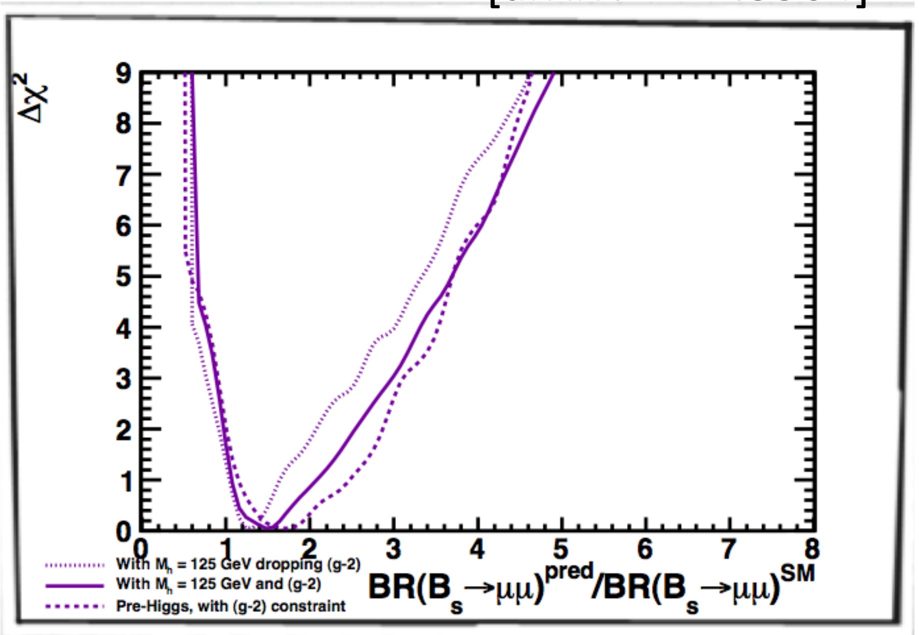
Experimental Status

- Existing LHCb limits (0.37fb^{-1}):
  - $B(B_s \to \mu\mu) < 1.4 \times 10^{-8}$ 95% C.L
  - $B(B_d \to \mu\mu) < 3.2 \times 10^{-8}$ 95% C.L

[arXiv:1112.1600, Phys. Lett. B 708 (2012), 55-67]

- CDF has an excess of events (10fb^{-1}):
  - $B(B_s \to \mu\mu) = (1.0^{+0.8}_{-0.6}) \times 10^{-8}$

[arXiv:1112.3564]



- CMS now have a limit from 5fb^{-1}
  - $B(B_s \to \mu\mu) < 7.7 \times 10^{-9}$ 95% C.L

- ATLAS limit from 2.4fb^{-1}
  - $B(B_s \to \mu\mu) < 22.0 \times 10^{-9}$ 95% C.L

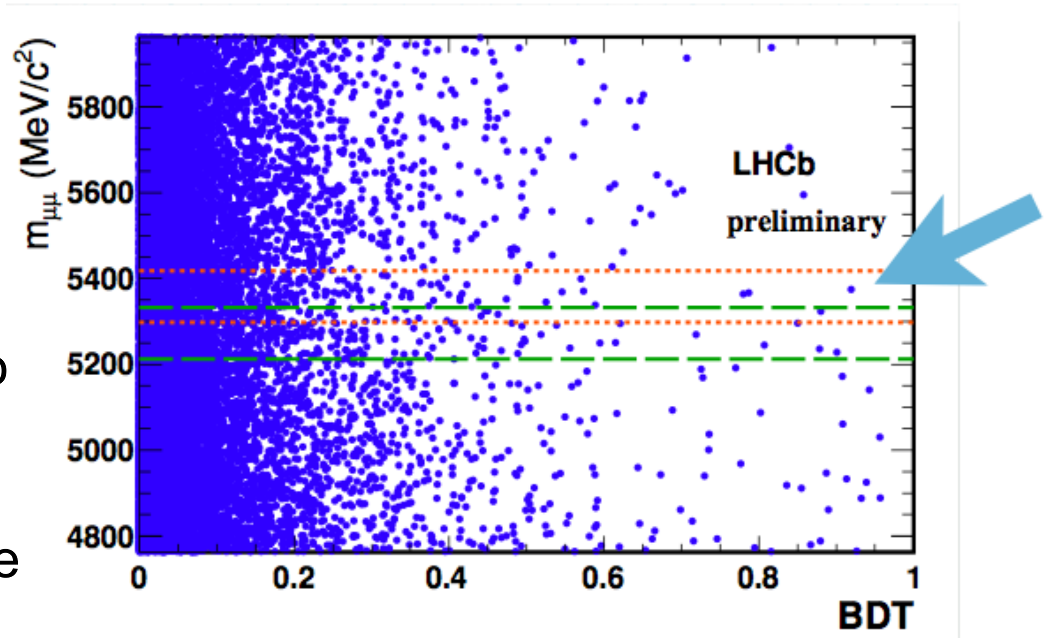
- LHCb results now updated to 1fb^{-1} (presented at Moriond EW)

Analysis Strategy

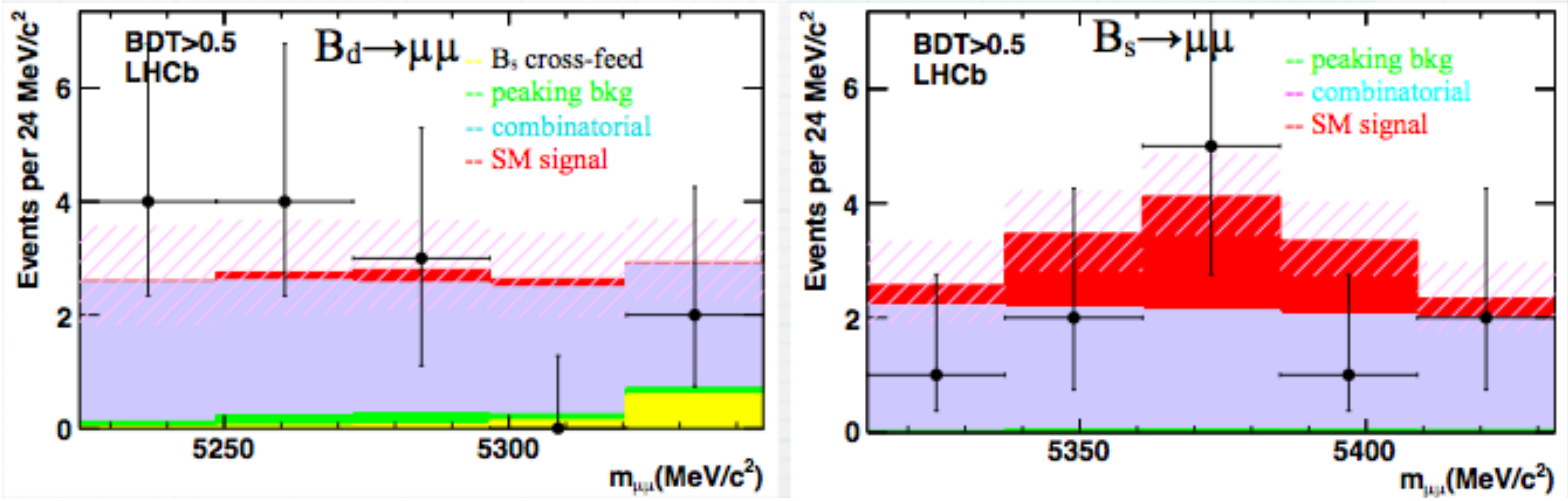
- Backgrounds controlled with a Boosted Decision Tree (BDT)
  - Combinatorial background ($bb \rightarrow \mu\mu X$)
  - $B \rightarrow hh$ events with $h \rightarrow \mu$ mis-id
  - $\mu\mu$ from elastic di-photon production
  - Exclusive decays ($B_s \rightarrow \mu\mu\gamma$, $B^+ \rightarrow \pi^+\mu\mu$, $B_c^+ \rightarrow J/\psi\mu\nu$…)

- Use a range of channels for normaln ($B^+ \rightarrow J/\psi(\mu\mu)K^+$, $B^+ \rightarrow J/\psi(\mu\mu)\phi(KK)$, $B \rightarrow K\pi$)

- BDT, mass plane divided into bins, estimate amount of background and signal (assuming a BR) in each, use CLs method



Results



- Events observed consistent with expected background level and SM signal expectation

- Simultaneous unbinned LL fit to the mass in the 8 BDT bins used to set limits :

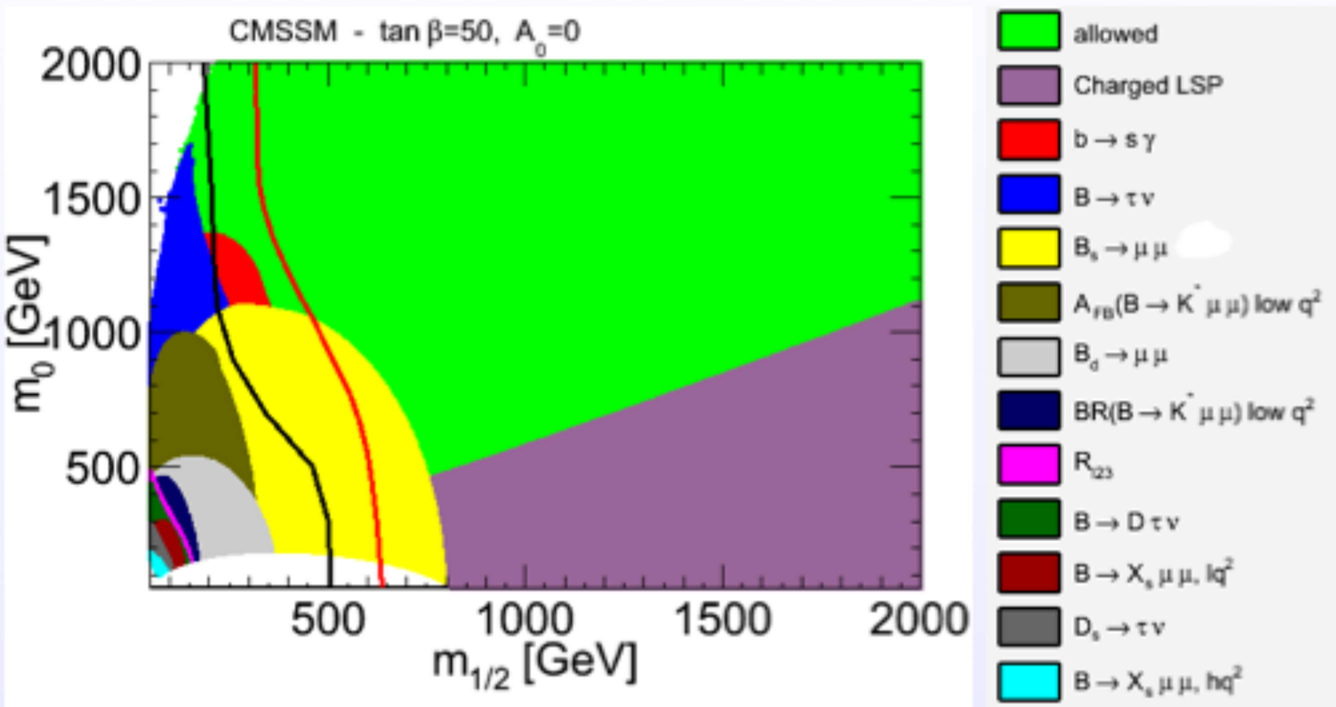
mode	limit	at 90 % C.L.	at 95 % C.L.
$B_s^0 \to \mu^+\mu^-$	expected bg+SM	6.3×10^{-9}	7.2×10^{-9}
	expected bg only	2.8×10^{-8}	3.4×10^{-9}
	observed	3.8×10^{-8}	4.5×10^{-9}
$B^0 \to \mu^+\mu^-$	expected	9.1×10^{-10}	11.3×10^{-10}
	observed	8.1×10^{-8}	10.3×10^{-10}

- LHCb estimate of BR :
  $\mathcal{B}(B_s \to \mu\mu) = (0.8^{+1.8}_{-1.3}) \times 10^{-9}$

Worlds best limits on $B \to \mu\mu$

Impact

- Nazila Mahmoudi, Moriond QCD yesterday:



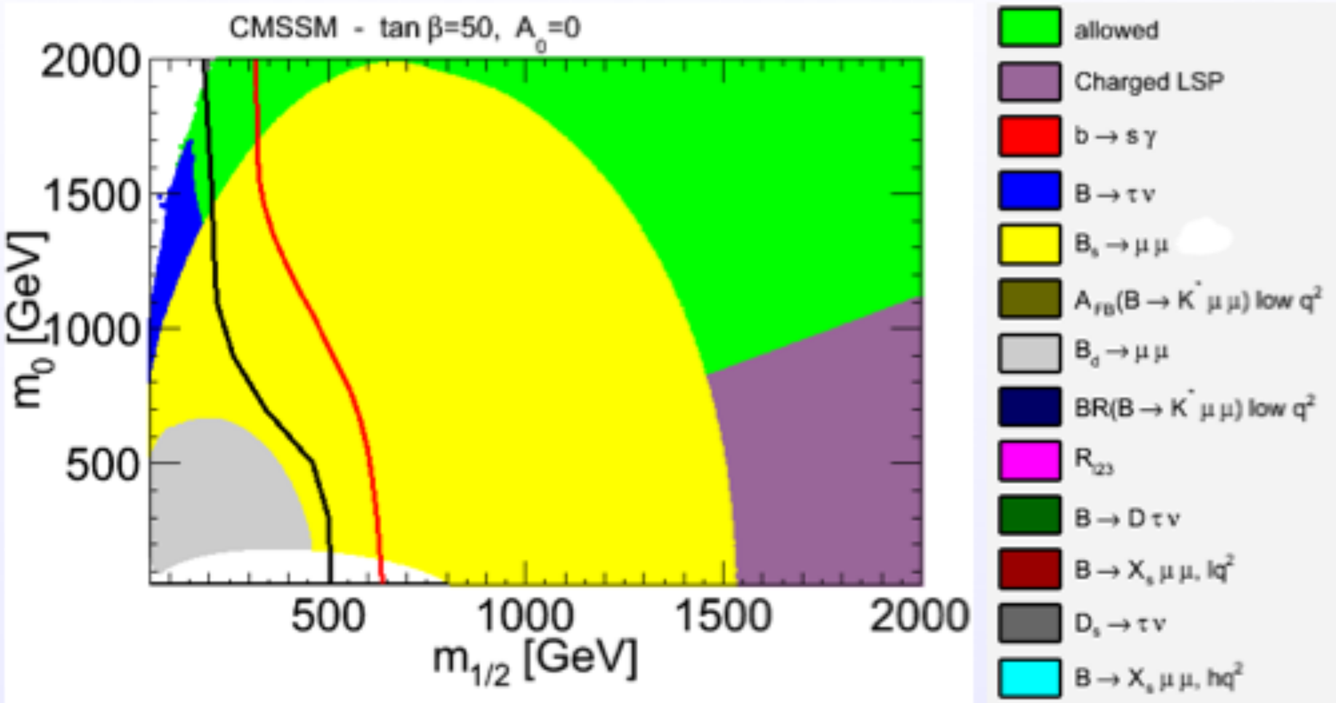
Black line: CMS exclusion limit with 1.1 fb^{-1} data

Red line: CMS exclusion limit with 4.4 fb^{-1} data

SuperIso v3.2+

Impact

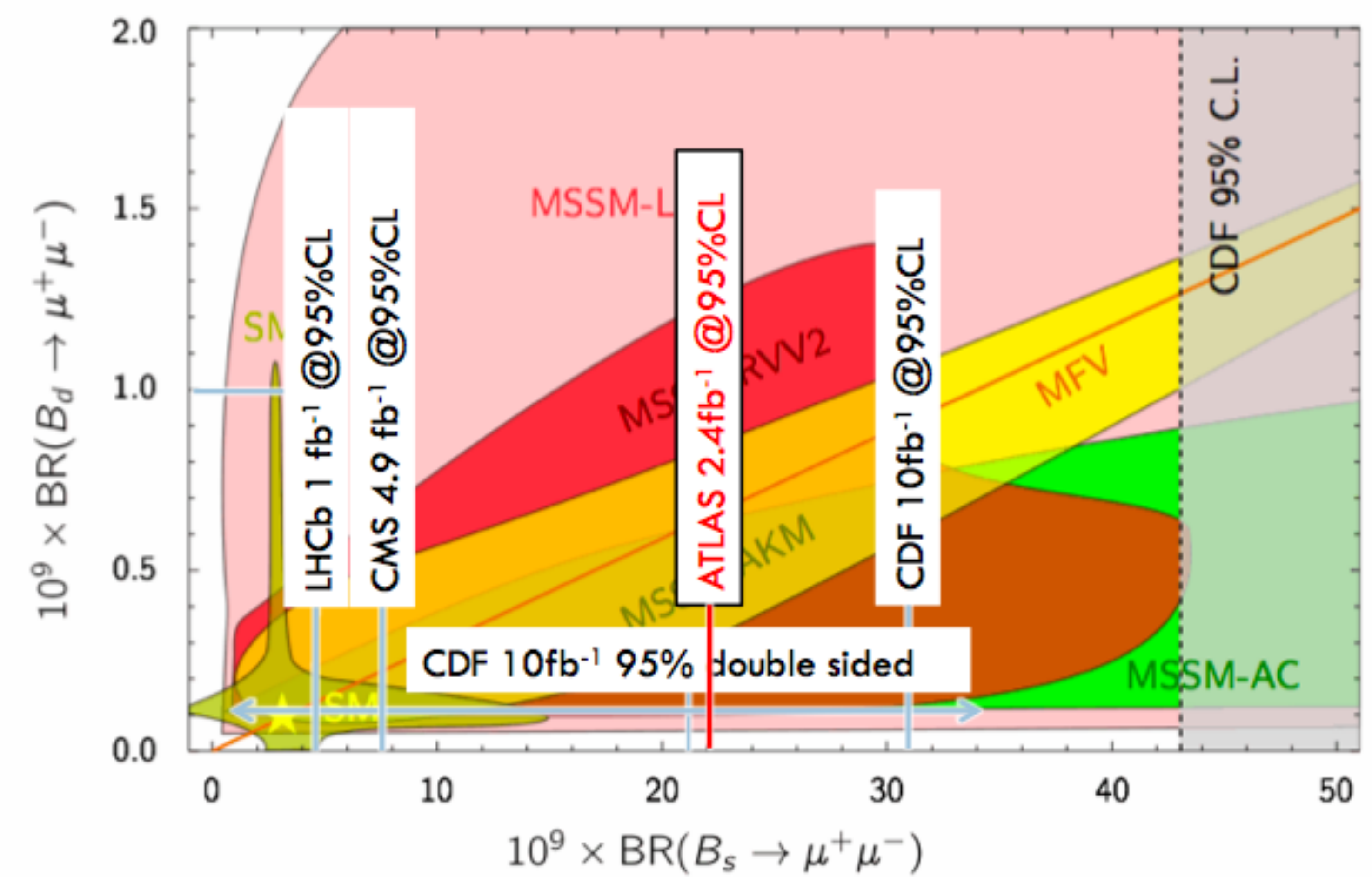
- Nazila Mahmoudi, Moriond QCD yesterday:



Black line: CMS exclusion limit with 1.1 fb^{-1} data
Red line: CMS exclusion limit with 4.4 fb^{-1} data
New LHCb limits for $BR(B_s \to \mu^+\mu^-)$ and $BR(B_d \to \mu^+\mu^-)$

SuperIso v3.2+

And in the future … ?



$D^0 \to \mu^+\mu^-$

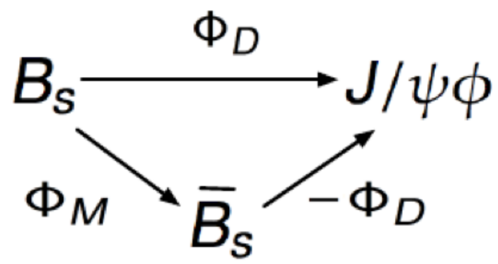
- LHCb collaboration showed the worlds best limit on $D^0 \to \mu^+\mu^-$ decay from $0.9 fb^{-1}$ at Moriond EW:
  - $B(D^0 \to \mu^+\mu^-) < 1.3 \times 10^{-8}$ at 95% C.L.

- An order of magnitude improvement from previous experiments [arXiv:1003.2345] and consistent with the SM prediction ($\sim 10^{-10}$ from LD processes) [arXiv:hep-ph/9512380]

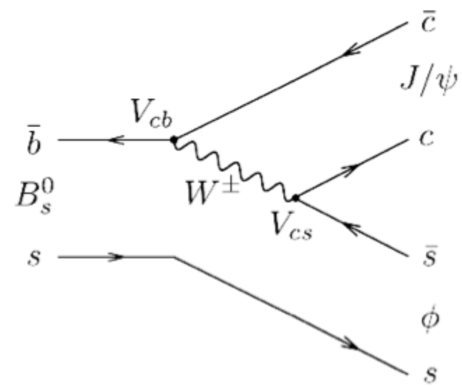
- Can improve with more data

ϕ_s – Introduction

- Interference between *decay* or *mixing and then decay* results in CP violating phase:
  - $\phi_S = \phi_M - 2\phi_D$



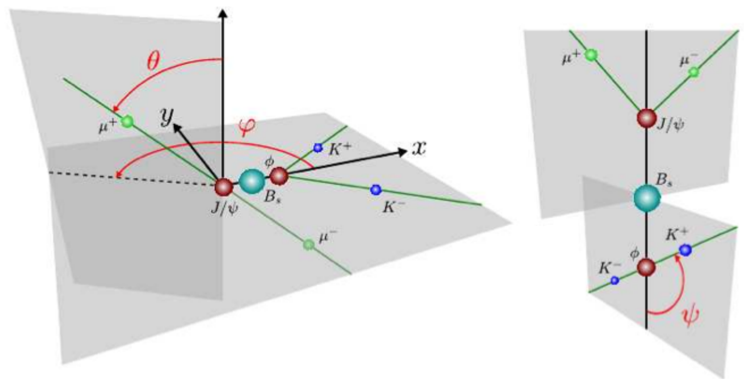
- $B_s \to J/\psi\phi$ decay dominated by $b \to c\bar{c}s$ transition
  - small penguin contribution, δP



- SM prediction:
  - $\phi_S = -2\beta_s + \delta P \sim -2\beta_s \quad = 0.04$

  New physics can add large phases

- New $1fb^{-1}$ results shown at Moriond EW
  - Measurement in $J/\psi\pi\pi$ decay
  - Measurement in $J/\psi\phi$ decay - not a CP eigenstate → required angular analysis to statistically separate CP-even/odd

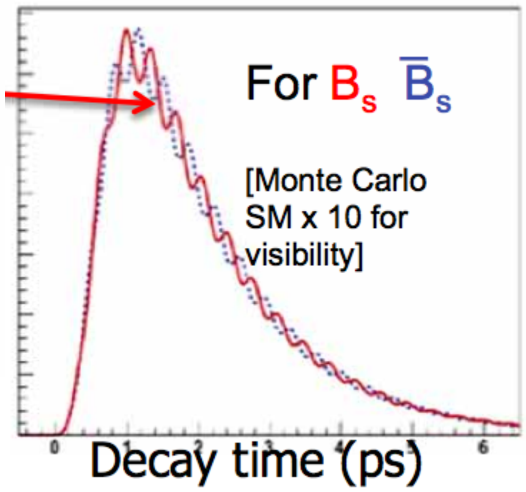


Principle of the measurement

- Differential decay rate for $B_s \to J/\psi\pi\pi$

$$\Gamma\left(B_s^0 \to J/\psi f_0\right) = \mathcal{N}_f e^{-\Gamma_s t}\left\{e^{\Delta\Gamma_s t/2}(1+\cos\phi_s) + e^{-\Delta\Gamma_s t/2}(1-\cos\phi_s) - \sin(\phi_s)\sin\left(\Delta m_s t\right)\right\},$$

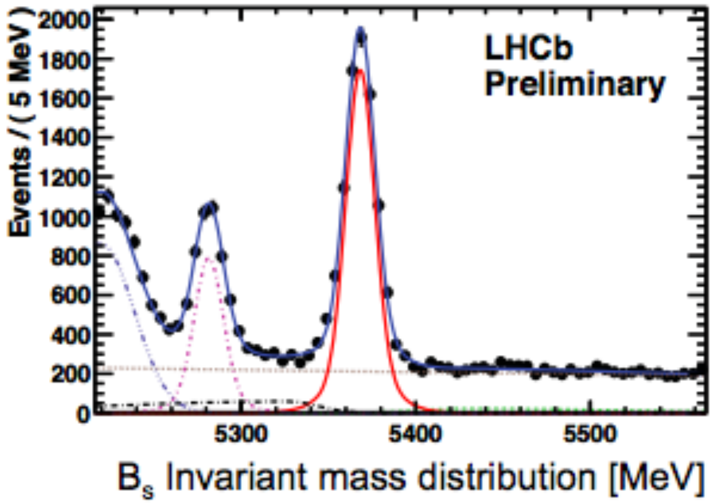
$$\Gamma\left(\overline{B}_s^0 \to J/\psi f_0\right) = \mathcal{N}_f e^{-\Gamma_s t}\left\{e^{\Delta\Gamma_s t/2}(1+\cos\phi_s) + e^{-\Delta\Gamma_s t/2}(1-\cos\phi_s) + \sin(\phi_s)\sin\left(\Delta m_s t\right)\right\}.$$

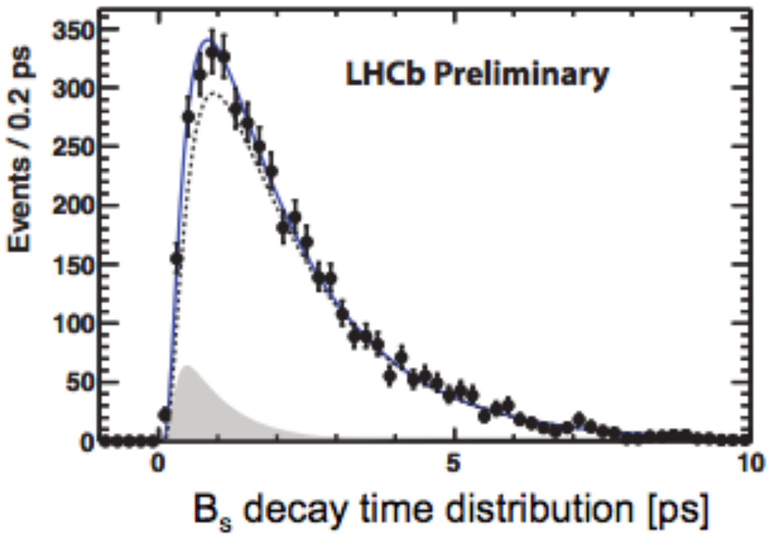


- Signal is sinusoidal time distribution
  - Amplitude proportional to $\sin(\phi_s)$
  - Opposite sign for B and $\overline{B}$ → must flavour tag
  - Diluted by wrong tagging probability w_{tag}
  - Diluted by detector resolution σ_t

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

$B_s \to J/\psi\pi\pi$





- Boosted Decision Tree seln
- Maxm likelihood fit to time and mass – approx. 7.4k signal evts
- ϕ_s =-0.02±0.17(stat.)±0.02(syst.)rad

[LHCb-PAPER-2012-006]

$B_s \rightarrow J/\psi\phi$

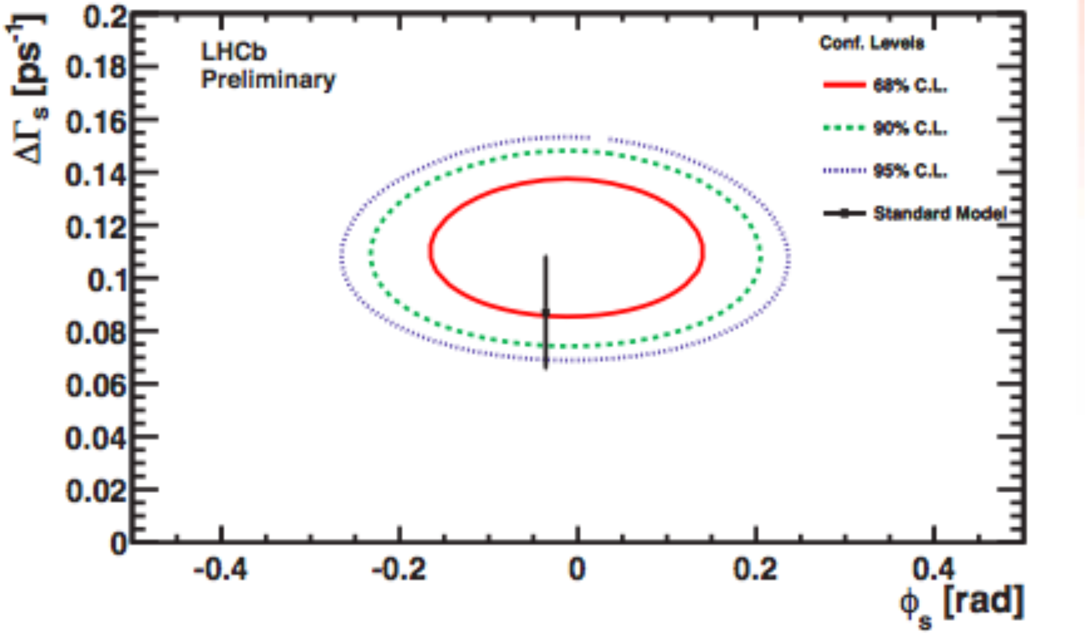
- Decay to CP-odd and CP-even final states → need analysis of decay angle distribution but fundamentally still measure

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

- There is a two fold ambiguity in the solutions: $\phi_s \rightarrow \pi - \phi_s$, $\Delta\Gamma_S \rightarrow -\Delta\Gamma_S$ + strong phase changes

- Much larger branching fraction, $B(B_s \rightarrow J/\psi\phi)/B(B_s \rightarrow J/\psi\pi\pi) \sim 5$

$B_s \to J/\psi\phi$: Preliminary Results 1.0 fb^{-1}



Γ_s = 0.6580 ± 0.0054(stat.) ± 0.0066(syst.) ps^{-1}

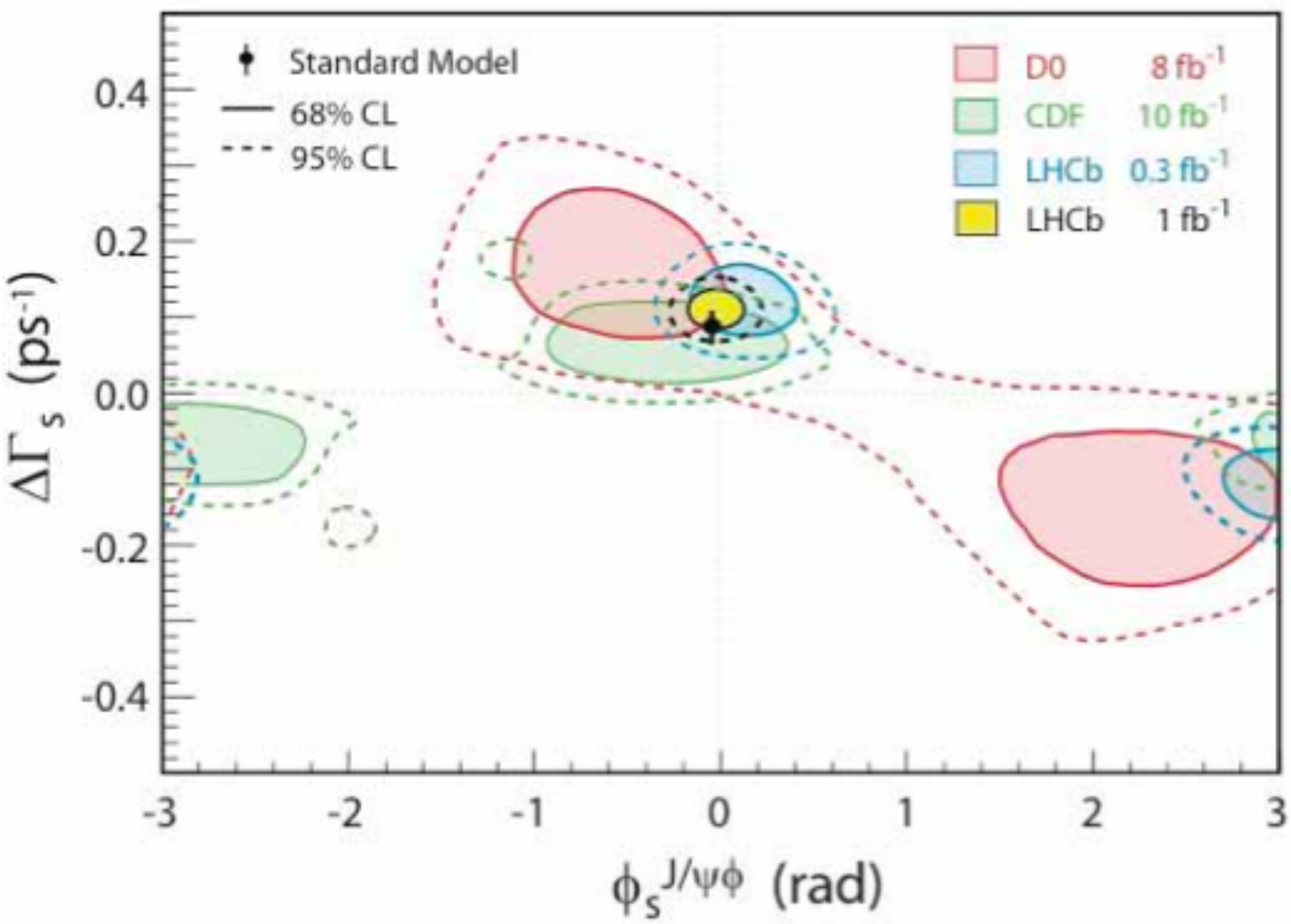
$\Delta\Gamma_s$ = 0.116 ± 0.018(stat.) ± 0.006(syst.) ps^{-1} LHCb-CONF-2012-002

ϕ_s = -0.001 ± 0.101(stat.) ± 0.027(syst.) rad

- Using a simultaneous fit to both datasets, taking all common parameters and correlations into account, combined result

ϕ_s = -0.002 ± 0.083(stat.) ± 0.027(syst.) rad Worlds best

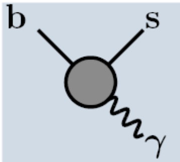
$B_s \to J/\psi\phi$: Preliminary Results 1.0 fb^{-1}



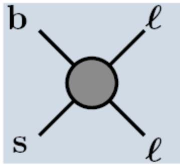
Can resolve the ambiguity : LHCb-PAPER-2012-28, submitted PRL, arXiv:1202.4717v2

$B_d \to K^*\mu\mu$ – Introduction

- Flavour changing neutral current → loop
- Sensitive to interference between



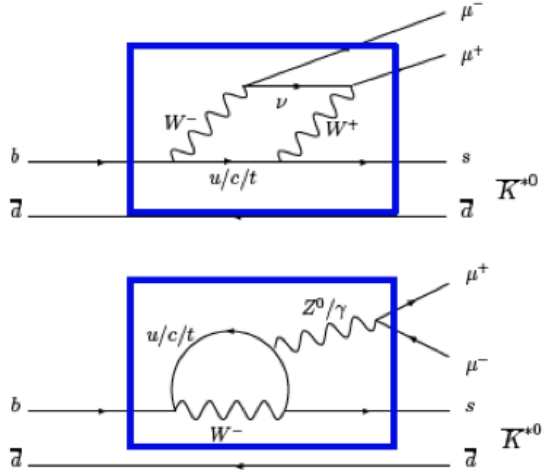
$O_{7\gamma}$

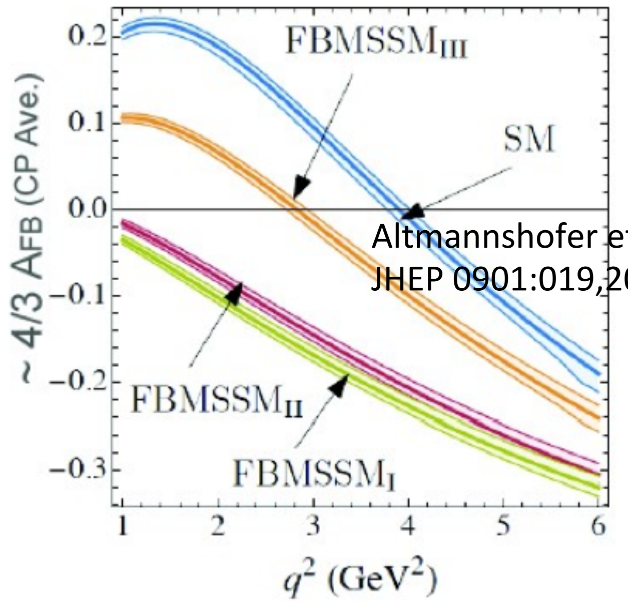


$O_{9,10}$

  and their primed counterparts

- Exclusive decay → theory uncertainty from form factors
- Multitude of observables in which uncert. cancel to some extent e.g. A_{FB}, $A_T^{(i)}$
  - zero-crossing point of A_{FB}





Altmannshofer et al, JHEP 0901:019,2009

Experimental Status

- Babar, Belle, CDF and LHCb have all measured ang. asymm. A_{FB} :

Babar: $(0.1<q^2<6.25\ GeV^2/c^2)$

$$\mathcal{A}_{FB} = 0.24^{+0.18}_{-0.23} \pm 0.05$$

Belle: $(1<q^2<6GeV^2/c^2)$

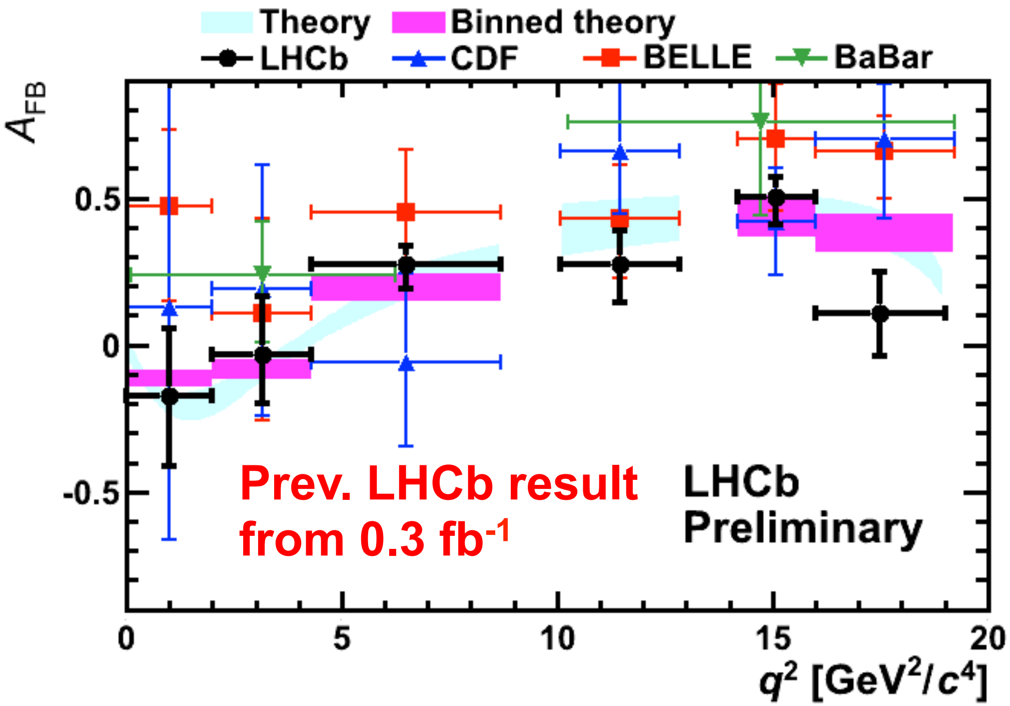
$$\mathcal{A}_{FB} = 0.26^{+0.27}_{-0.30} \pm 0.07$$

CDF: $(1<q^2<6GeV^2/c^2)$

$$\mathcal{A}_{FB} = 0.43^{+0.36}_{-0.37} \pm 0.06$$

LHCb: $(1<q^2<6\ GeV^2/c^2)$

$$A_{FB} = -0.10 \pm 0.14 \pm 0.05$$

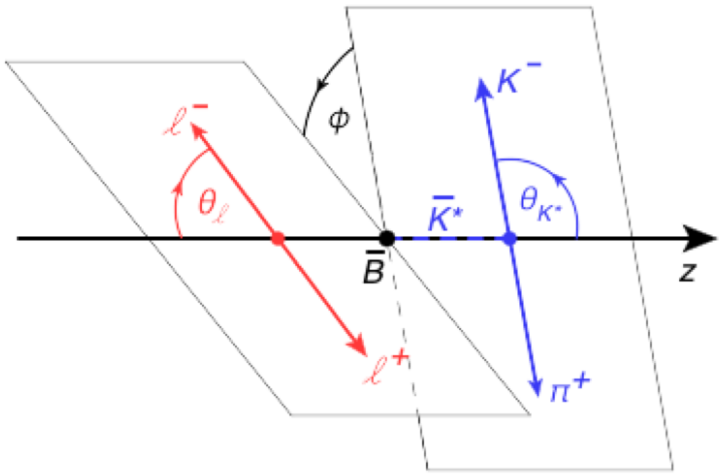


- Measurements look consistent with each other but errors still large
- Latest LHCb results ($1fb^{-1}$) shown yesterday at Moriond QCD…

BABAR: PRL 102, 091803 (2009); CDF: Note 10047 (2010); Belle: PRL 103, 171801 (2009); LHCb arXiv:1112.3515

$B_d \rightarrow K^*\mu\mu$ – angular analysis

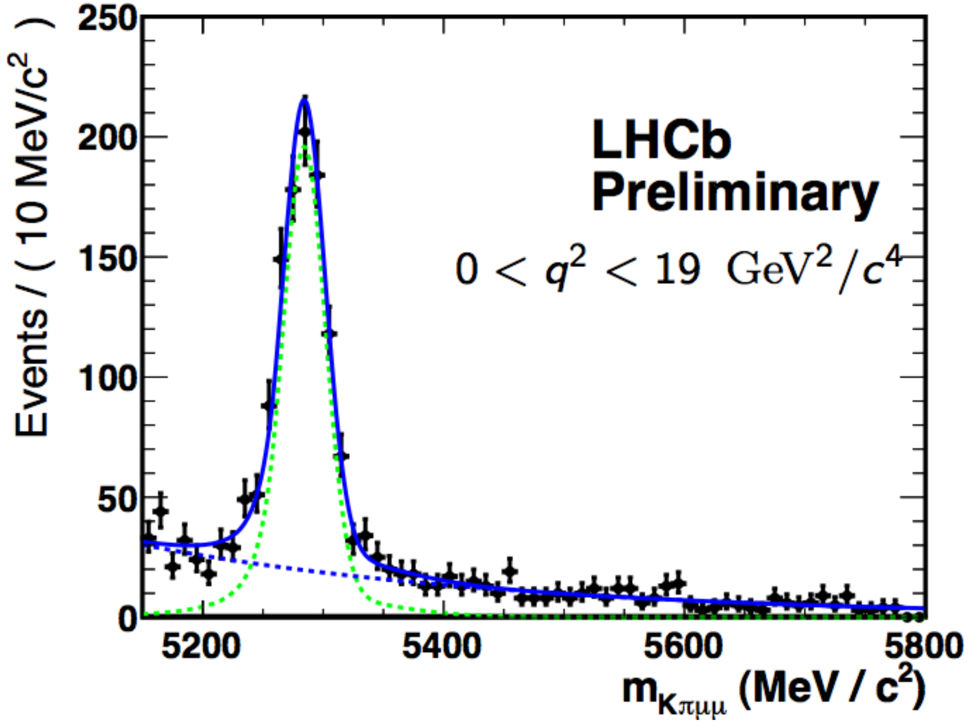
- The angular distribution is described in terms of three angles, θ_l, θ_K and ϕ, and $q^2 = m^2_{\mu\mu}$



- Fitting these angles allows access to theoretically clean, experimentally accessible angular observables:
  - F_L, the fraction of K^{*0} longitudinal polarisation
  - A_{FB}, the forward-backward asymmetry – and zero-crossing point [**NEW**]
  - $S_3 \propto A^2_T(1-F_L)$, the asymmetry in K^{*0} transverse polarisation [**NEW**]
  - A_{IM}, a T-odd CP asymmetry [**NEW**]

Selection

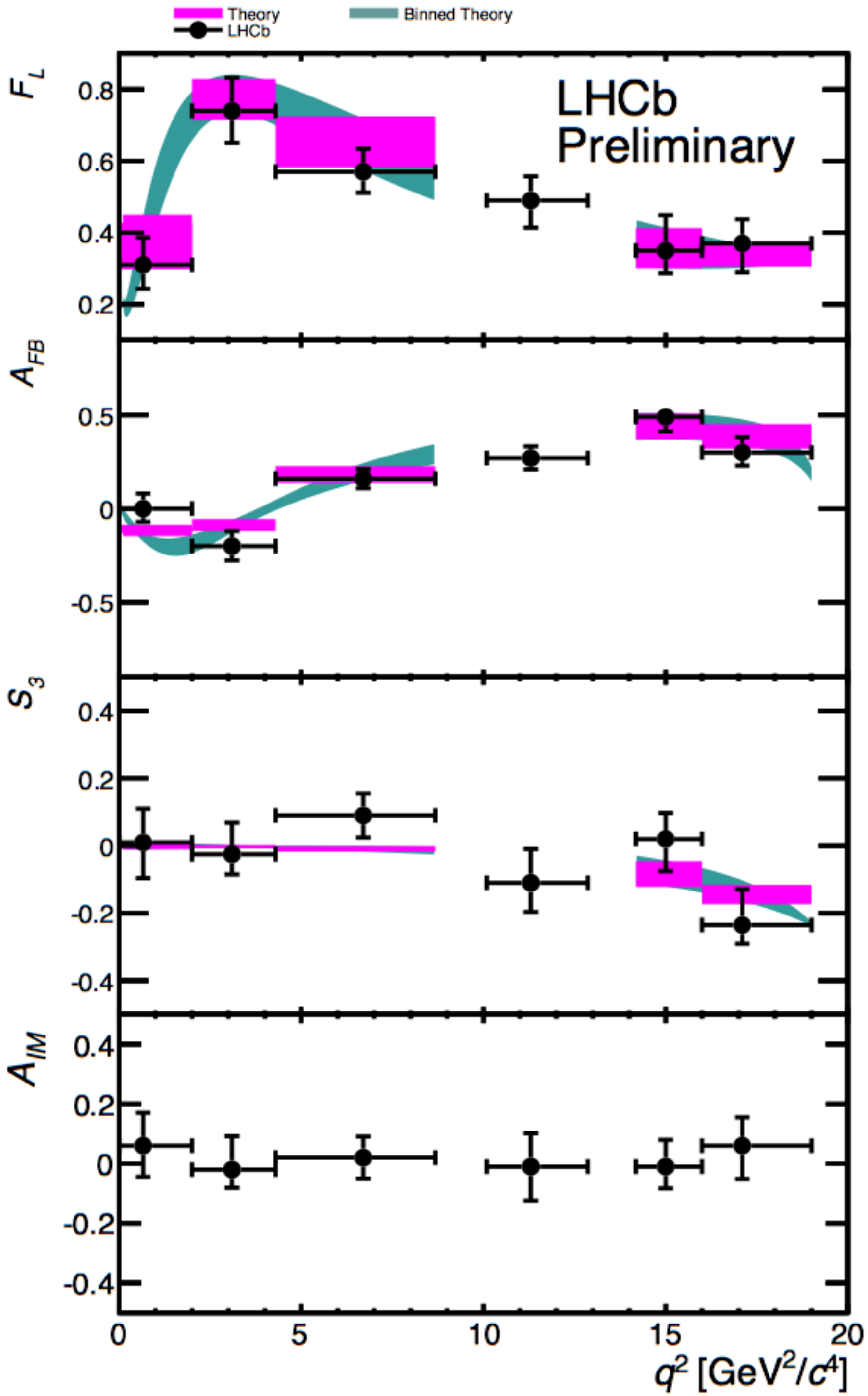
- Events isolated using multivariate (BDT) selection
- Isolate peaking backgrounds and reject with PID requirements e.g. $B_s \to \phi\mu^+\mu^-$ with $K \to \pi$ mis-ID
- With 1.0 fb^{-1} find 900±34 signal events
- B/S≈0.25 in region $5230 < m_{K\pi\mu\mu} < 5330$ MeV/c^2



Results – $1fb^{-1}$

LHCb-CONF-2012-008

- 4D fit to 3 angles and mass
- Error bars include systematic uncertainties
- Data points at average q^2 of signal candidates in data
- These are the most precise measurements to-date
- The results are consistent with the SM prediction [arXiv:1105.0376]
- Also : world's best measurements of differential BR

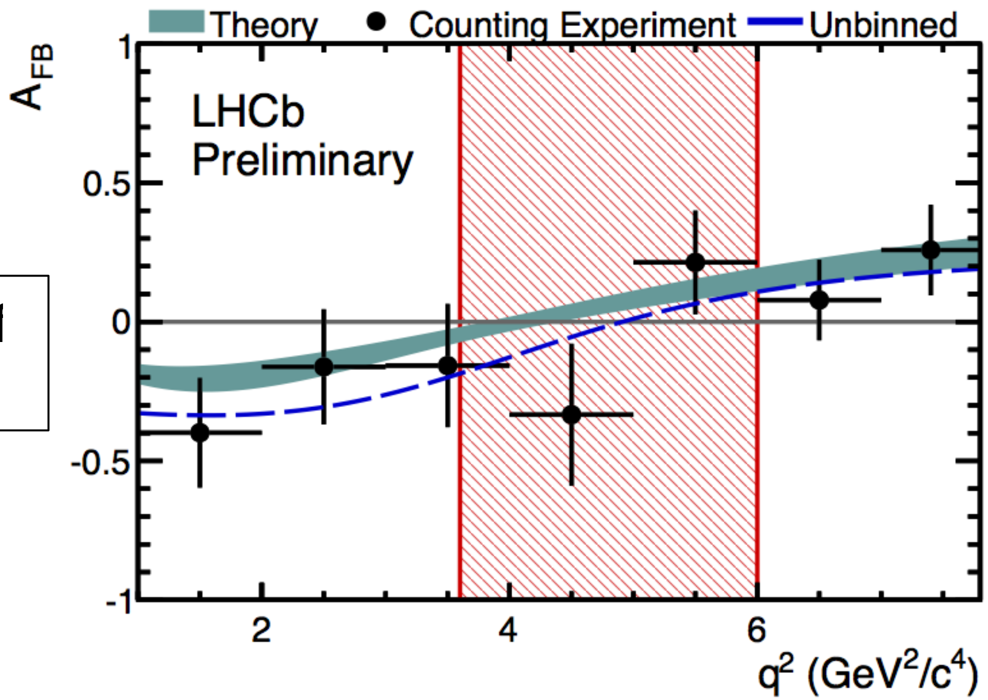


A_{FB} zero-crossing point

- The zero-crossing point, q_0^2 extracted through a 2D fit to the forward- and backward-going $m_{K\pi\mu\mu}$ and q^2 distributions

- The worlds first measurement of q_0^2, at $q_0^2 = 4.9^{+1.1}_{-1.3}$ GeV^2/c^4

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



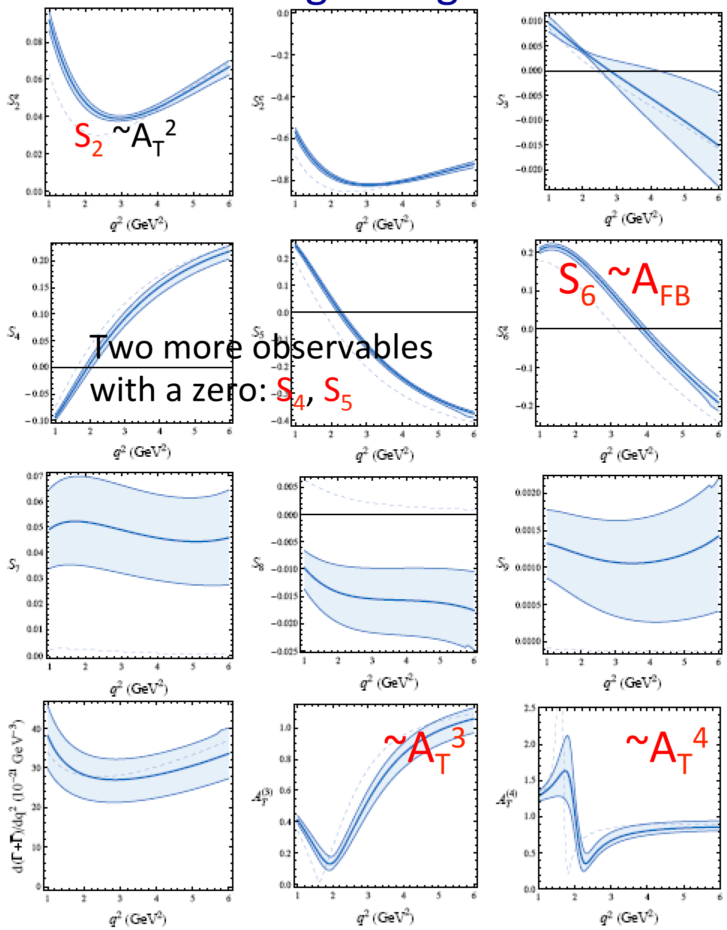
Outlook

- More data will enable a full angular fit to extract complete information from $B_d \to K^* \mu\mu$ decays

  $\to$ host of theoretically well calculable observables

- $B_s \to \phi\mu\mu$ and $B^+ \to K^+\mu\mu$ angular analyses also in prospect, higher K^* resonances also under study

CP-averaged angular coeff.



Ball *et al.* arXiv:0811.1214v2

Charm Physics LHCb → LHCc

- Enormous sample of charm decays also available at LHCb
- Already looked at CP asymmetry in 2010 data (38pb^{-1}), latest analysis 0.6fb^{-1}

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

physics CP asymmetry

Detection asymmetry of D^0

Detection asymmetry of soft pion

Production asymmetry

- If take $\Delta A_{CP} = A_{RAW}(D^0 \to K^+K^-) - A_{RAW}(D^0 \to \pi^+\pi^-)$
  - production and soft pion detection asymmetries will cancel
  - No detector asymmetry

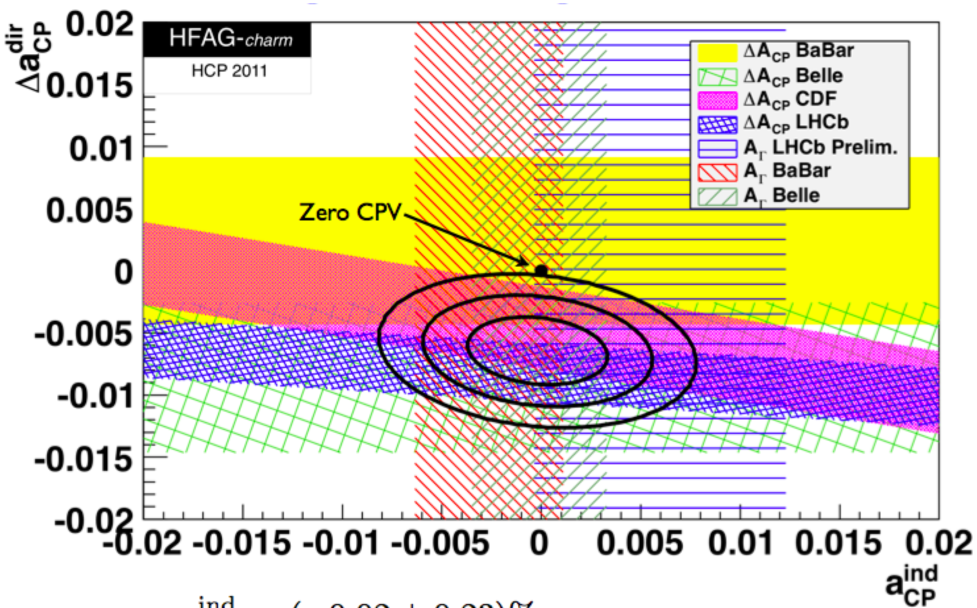
  i.e. all the D*-related production and detection asymmetries cancel
- Theoretical predictions for ΔA_{CP} are at the 0.1% level

ΔA_{CP}

- LHCb result, 0.6fb^{-1}
  - ΔA_{CP} =[−0.82±0.21(stat.)±0.11(sys.)]%   3.5σ significance

- Indirect CP violation suppressed in the difference ($\Delta\langle t\rangle/\tau$=9.8±0.9%) so this is mostly direct CPV

- Value is consistent with HFAG average at 1σ level but more negative and more precise



$a^{ind}_{CP} = (-0.02 \pm 0.23)\%$

$\Delta a^{dir}_{CP} = (-0.65 \pm 0.18)\%$

Consistency with no CPV: 0.15%

- CDF showed new result at La Thuile
  - ΔA_{CP} =[−0.62±0.21(stat.)±0.10(sys.)]%

  Less than 1σ from LHCb result

44

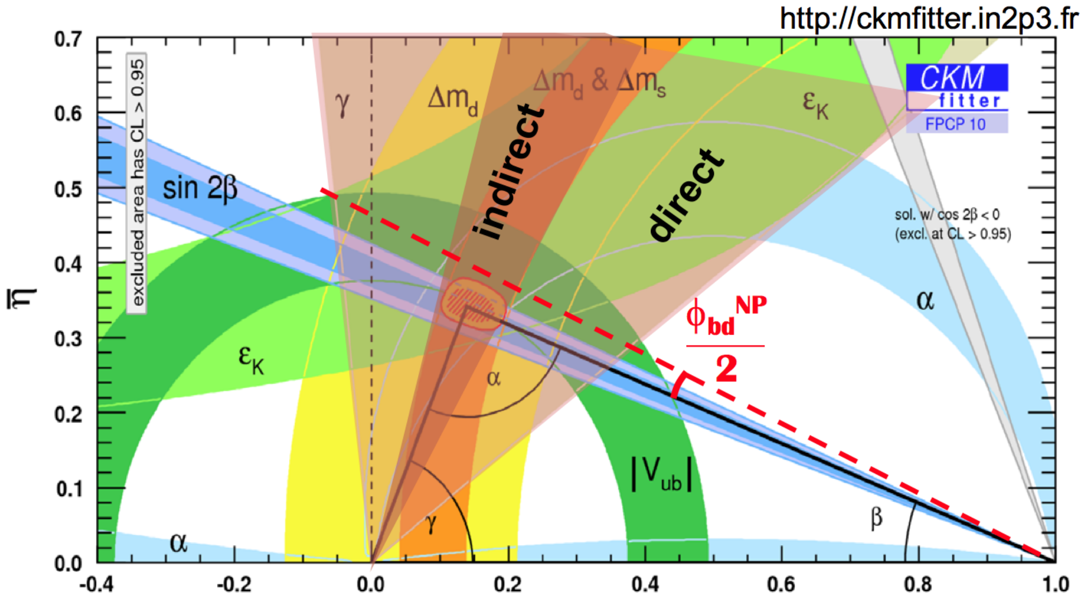
ΔA_{CP}

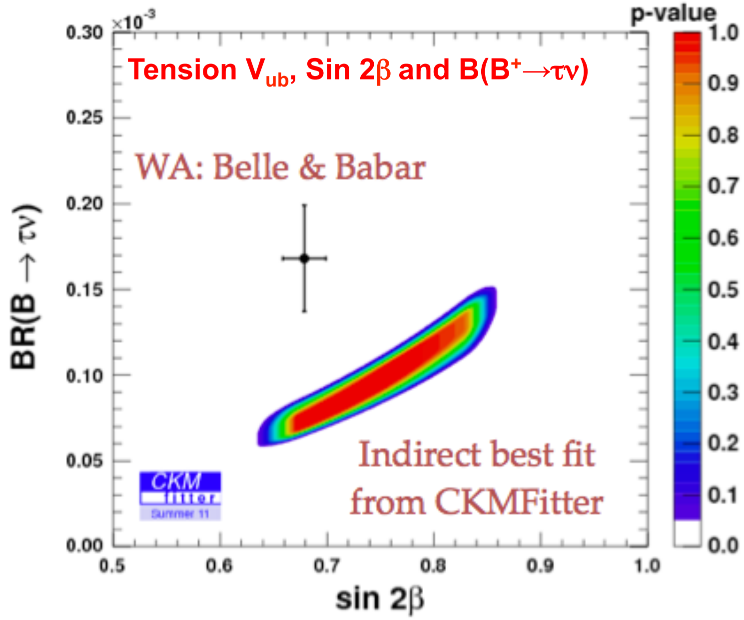
- Spate of theory papers discussing how difficult it is to accommodate 1% in the SM – my understanding is: hard but not completely impossible

arXiv:1202.3795: Repercussions of Flavour Symmetry Breaking on CP Violation in D-Meson Decays (Feldmann, Nandi, Soni)
arXiv:1202.5038: On the Universality of CP Violation in Delta F = 1 Processes (Gedalia, Kamenik, Ligeti, Perez)
arXiv:1202.3300: CP violation in D0 -> K+K-, pi+pi- from diquarks(Chen, Geng, Wang)
arXiv:1202.2866: New Physics Models of Direct CP Violation in Charm Decays (Altmannshofer, Primulando, Yu, Yu)
arXiv:1201.6204: Direct CP violation in charm and flavor mixing beyond the SM (Giudice, Isidori, Paradisi)
arXiv:1201.2565: LHCb Delta A_CP of D meson and R-Parity Violation (Chang, Du, Liu, Lu, Yang)
arXiv:1201.2351: CP asymmetries in singly-Cabibbo-suppressed D decays to two pseudoscalar mesons (Bhattacharya, Gronau, Rosner)
arXiv:1201.0785: Direct CP violation in two-body hadronic charmed meson decays (Cheng, Chiang)
arXiv:1112.5268: Relating direct CP violation in D decays and the forward-backward asymmetry in ttbar production (Hochberg, Nir)
arXiv:1112.5451: CP Violation and Flavor SU(3) Breaking in D-meson Decays (Pirtskhalava, Uttayarat)
arXiv:1111.6949: (ΔA_{CP})_{LHCb} and the fourth generation (Rozanov, Vysotsky)
arXiv:1111.5196: Can Up FCNC solve the $ΔA_{CP}$ puzzle? (Wang, Zhu)
arXiv:1111.5000: On the size of direct CP violation in singly Cabibbo-suppressed D decays (Brod, Kagan, Zupan)
arXiv:1111.4987: Implications of the LHCb Evidence for Charm CP Violation (Isidori, Kamenik, Ligeti, Perez)
hep-ph/0609178: New Physics and CP Violation in Singly Cabibbo Suppressed D Decays (Grossman, Kagan, Nir)

- Future prospects
  - Another 0.5fb^{-1} already on tape, expect further $\sim 1\text{fb}^{-1}$ in 2012
  - Independent measurements with other tagging methods
  - Look for direct CPV in e.g. 3-body decays

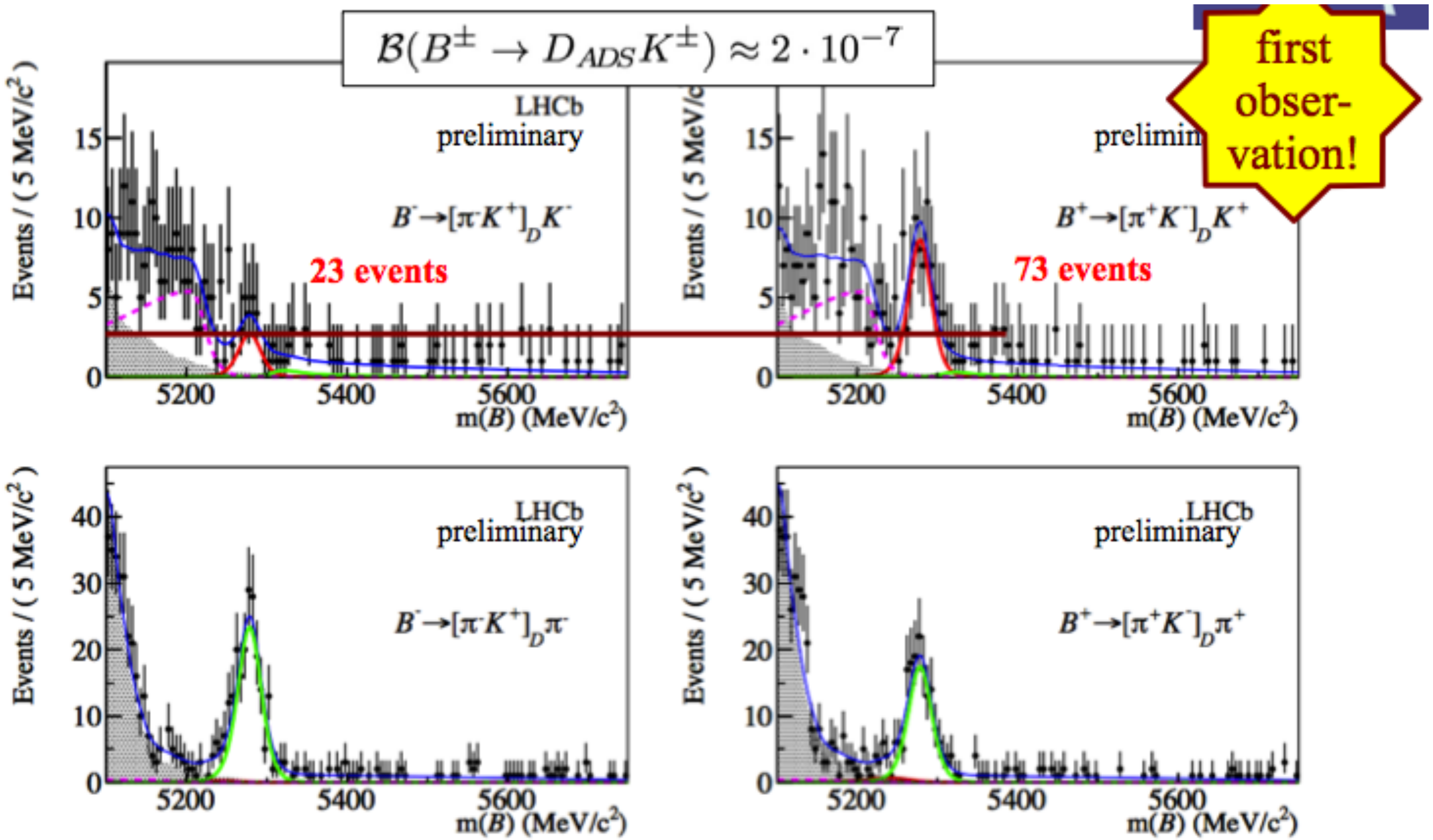
CKM Measurements





- $B_s \to J/\psi\phi$ measurement about looking for NP in B_s mixing
- Still scope for NP in B_d mixing?
  - Loop processes → sin $(2\beta + \varphi^{NP})$
  - CKM angle γ determined indirectly very precisely
  - cf. direct measurement of γ from tree processes where precision poor
- LHCb using a range of $B \to DK$ decays to measure γ in tree processes

ADS/GLW modes

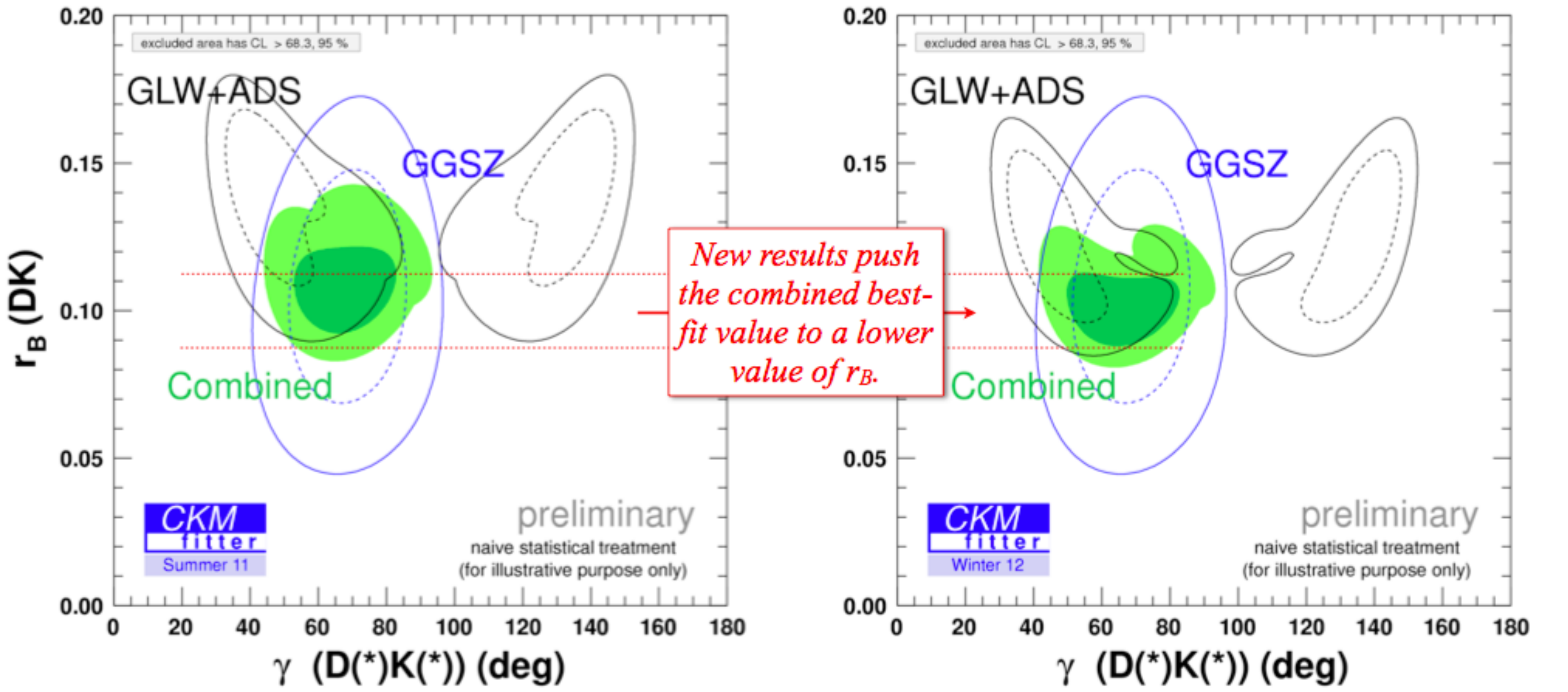


LHCB-PAPER-2012-001

- First observation of the suppressed ADS modes (10σ)

Impact on γ

CKM Fitter put it all together…



Future Prospects

Many direct CPV analyses coming to maturity:

$B^- \to D\, K^-$

$D \to K^+\pi^-$
$D \to K^-K^+$
$D \to \pi^-\pi^+$

presented today. *CP* violation observed

$D \to K_S^0\pi^+\pi^-$
$D \to K_S^0K^+K^-$
$D \to K^+\pi^-\pi^+\pi^-$
$D \to K^+\pi^-\pi^0$

$B^0 \to D\, K^{*0}$

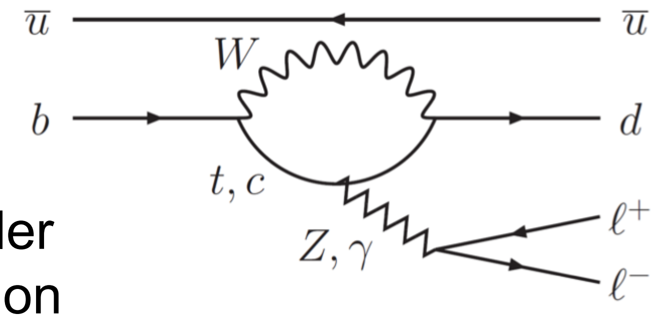
$D \to K^+\pi^-$
$D \to K^-K^+$
$D \to \pi^-\pi^+$

$B^- \to D\, K^-\pi^+\pi^-$

$D \to K^+\pi^-$
$D \to K^-K^+$
$D \to \pi^-\pi^+$

- LHCb on track to make a 5-8° measurement of γ with 2011,12 data
- In addition to tree determination, $B\to hh$ decays will determine γ from loop processes

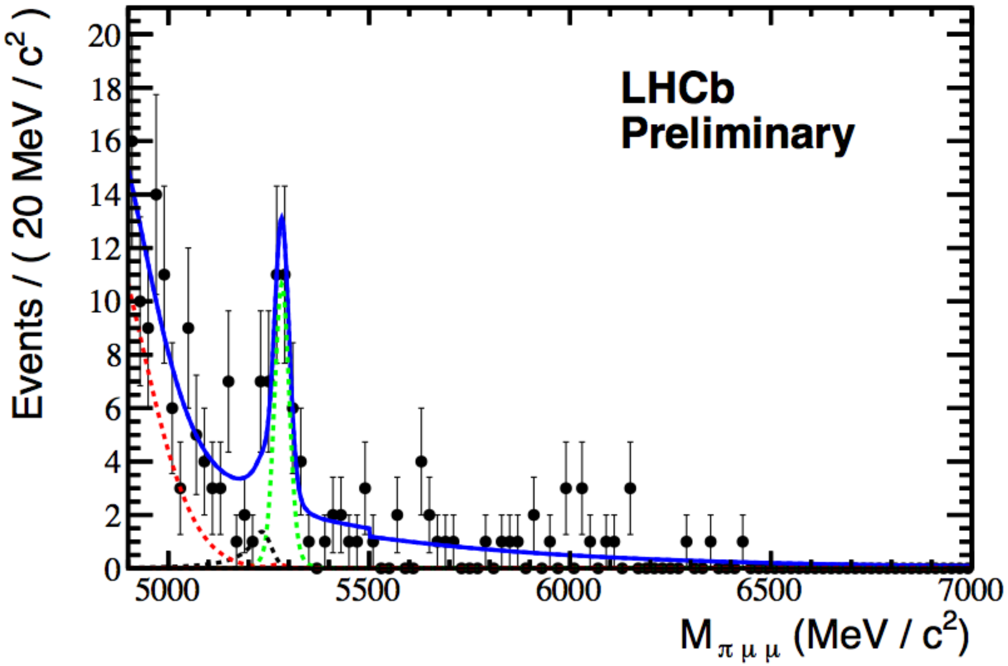
First observation of $B^+ \rightarrow \pi^+ \mu^+ \mu^-$



- The $B^+ \rightarrow \pi^+ \mu^+ \mu^-$ decay is a $b \rightarrow d$ transition
- In the SM the branching fraction is ~25x smaller than the well known $B^+ \rightarrow K^+ \mu^+ \mu^-$ ($b \rightarrow s$) transition and can be enhanced in new physics models
- While ratio CKM elements V_{ts}/V_{td} known from oscillation measurements, this would probe in penguin decays
- SM prediction: $\mathcal{B}(B^+ \rightarrow \pi^+ \mu^+ \mu^-) = (1.96 \pm 0.21) \times 10^{-8}$
- Previous best limit from Belle: $\mathcal{B}(B^+ \rightarrow \pi^+ \mu^+ \mu^-) < 6.9 \times 10^{-8}$ (90% CL)

First observation of $B^+ \to \pi^+ \mu^+ \mu^-$

- With 1.0 fb^{-1} LHCb finds $25.3^{+6.7}_{-6.4}$ $B^+ \to \pi^+ \mu^+ \mu^-$ signal events
  - 5.2σ excess above background

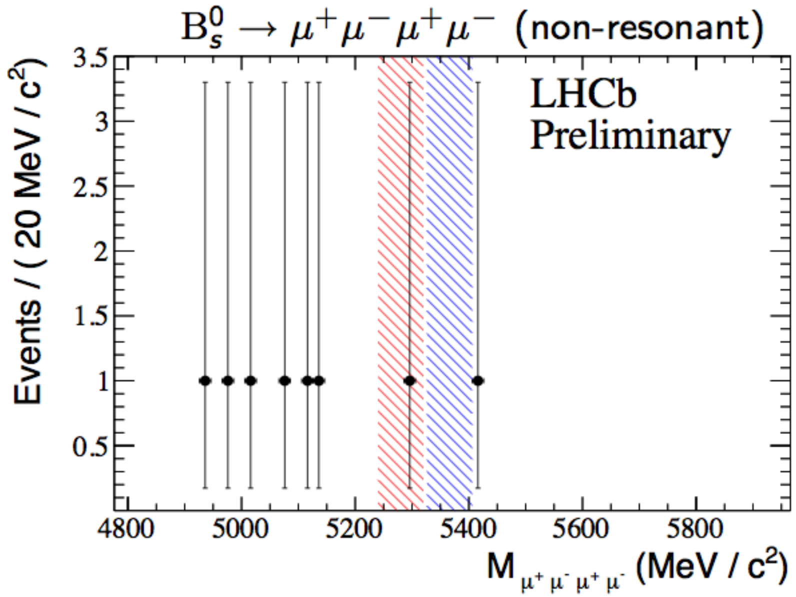


[LHCb-CONF-2012-006]

- $B(B^+ \to \pi^+ \mu^+ \mu^-) = (2.4 \pm 0.6(stat) \pm 0.2(syst)) \times 10^{-8}$, within 1σ of SM pred.
- The rarest B decay ever observed

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

- No search for $B \to 4\mu$ performed until now — LHCb-CONF-2012-010
- Can be mediated by decay to new physics S,P particles where both decay $\to \mu^+\mu^-$ e.g. P particle could explain HyperCP observation of 3 events with mass ≈ 214 MeV
- Expect 4μ final state from $B_s \to J/\psi\phi$ decay where both J/ψ and $\phi \to \mu^+\mu^-$, BR ~ $(2.3\pm0.9)\times10^{-8}$
- For the non-resonant decay SM prediction < 10^{-10}
- Observed number of non-resonant events consistent with background expectation → limits:
  - $B(B_s \to 4\mu) < 1.3\times10^{-8}$ at 95% C.L.
  - $B(B_d \to 4\mu) < 5.4\times10^{-9}$ at 95% C.L.
- Worlds first limits on these decays



Conclusions

- $B_d \to \mu^+\mu^-$ and $B_s \to \mu^+\mu^-$
  - [NEW] Worlds best limits, little scope left for enhancement (suppression?)
  - [NEW] Worlds best limit for $D^0 \to \mu^+\mu^-$
- CPV phase ϕ_s
  - [NEW] Worlds best measurement, little scope left for difference from SM
- $b \to qll$ penguins
  - [NEW] $B_d \to K^*\mu\mu$ Worlds best measurements, new observables, first extraction zero-crossing point, "SM wins again"
  - [NEW] $B_d \to \phi\mu\mu$ differential BR measurements
  - [NEW] First observation of $B^+ \to \pi^+\mu^+\mu^-$, [NEW] First limits on $B \to 4\mu$
- Charm
  - Anomalous ΔA_{CP} measurement → theory problem? Or NP?
- CKM measurements
  - γ measurements: [NEW] first observation of suppressed ADS modes
  - No time to talk about γ measurement from loops ($B \to hh$ decays), other tree determinations, time dependent measurements ($B_s \to D_s K$)…
- Radiative decays, EW programme, searches for exotics…

Backup

The Experimental Environment

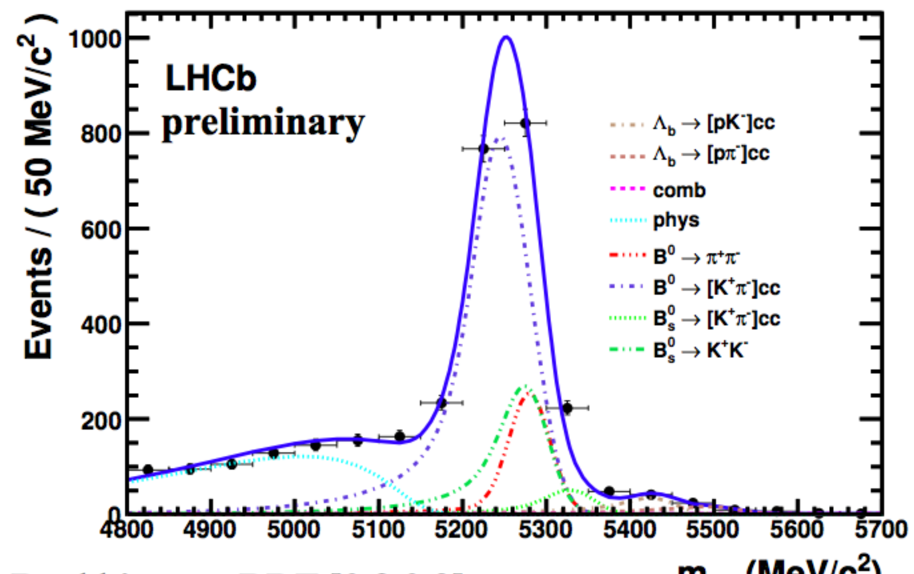
- σ(pp, inelastic) @ $\sqrt{s}$=7 TeV ~60 mb, only 1/200 events contains a b quark, looking for small BR in some cases ~10^{-9}
- In nominal conditions LHCb would operate at an instantaneous luminosity of 2×10^{32} cm^{-2}s^{-1}, 50× lower than ATLAS/CMS, with a mean number of pp interactions per crossing ~0.5
- However, during 2011 data-taking, reduced number bunches; to get high luminosity → smaller β^*
  - Mean number of pp interactions of 1.5 (3× design)
  - Instantaneous luminosity 3×10^{32} cm^{-2}s^{-1} (1.5× design)
  - Using "luminosity leveling" to keep this constant during fill

ϕ_s systematics

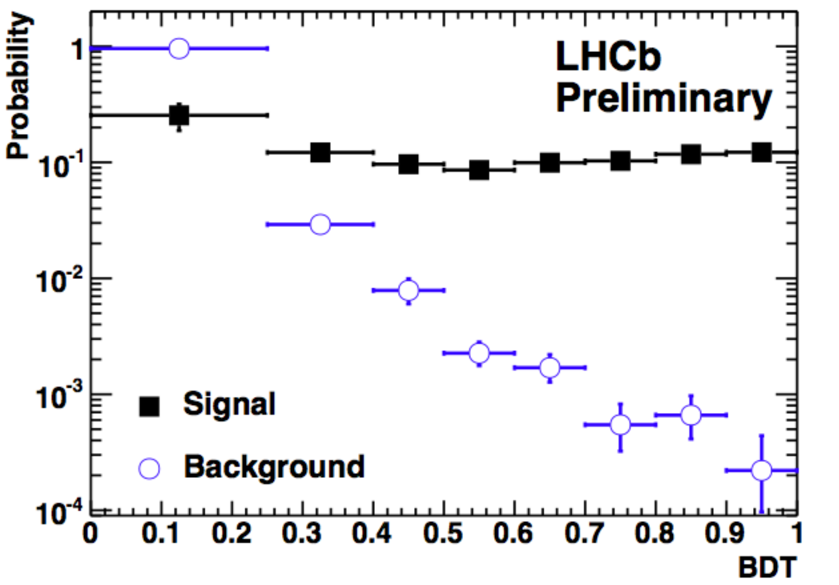
Source	Γ_s [ps^{-1}]	$\Delta\Gamma_s$ [ps^{-1}]	$A_\perp^2$	A_0^2	F_S	$\delta_\parallel$ [rad]	$\delta_\perp$ [rad]	δ_s [rad]	ϕ_s [rad]
Description of background	0.0010	0.004	-	0.002	0.005	0.04	0.04	0.06	0.011
Angular acceptances	0.0018	0.002	0.012	0.024	0.005	0.12	0.06	0.05	0.012
t acceptance model	0.0062	0.002	0.001	0.001	-	-	-	-	-
z and momentum scale	0.0009	-	-	-	-	-	-	-	-
Production asymmetry (± 10%)	0.0002	0.002	-	-	-	-	-	-	0.008
CPV mixing & decay (± 5%)	0.0003	0.002	-	-	-	-	-	-	0.020
Fit bias	-	0.001	0.003	-	0.001	0.02	0.02	0.01	0.005
Quadratic sum	0.0066	0.006	0.013	0.024	0.007	0.13	0.07	0.08	0.027

Analysis Strategy (1)

- Background rejection achieved with a boosted decision tree (BDT):
  - kinematical and geometrical variables
  - signal uniformly distributed 0-1
  - Trained with Monte Carlo simulation, calibrated with data
    - mass lineshape & BDT shape from B→hh events
    - expected background in search windows from fit of data sidebands



B→hh' mass, BDT [0.8,0.9]

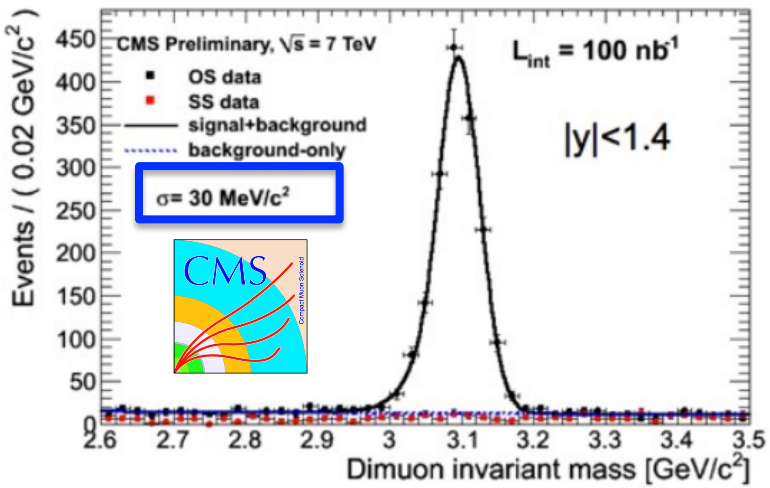


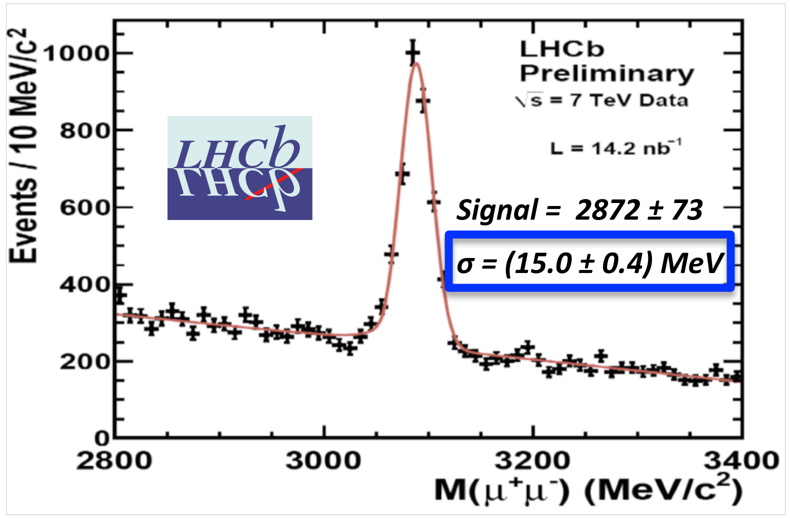
Key ingredients for $B_{s,d} \to \mu^+\mu^-$

- Efficient trigger:
  - p_T cuts on muons kept low → ε(trigger $B_{s,d} \to \mu^+\mu^-$) ~ 90%

- Background reduction:
  - Excellent vertex & IP resolution: σ(IP) ~25 μm @ p_T=2 GeV/c
  - Particle identification: ε(μ→μ) ~97% for ε(h→μ)<1% for p>10 GeV/c
  - Very good mass resolution: δp/p~ 0.35%→0.55% for p=(5-100) GeV/c

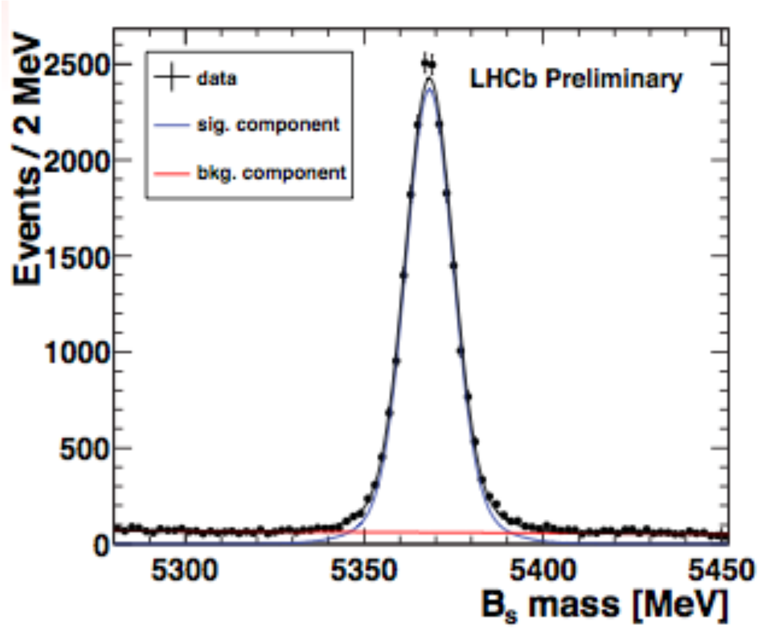
→ $\sigma(MB_{s,d})$ ~ 26 MeV [CDF: 25 MeV, CMS: 40 → >80 MeV]

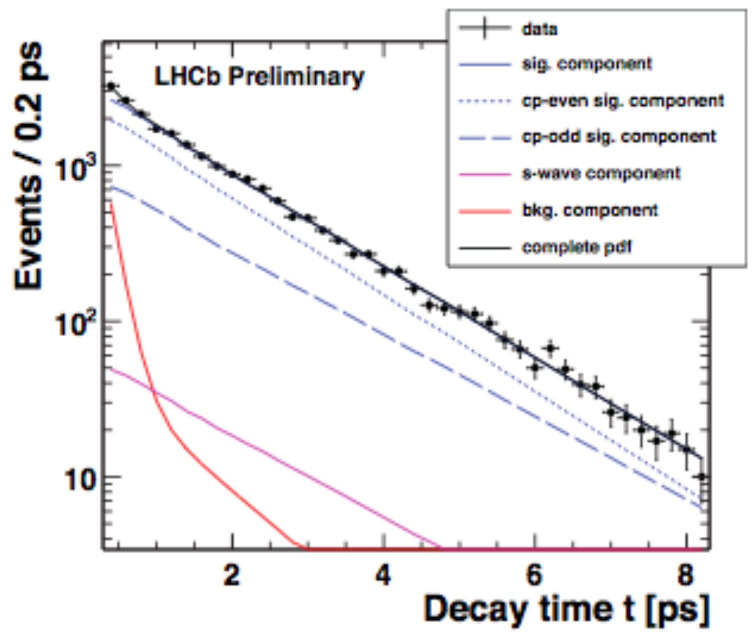




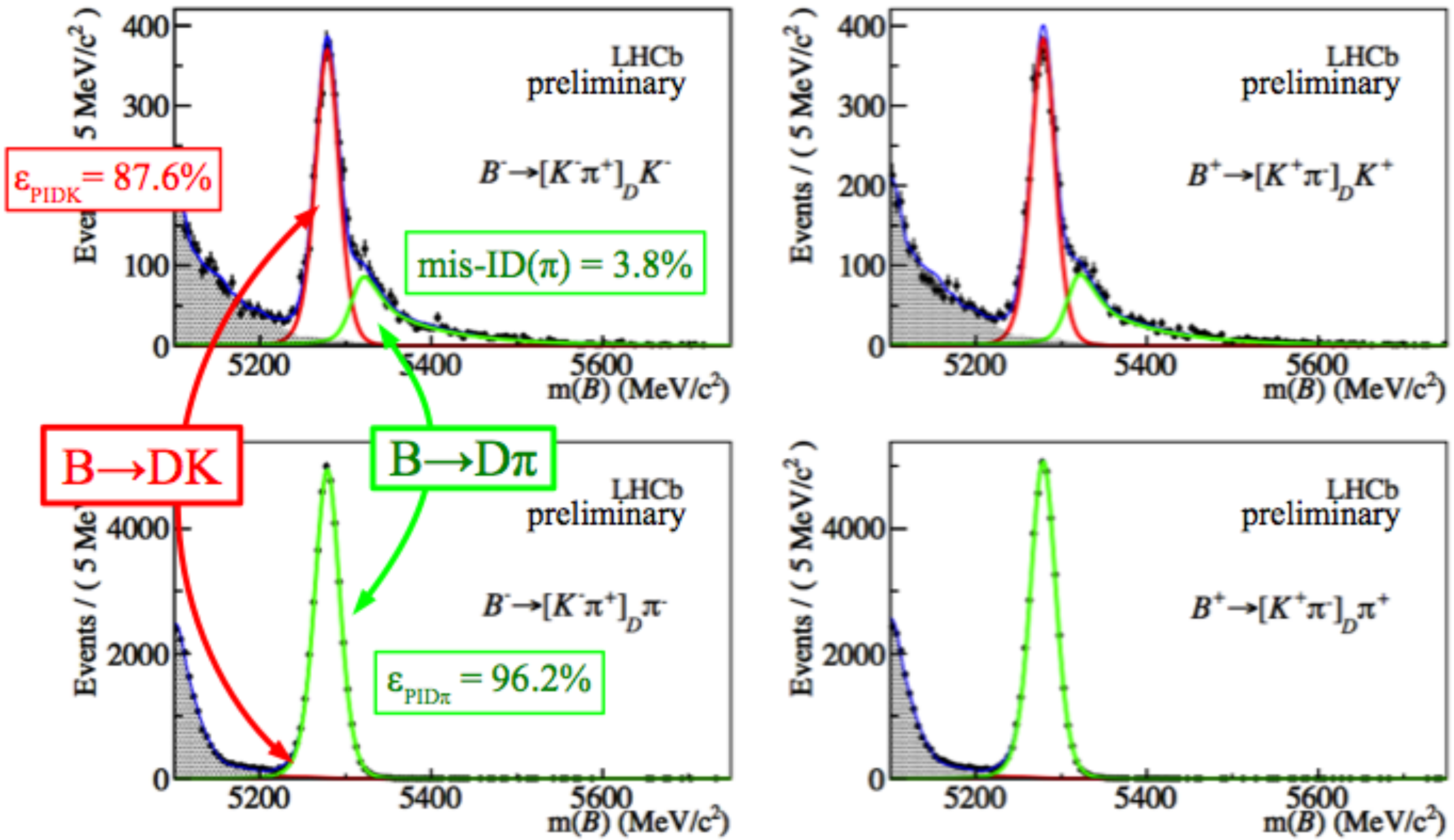
$B_s \to J/\psi\phi$

- Simple seln with kinematic cuts
- Most bkgrd removed by t>0.3 ps cut
  → clean signal ~21.2k events
- The data has sinusoidal terms which measure Δm_s independently of ϕ_s
  - Observe a central value
    - Δm_s= 17.50 ± 0.15 (stat) ps^{-1}
  - cf. LHCb published measurement
    - 17.63 ± 0.11 ± 0.02 ps^{-1} arXiv1112.4311
  - Gives confidence that if there is a $\sin(\phi_s)$ x $\sin(\Delta m_s t)$ term we would see it





ADS/GLW modes



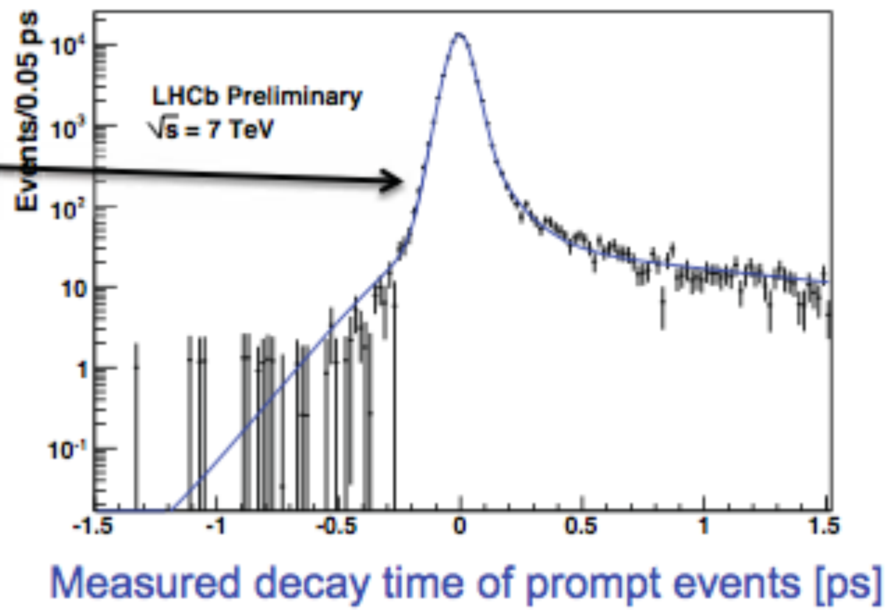
LHCB-PAPER-2012-001

Decay time resolution

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

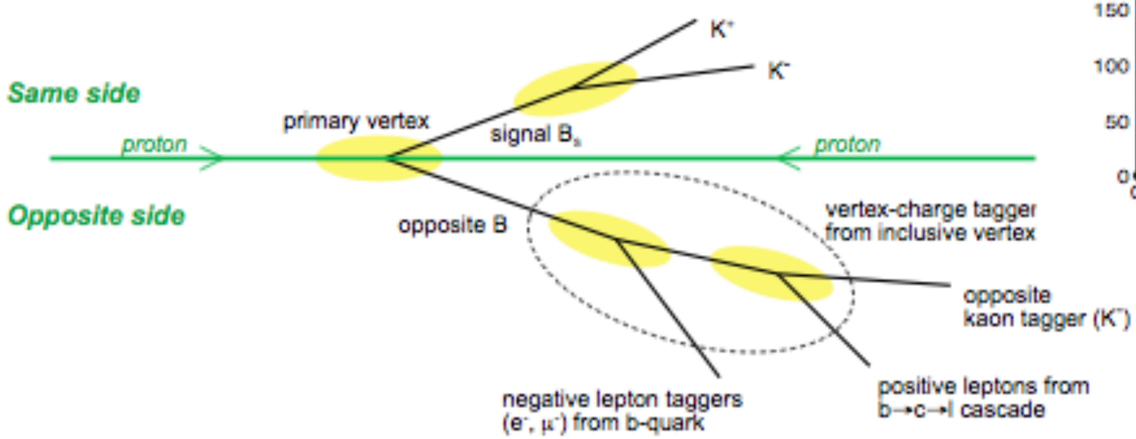
- Need good proper time resolution w.r.t. sinusoid period ~ 350fs

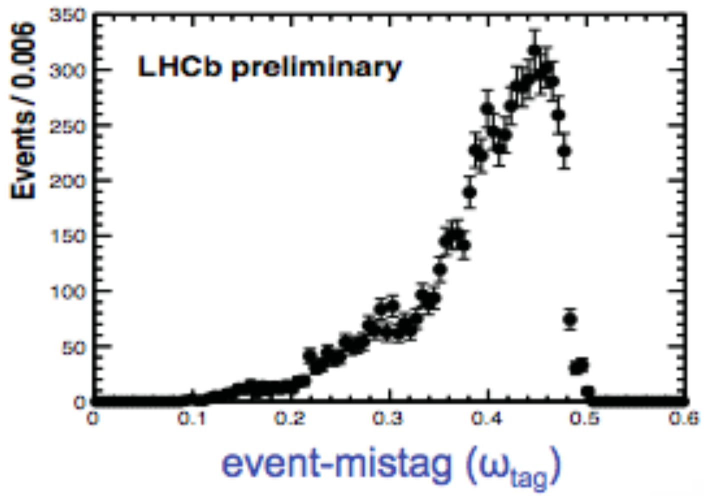
- We measure from data using prompt J/ψ which decay at t=0
- width ~ 45fs
- In analysis we actually use a resolution estimated per-event



Flavour Tagging

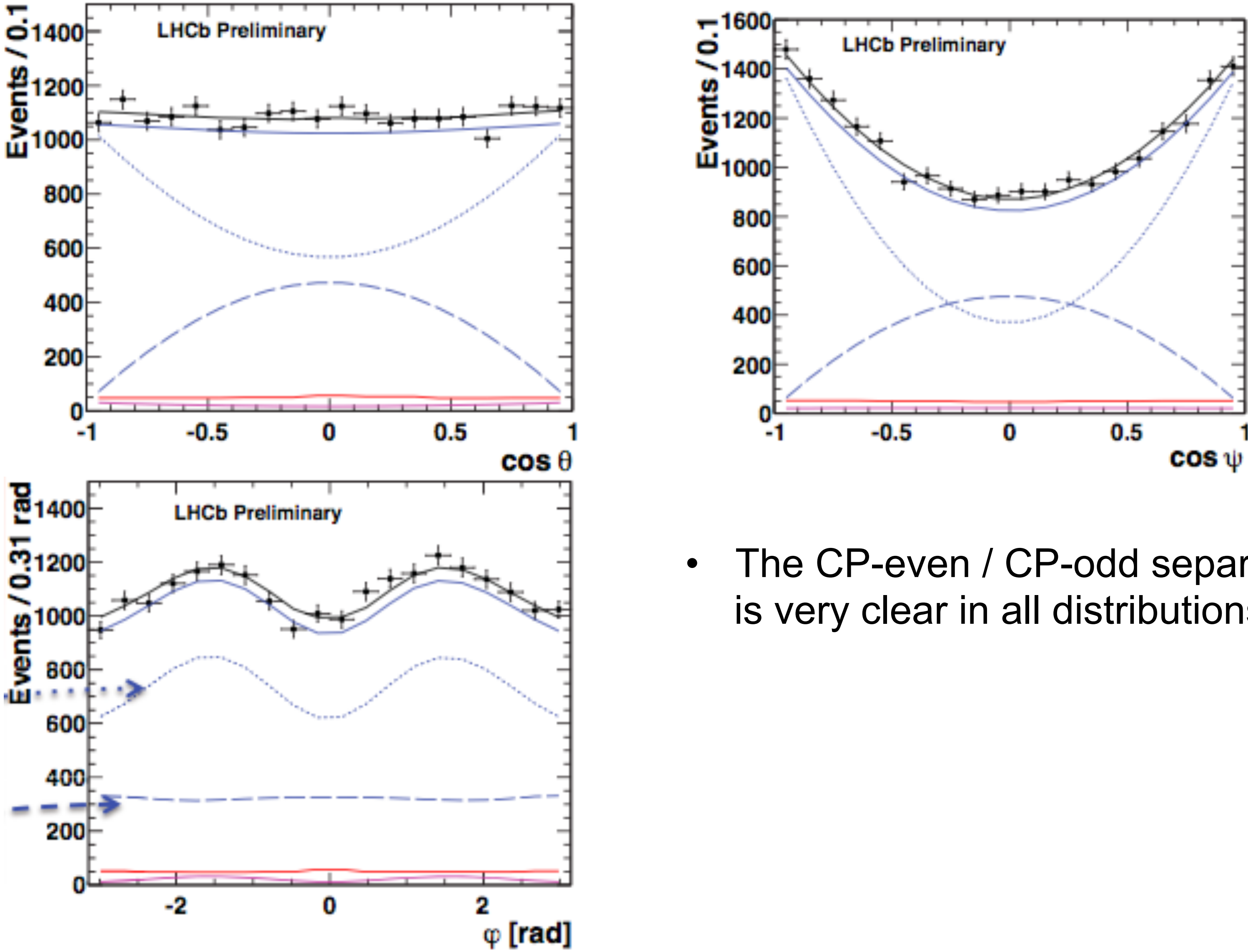
$\sin(\phi_s) \times D(\sigma_t) \times (1 - 2\omega_{tag}) \times \sin(\Delta m_s t)$





tagging efficiency ε_{tag} ~ 33%
effective mistag ω_{tag} ~ 36.8%
effective tagging power $\varepsilon_{tag}(1 - 2\omega_{tag})^2$ ~ 2.3%

$B_s \to J/\psi\phi$ decay angle distributions



- The CP-even / CP-odd separation is very clear in all distributions

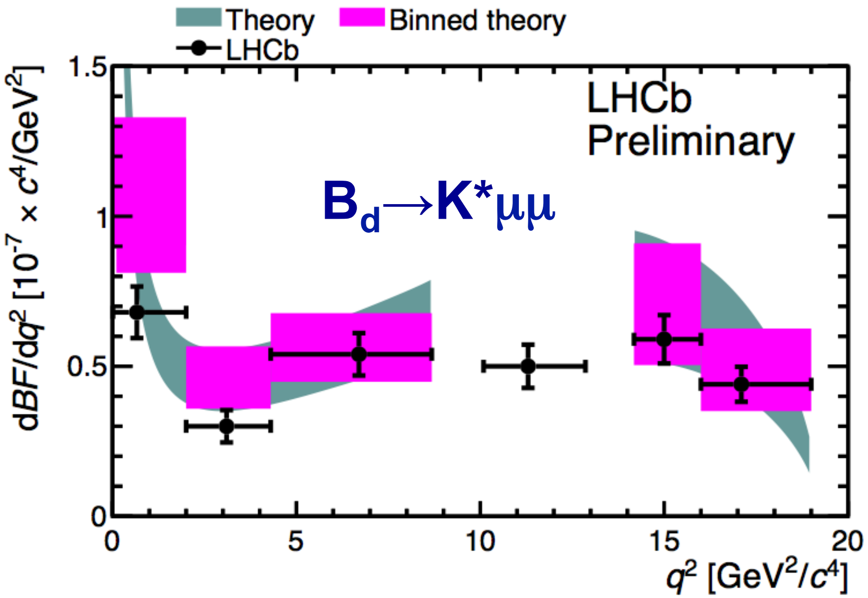
Motivation

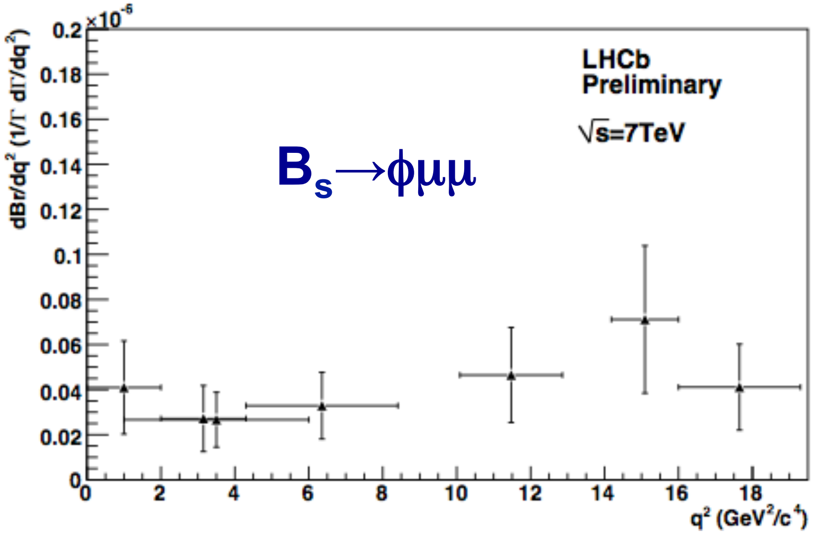
- Look for new physics in b,c decays
  - Heavy flavour an excellent source of loop processes
    - CP violation – in the SM insufficient to explain baryogeneisis
    - Rare decays – study processes with precise SM predictions where SM contribution suppressed st new physics contribution might be comparable
  - Complementary to direct searches at ATLAS/CMS

- Enormous bb, cc cross-sections at LHC → statistics, precision
  - In LHCb acceptance σ(cc)=1200μb, σ(bb)=75μb → in 1fb^{-1} roughly 10^{12} cc and 10^{11} bb produced

- High momenta, boost → good for time dependent measurements

$B_d \to K^*\mu\mu$ and $B_s \to \phi\mu\mu$ differential BR measurements

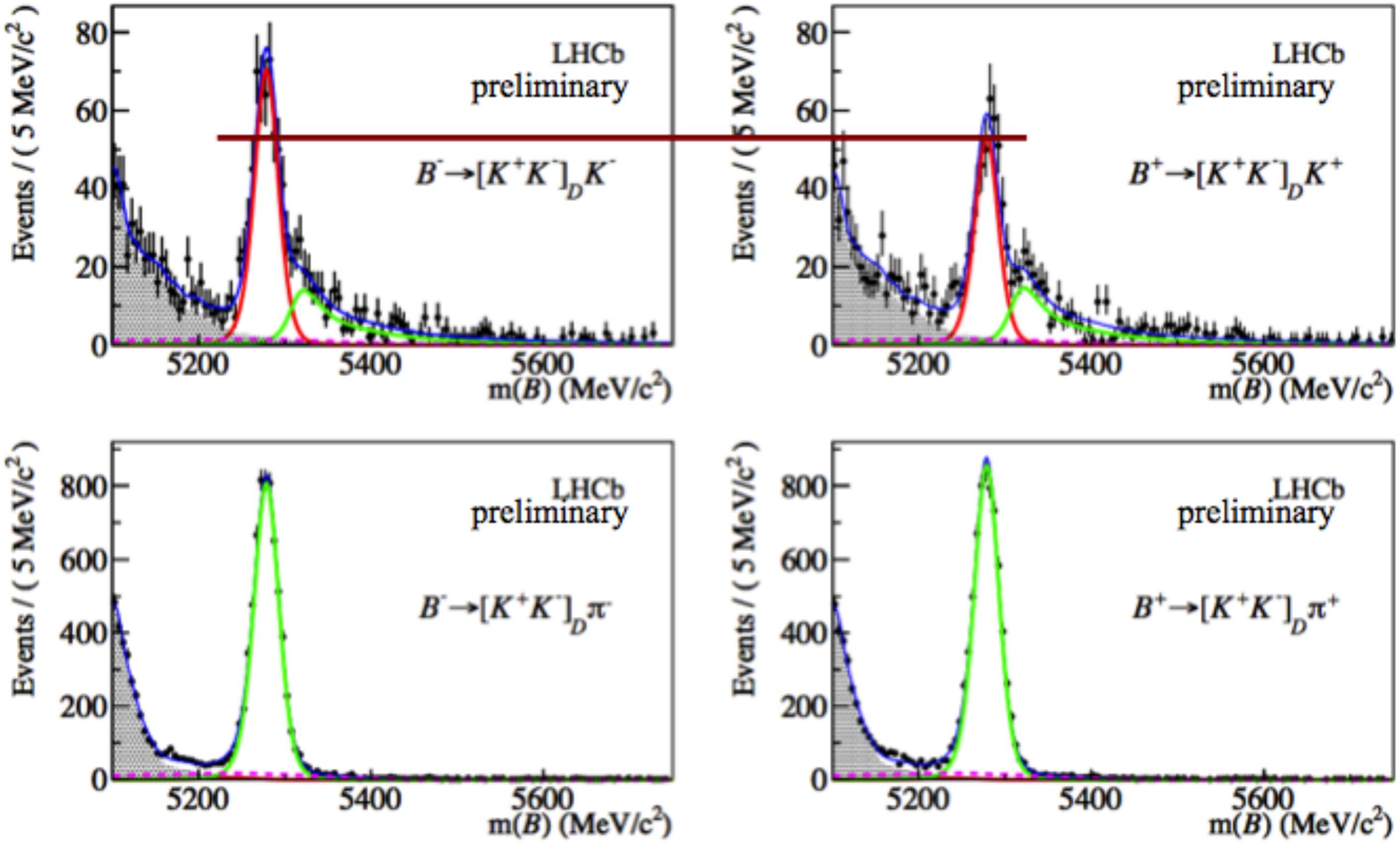




- $B_s \to K^*\mu\mu$: 900±34 signal events
- $B_s \to \phi\mu\mu$: 77±10 signal events
- These are the most precise measurements to-date and are consistent with SM expectations [J.Phys.G G29 (2003) 1103–1118]

LHCb-CONF-2012-008
LHCb-CONF-2012-003

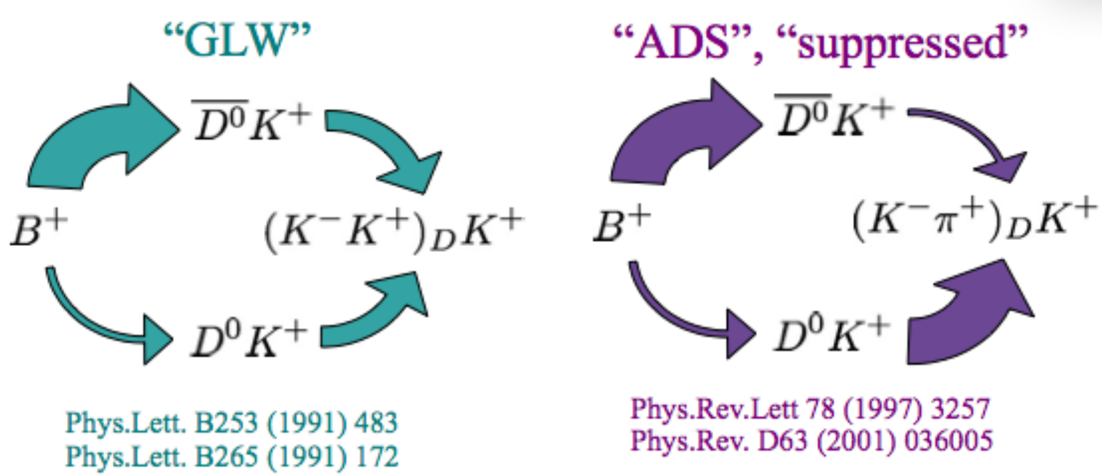
ADS/GLW modes



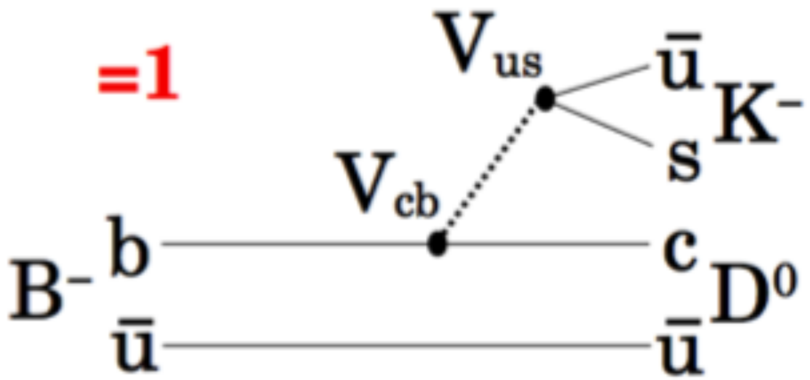
LHCB-PAPER-2012-001

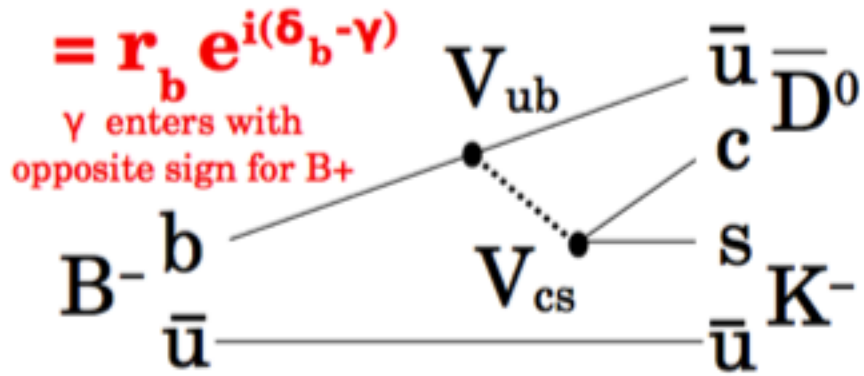
CKM Measurements

- Time independent strategies:
  - $B^+ \to D(hh)K^+$
  - $B^0 \to D(hh)K\pi^+$
  - $B^+ \to D(K_S\pi\pi)K^+$
  - $B^+ \to D(K\pi\pi\pi)K^+$
  - $B_s \to D_s\phi$
- Time dependent strategies:
  - $B_s \to D_s^- K^+$ $B \to hh$ [loops]



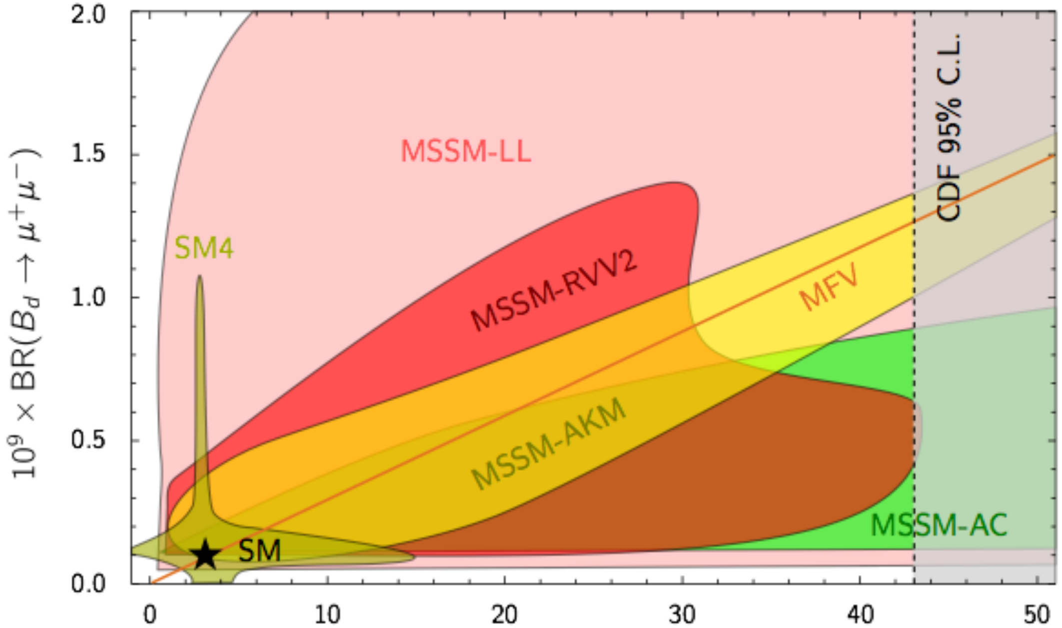
CERN seminar yesterday…





From D. Straub, Moriond-EW:

Then:



Now: