New physics through Beauty

- The historical context
- Current concerns: five selected measurements
- Next steps

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UK HEP Forum, Cosener's House
15/11/2013

Breaching the walls of the Standard Model

Full frontal assault

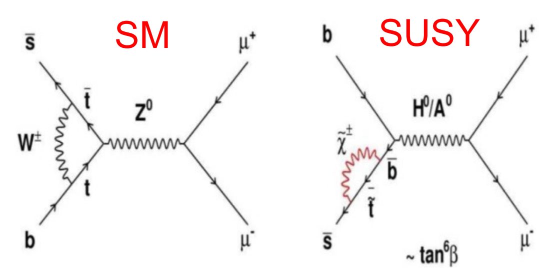
the direct search approach i.e. on-shell production of *e.g.* SUSY particles

Something more cunning

the indirect approach: **flavour physics**
e.g. virtual SUSY in rare b/c-transitions

Both are needed to understand nature of any New Physics !

One example: the super-rare $B_s \to \mu\mu$ decay



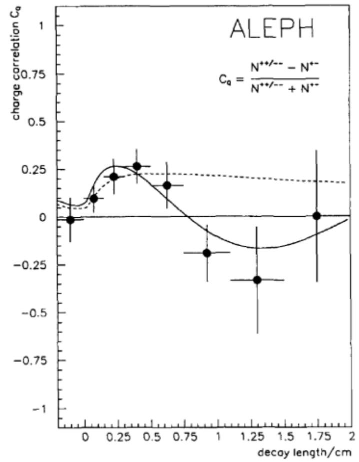
B physics – 25 years of steady progress, *e.g.* time-dependent CPV

Observation of mixing in (B^0+B_s) and B^0 system

UA1, PLB 186 (1987) 247

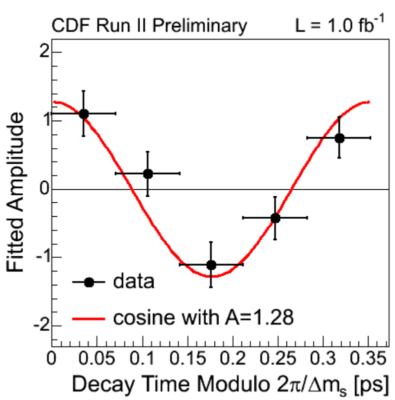
Argus, PLB 192 (1987) 245

Resolution of B^0 oscillations



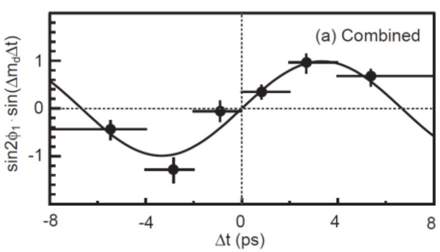
ALEPH, PLB 313 (1993) 498

Resolution of B_s oscillations

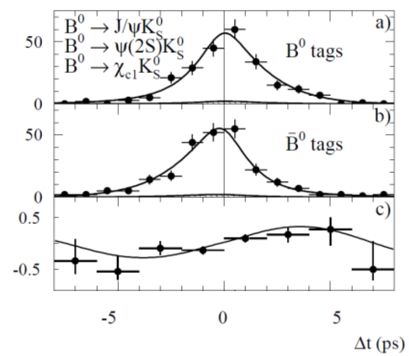


CDF, PRL 97 (2006) 242003

Observation of CPV in interference between B^0 mixing and decay



BELLE, PRL 87 (2001) 091802

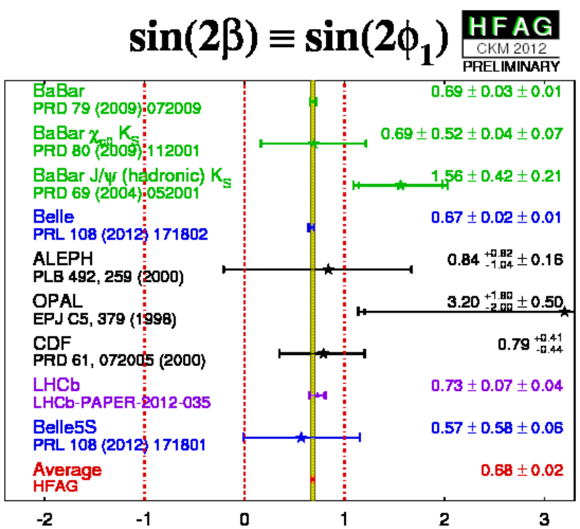


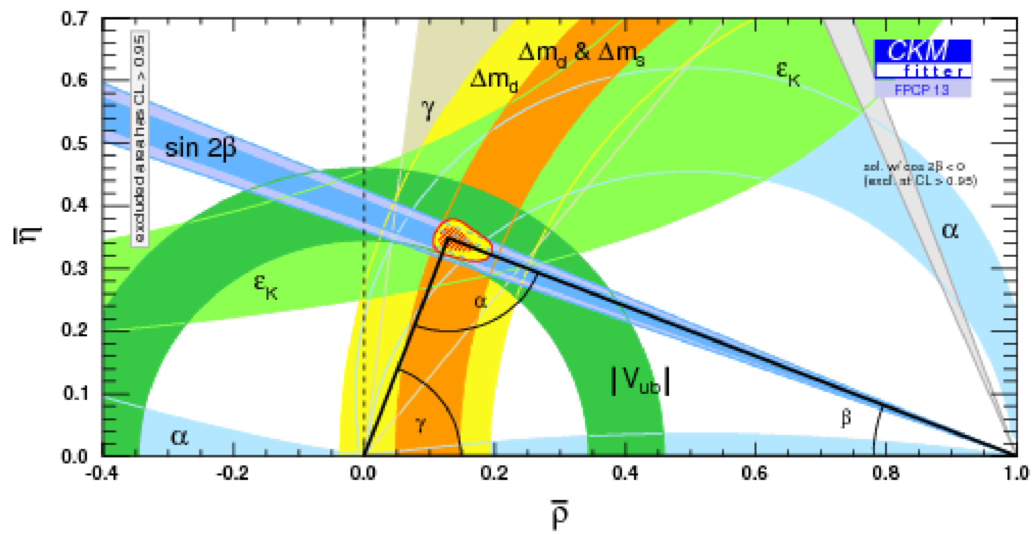
BaBar, PRL 87 (2001) 091801

Many facilities, many experiments...

The B-factory legacy – validating the CKM mechanism

BaBar & Belle made a host of very significant measurements, & flavour physics in the last decade has also received critical inputs from the Tevatron, but most important achievement remains the measurement of sin2β, primarily though $B^0 \rightarrow J/\psi K_S$ decays





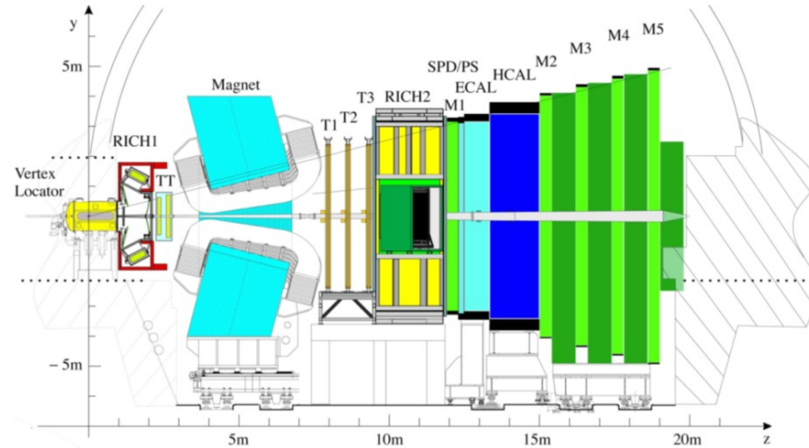
This measurement validates the CKM mechanism as being the leading order agent of CP-violation in nature (and gave the cue for K & M's 2008 Nobel prize)

Last decade we had 3 B-physics colliders in operation, now we have 1 - the LHC

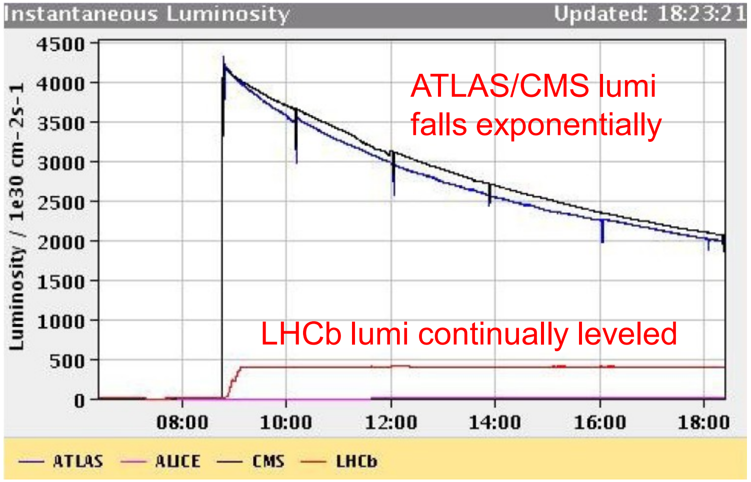
LHCb – the essentials

LHCb – a forward spectrometer optimised for heavy-flavour physics at the LHC

- forward acceptance ($2 < \eta < 5$)
- high bandwidth trigger
- acceptance down to low p_t
- precise vertexing (VELO)
- hadron identification (RICHes)



LHCb operation proceeds in harmony with higher luminosity operation of ATLAS/CMS thanks to luminosity leveling.



- 37 pb^{-1} collected in 2010
- 1 fb^{-1} in 2011 and 2 fb^{-1} in 2012
- aim for ~8 fb^{-1} before 2018-19 shutdown

UK is the biggest single national contributor, & has led the design, construction & operation of the VELO & RICH subdetectors

Beauty physics – current concerns

Five *selected* topics with genuine New Physics discovery potential...

- CKM metrology – the quest for precise knowledge of γ
- CPV in B_s mixing-related phenomena
- In search of the super-rare: $B^0_{(s)} \rightarrow \mu\mu$
- LHC data confronts electroweak Penguins: $B \rightarrow K^{(*)}\mu\mu$
- Loose ends (?) from the B-factories: $B \rightarrow \tau\nu$, $D^{(*)}\tau\nu$

...for which results have recently become available &/or progress is soon expected

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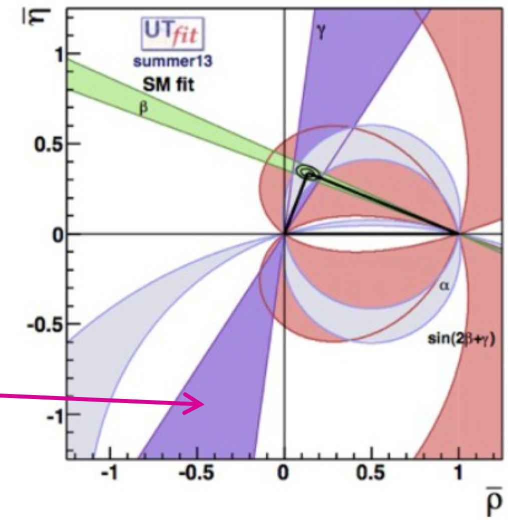
Precision CKM-metrology: the next challenge



B-factories (& others) have done a great job in mapping out unitarity triangle. But further progress needs, in particular, improved knowledge of angle γ

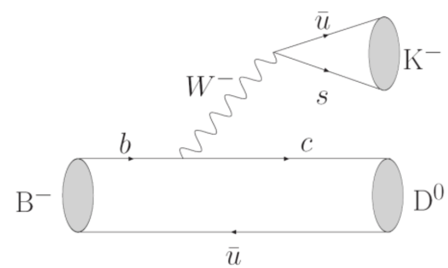
Look in $B^\pm \to DK^\pm$ decays using common mode for D^0 & $\bar{D}^0$

→ γ sensitive interference

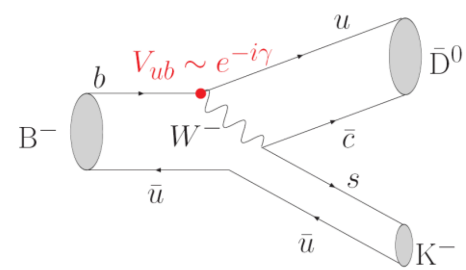
→ different rates for B^+ & B^- (CPV!)

Many possibilities: *Kπ*, *KK*, *Kπππ*...

Favoured



Suppressed

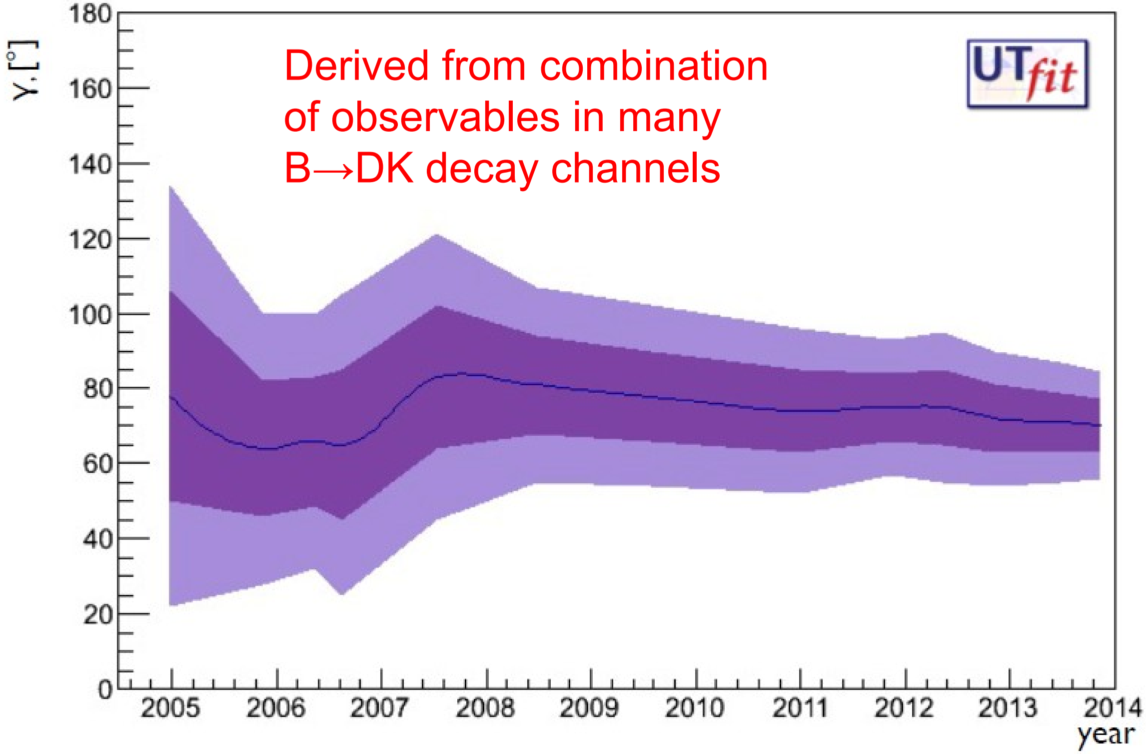


Tree-level decays: strategy very clean & yields result unpolluted by New Physics

This is a good thing! Provides SM benchmark against which other loop-driven NP sensitive observables can be compared (e.g. $\Delta m_d/\Delta m_s$, sin2β, γ measured in $B \to hh$)

γ measurement – the last ~10 years

The story so far...



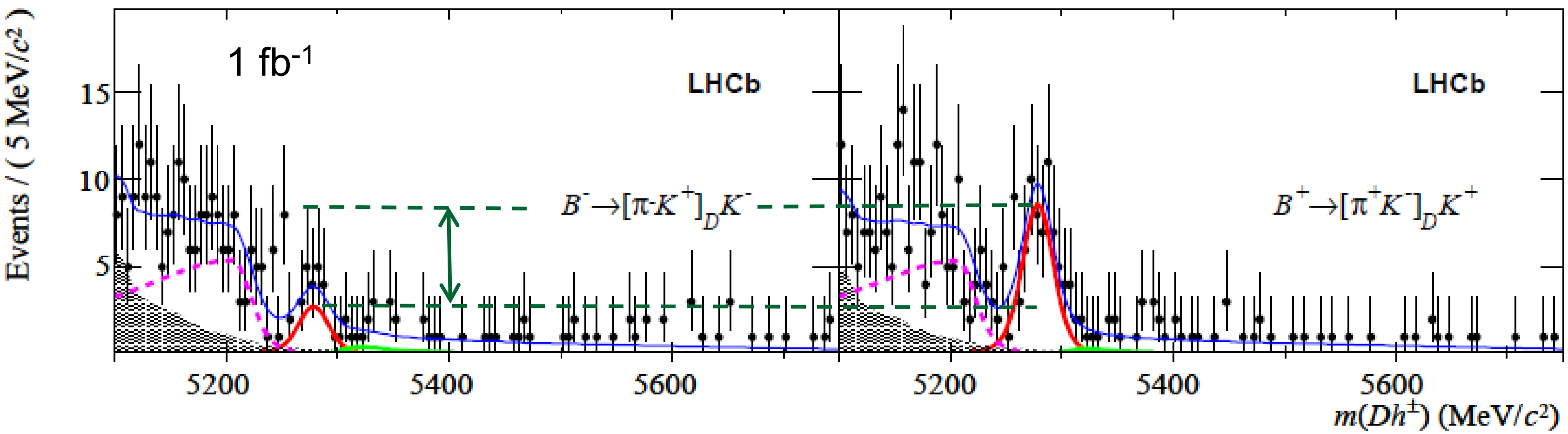
Consistent with the indirect prediction...

...but half as precise

...factor 3 improvement in 10 years.

γ measurement: true precision needs statistical muscle of LHCb

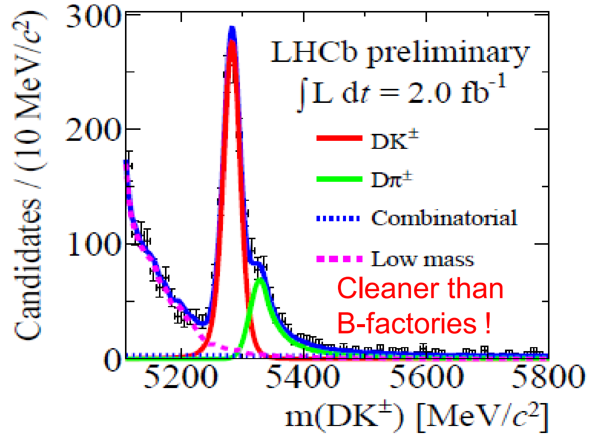
Rare, important decays just beyond the reach of the B-factories (*e.g.* the suppressed 'ADS' $B^{\pm} \rightarrow (K^{\mp}\pi^{\pm})_D K^{\pm}$ mode (BR ~ 10^{-7}) was soon seen at LHCb



[PLB 712 (2012) 203]

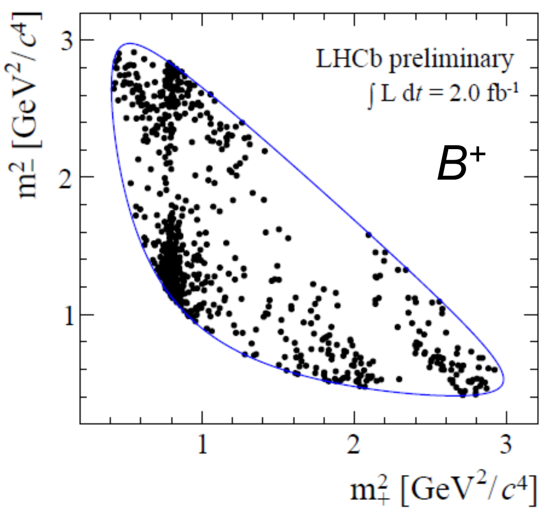
This CP asymmetry carries ultra-clean, easy to interpret, information on γ !

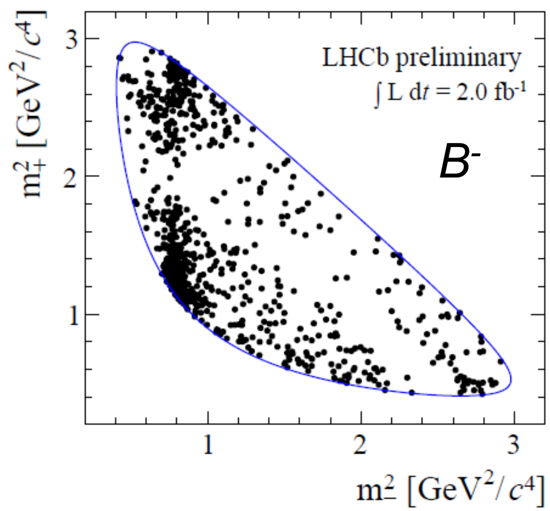
$B \to [K_S hh]_D K$ at LHCb

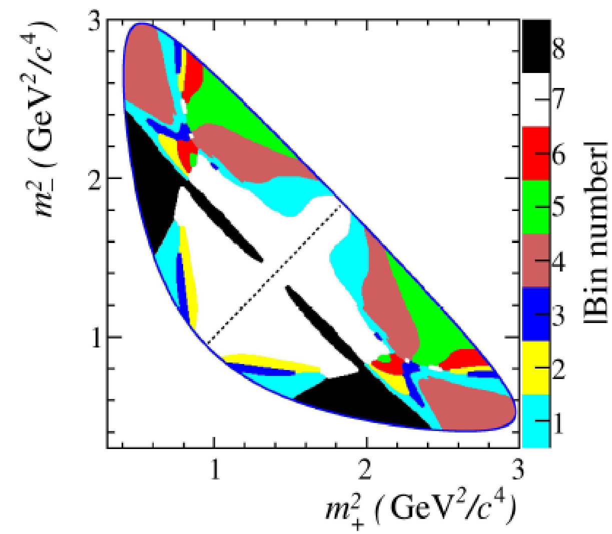


B→DK method has been applied by LHCb to *D*→$K_S\pi\pi$ and K_SKK (here with 2012 data). CPV leads to difference in *D* Dalitz plots for B^+ and B^- decays

[LHCb,CONF-2013-004]





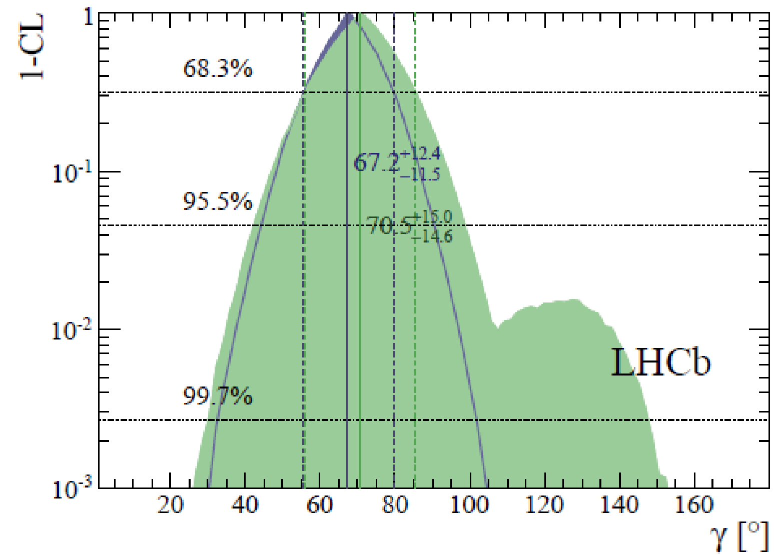


Data analysed in bins which have similar *D* decay strong-phase. To retain model independence these phases are taken from measurements of quantum-correlated *DD*bar pairs at CLEO-c [PRD 82 (2010) 112006] - will be improved by BES-III.

Cleanliness of measurement preserved exploiting synergy of facilities !

LHCb: current precision on γ and future prospects

Combination of LHCb *B→DK* results obtained so far



LHCb-CONF-2013-006

Precision of ~12° - now better than that obtained with B-factory samples

Will improve steadily:

- more modes to be analysed (there are many...)
- Add 2012 updates for many key modes and post-LS1 data

Aim for ~ 4° uncertainty after first stage LHCb (matches current indirect precision)

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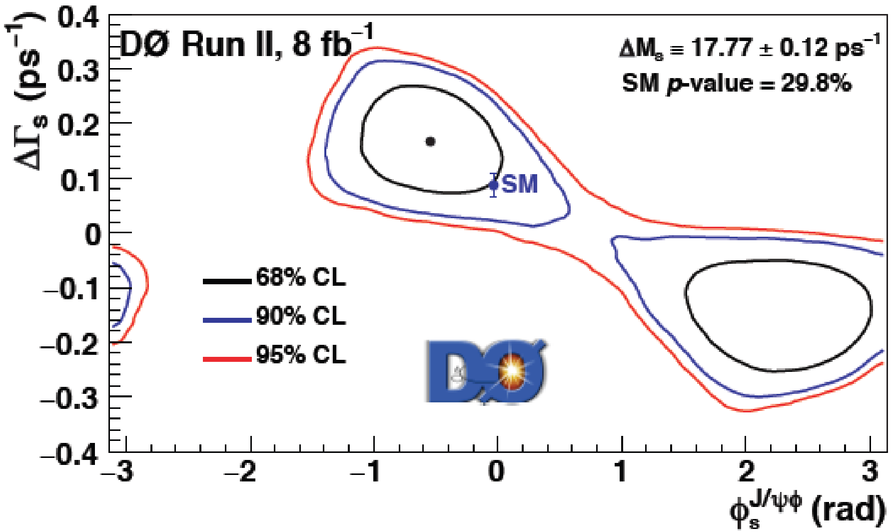
Mixing induced CPV in B_s system

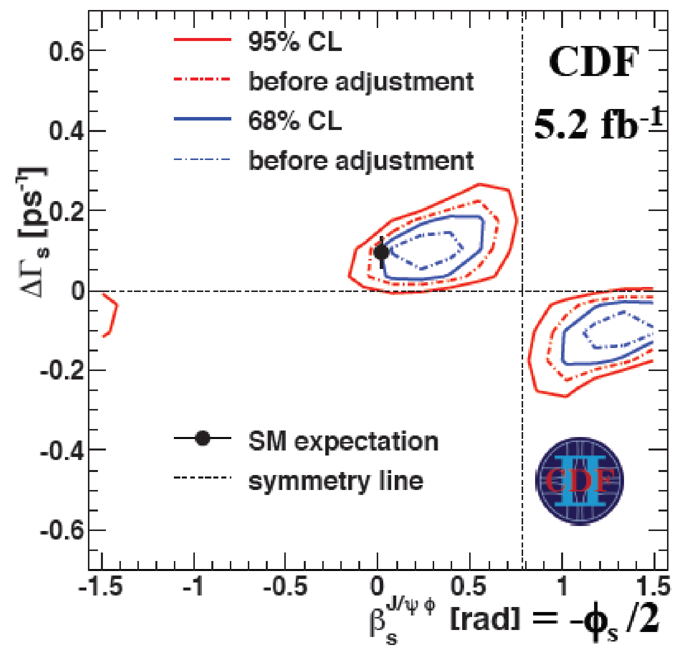
CPV phase, φ_s, in B_s mixing-decay interference, e.g. measured in $B_s \rightarrow J/\Psi\Phi$, very small & precisely predicted in SM. Box diagram offers tempting entry point for NP!

Tevatron results were tantalising with early data and remain intriguing with final sample:

[PRD 85 (2012) 032006]



[PRD 85 (2012) 072002]



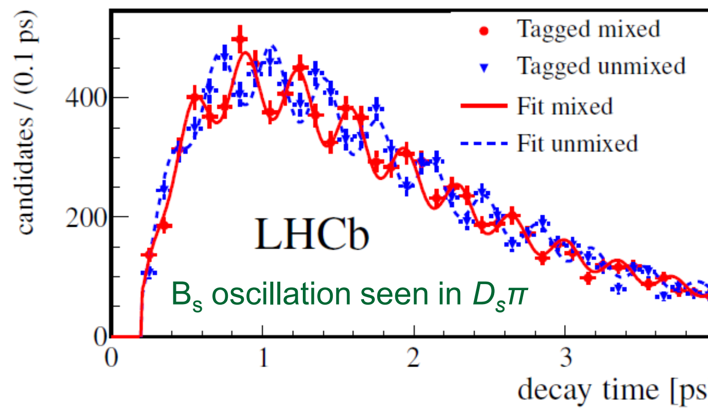
Results are consistent, & both are ~1σ away from SM. What about the LHC?

Precision studies of Φ_s

The LHC (firstly LHCb & now ATLAS/CMS) has brought clarity to the φ_s picture.

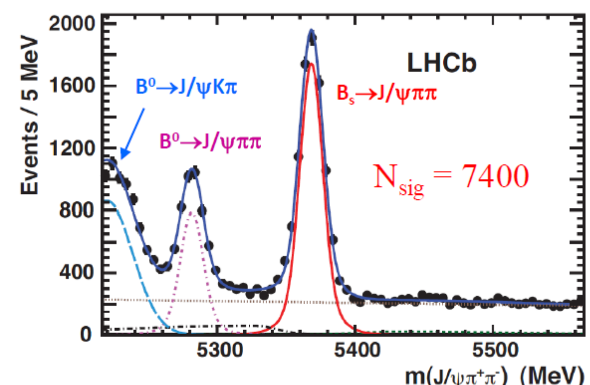
LHCb attributes/contributions:

- Statistics and time resolution! $B_s \to J/\Psi\varphi$ analysis with ~4x precision of Tevatron [LHCb-CONF-2012-002]

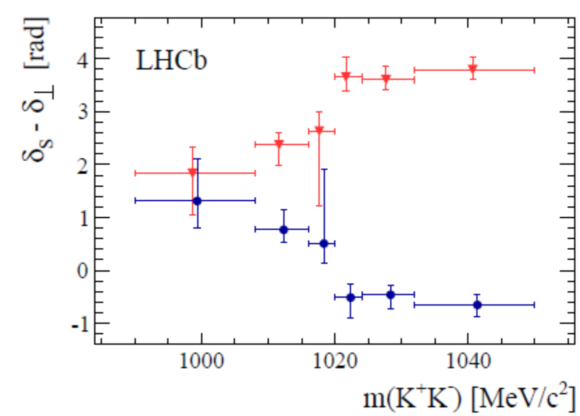


LHCb-PAPER-2013-006

- Augment this with novel analysis in complementary channel $B_s \to J/\Psi\pi\pi$ [PLB 713 (2012) 378]



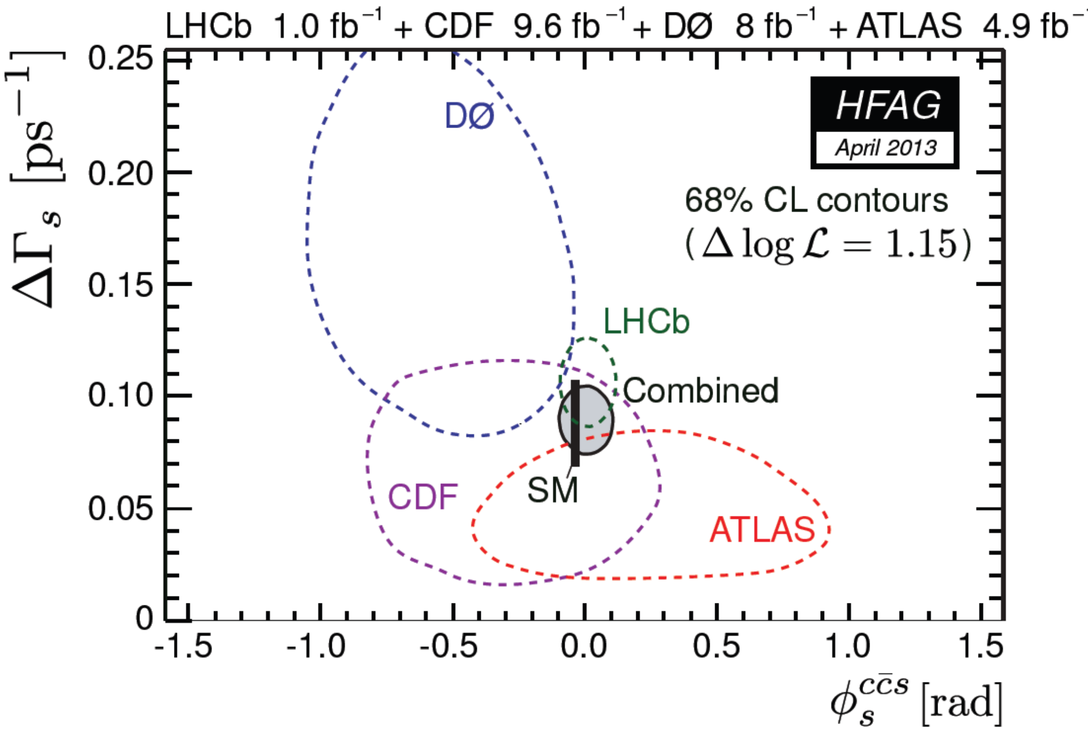
- Finally, perform study looking at strong-phase change w.r.t. *KK* invariant mass in *J/ΨKK* which resolves 2-fold ambiguity [PRL 108 (2012) 241801]



Final LHCb 2011 results recently published [PRD 87 (2013) 112010] and overall picture now clear.

Precision studies of Φ_s

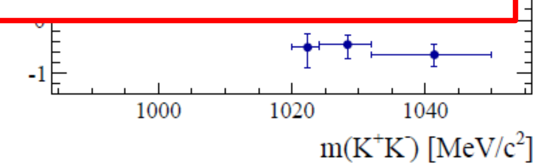
Earlier hints of *large* NP effects emphatically not confirmed...



Not including ATLAS tagged analysis update [ATLAS-CONF-2013-039]

...but observable remains a priori very sensitive to non-SM contributions and essential to improve precision over coming 5 years (and beyond).

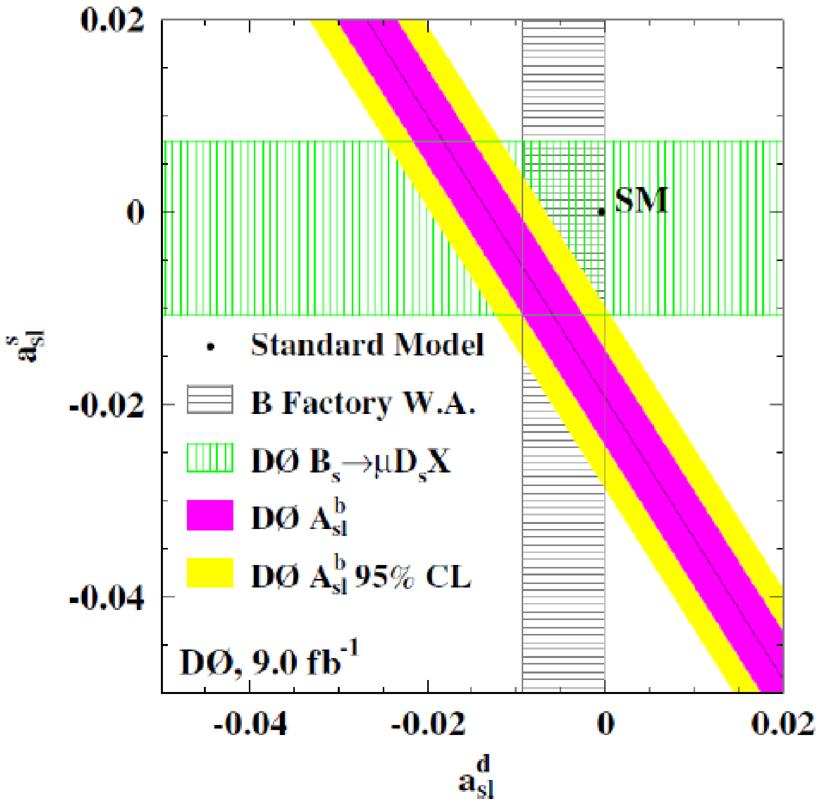
LHCb-PAPER-2013-006



The elephant in the room: a_{sl}

Flavour-specific CP asymmetry in B decays, most easily measured in semileptonics (hence a_{sl}) accesses CP-violation in mixing. Extremely small in SM, especially in B_s system.

[D0, PRD 84 (2011) 052007]



D0 measurement, made with dileptons, measures a superposition of a^s_{sl} and a^d_{sl}

2011 result lies 3.9σ from SM.

Most easily interpreted as a B_s driven effect. Challenging, however, to reconcile with other measurements, *e.g.* $B_s \to J/\Psi\varphi$, $J/\Psi\pi\pi$

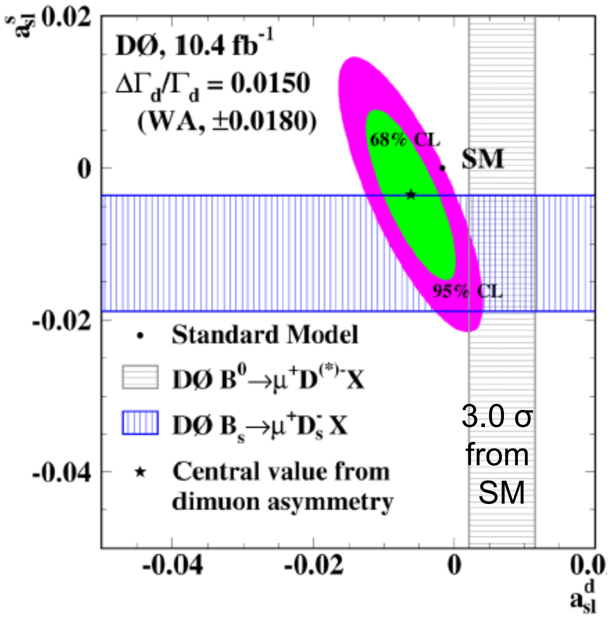
Last month the D0 'final word' was published

Final D0 like-sign dimuon charge asymmetry

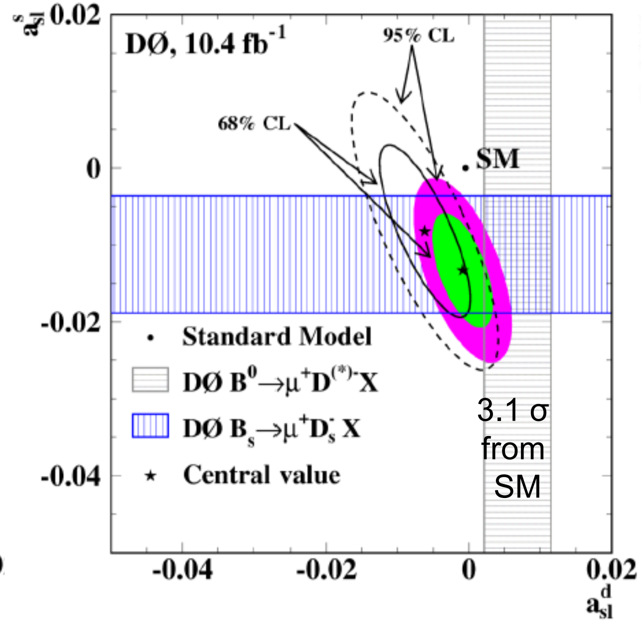
What's new in 'last word' D0 analysis [arXiv:13110.0447] ?

- Int. lumi 9.0→10.4 fb^{-1}
- Detailed study of IP info
- Detailed study on kinematic dependence
- New cross-checks in bckgd studies
- Improved sophistication in interpretation

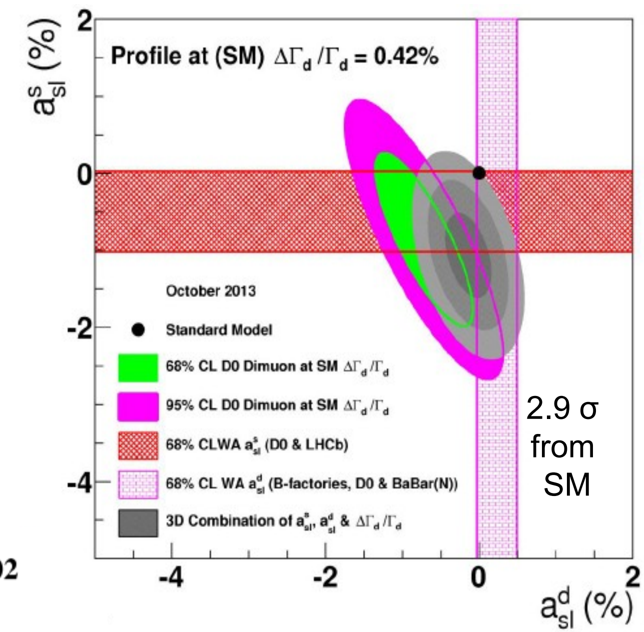
Contours from dimuon result alone



Including dedicated D0 results on a^s_{sl} and a^s_{sd}



Including input from B-factories and LHCb



(Note these fits are floating a^s_{sl}, a^d_{sl} and $\Delta\Gamma_d/\Gamma_d$ – other possibilities presented in paper)

Best bet for enlightenment: super-precise measurements of a^s_{sl} and a^d_{sl} at LHCb

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$B^0_{(s)} \to \mu\mu$ – a twenty-five year old quest

We have been searching for B^0 and $B^0_s \to \mu\mu$ for a long time...

Volume 199, number 3 PHYSICS LETTERS B 24 December 1987

B MESON DECAYS INTO CHARMONIUM STATES

ARGUS Collaboration

H. ALBRECHT, A.A. ANDAM [1], U. BINDER, P. BÖCKMANN, R. GLÄSER, G. HARDER, A. KRÜGER, A. NIPPE, M. SCHÄFER, W. SCHMIDT-PARZEFALL, H. SCHRÖDER, H.D. SCHULZ, R. WURTH, A. YAGIL [2,3]
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J.P. DONKER, A. DRESCHER, D. KAMP, H. KOLANOSKI, U. MATTHIESEN, H. SCHECK, B. SPAAN, J. SPENGLER, D. WEGENER
Institut für Physik, Universität Dortmund [4], Universität Dortmund, D-6400 Dortmund, Fed. Rep. Germany

Table 2
Upper limits for exclusive dilepton decays.

Decay channel	Upper limit with 90% CL [$\times 10^{-5}$]
$B^0 \to e^+e^-$	8.5
$B^0 \to \mu^+\mu^-$	5.0
$B^0 \to e^\pm\mu^\mp$	5.0

Volume 262, number 1 PHYSICS LETTERS B 13 July 1991

A search for rare B meson decays at the CERN Sp$\bar{p}$S Collider

UA1 Collaboration, CERN, Geneva, Switzerland

Aachen–Amsterdam (NIKHEF)–Annecy (LAPP)–Birmingham–Boston–CERN–Helsinki–Kiel–Imperial College, London–Queen Mary Westfield College, London–Madrid (CIEMAT)–MIT–Padua–Paris (Collège de France)–Rome–Rutherford Appleton Laboratory–Saclay (CEN)–UCLA–Vienna

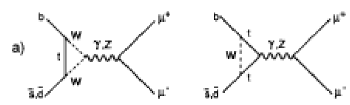
C. Albajar [a], M.G. Albrow [b], O.C. Allkofer [c,1], K. Ankoviak [d], R. Apsimon [b], B. Aubert [e], C. Bacci [f], S. Bartha [c], G. Bauer [g], A. Bettini [h], A. Bezaguet [a], P. Biddulph [i], H. Bohn [c], A. Böhrer [j], R. Bonino [a], K. Bos [k], M. Botlo [a], D. Brockhausen [c], C. Buchanan [d], B. Buschbeck [g], G. Busetto [h], A. Caner [h], P. Casoli [h], H. Castilla-Valdez [d], F. Cavanna [e], P. Cennini [a], S. Centro [h], F. Ceradini [f], G. Ciapetti [f], S. Cittolin [a], E. Clayton [m], D. Cline [d], J. Colas [e], R. Conte [h], J.A. Coughlan [b], D. Dau [c], C. Daum [k], M. Della Negra [a], M. Demoulin [a], D. Denegri [n], H. Dibon [g], A. DiCiaccio [f], F.J. Diez Hedo [a], L. Dobrzynski [o], J. Dorenbosch [k],

Received 21 March 1991

We report on a search for the decays $B^0 \to \mu^+\mu^-$, $B \to \mu^+\mu^- X$ and $B^0_d \to \mu^+\mu^- K^{0*}$, which are expected to be rare if mediated by flavor changing neutral currents. Using data collected during the 1984–1989 CERN $p\bar{p}$ Collider runs, the UA1 search was carried out using $\mu^+\mu^-$ events with $3.9 < M_{\mu\mu} < 5.5$ GeV/c^2. We find 90% confidence level upper limits on the branching ratios for $B^0 \to \mu^+\mu^-$ of 8.3×10^{-6}, for $B \to \mu^+\mu^- X$ of 5.0×10^{-5}, and for $B^0_d \to \mu^+\mu^- K^{0*}$ of 2.3×10^{-5}. Implications for upper limits on the t-quark mass are discussed.

1. Introduction

Flavor changing neutral currents are forbidden at the tree level in the standard model of electroweak interactions. However, these transitions are expected ...e-loop level through the so-called penguin



RAPID COMMUNICATIONS

PHYSICAL REVIEW D, VOLUME 62, 091102(R)

Search for decays of B^0 mesons into pairs of leptons: $B^0 \to e^+e^-$, $B^0 \to \mu^+\mu^-$, and $B^0 \to e^\pm\mu^\mp$

T. Bergfeld, B. I. Eisenstein, J. Ernst, G. E. Gladding, G. D. Gollin, R. M. Hans, E. Johnson, I. Karliner, M. A. Marsh, M. Palmer, C. Plager, C. Sedlack, M. Selen, J. J. Thaler, and J. Williams
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(CLEO Collaboration)

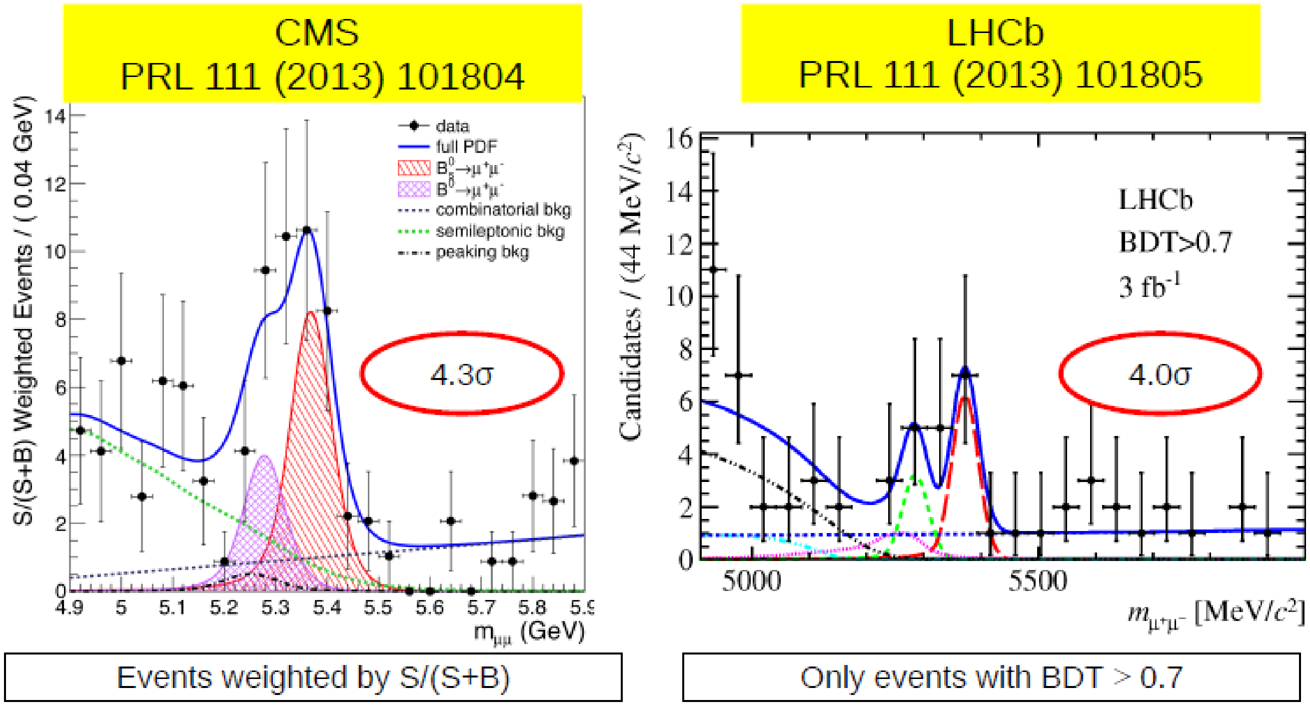
(Received 19 July 2000; published 2 October 2000)

We search for the decay of the B^0 meson into a pair of leptons in the suppressed channels $B^0 \to e^+e^-$, $B^0 \to \mu^+\mu^-$ and in the lepton number violating channel $B^0 \to e^\pm\mu^\mp$ in a sample of 9.7×10^6 $B\bar{B}$ pairs recorded by CLEO detector. No signal is found, and the following upper limits on the branching fractions are established: $\mathcal{B}(B^0 \to e^+e^-) < 8.3 \times 10^{-7}$, $\mathcal{B}(B^0 \to \mu^+\mu^-) < 6.1 \times 10^{-7}$, $\mathcal{B}(B^0 \to e^\pm\mu^\mp) < 15 \times 10^{-7}$ at 90% confidence level. A new lower limit on the Pati-Salam leptoquark mass $M_{LQ} > 27$ TeV is established at 90% confidence level.

$B^0_s \rightarrow \mu\mu$ – the hunt is over

For many years, an enhancement in $B_s \rightarrow \mu\mu$ was best bet for finding NP in flavour.

The good news: We now see the decay!



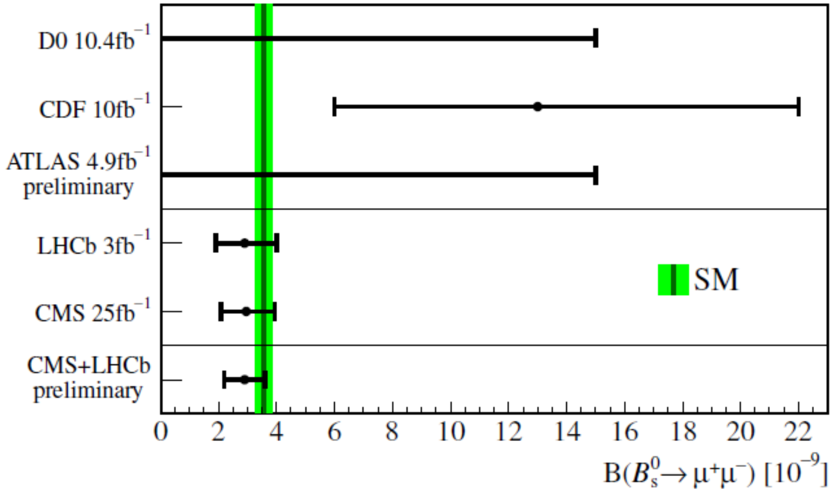
The bad news: it is entirely compatible with SM (albeit a little low).

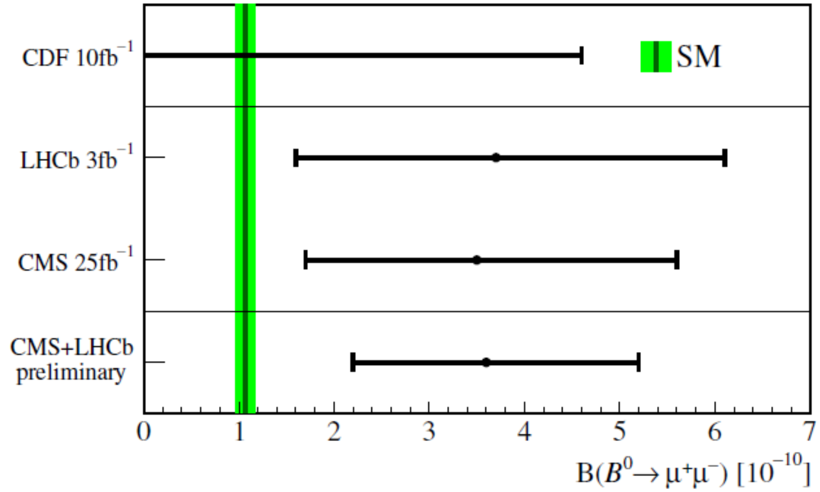
$B^0_s \to \mu\mu$ – the hunt is over

LHCb-CONF-2013-012
CMS-PAS-BPH-13-007

Here is the combination – note the rapid progress since LHC turn on

Also note we are starting to gain sensitivity to the even rarer sister decay $B^0 \to \mu\mu$



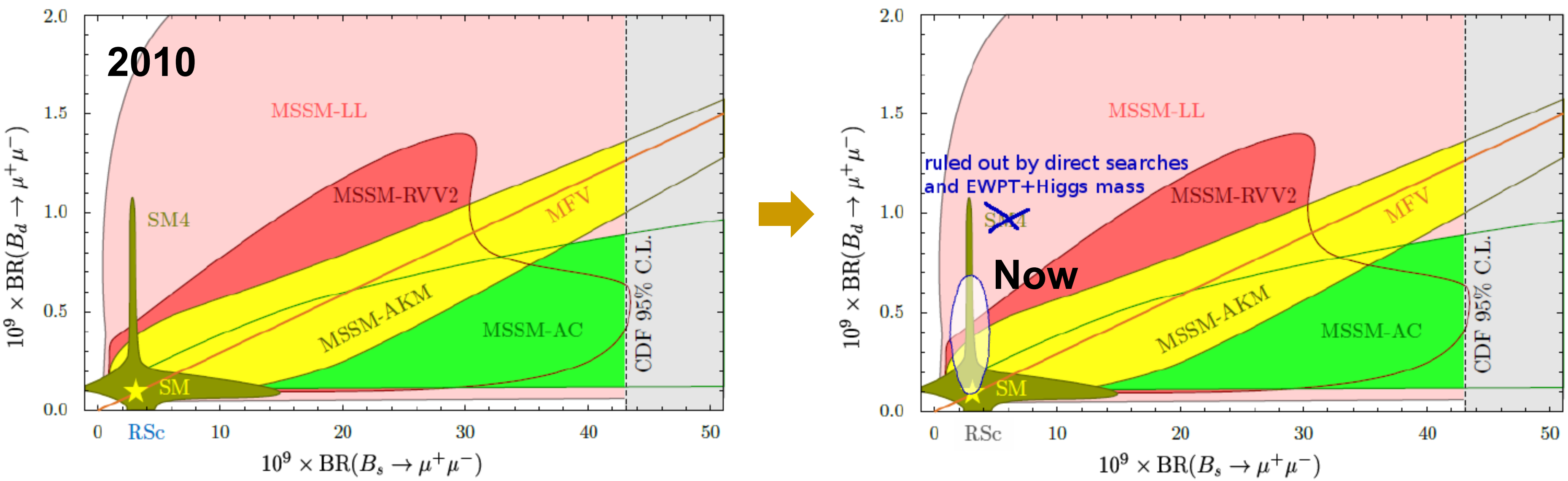


$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9},$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (3.6\,^{+1.6}_{-1.4}) \times 10^{-10},$$

$B^0_{(s)} \rightarrow \mu\mu$ – implications

We were we so excited? Because decay so very precisely predicted in SM, and so very sensitive to *certain* models of New Physics (*e.g.* high tanβ SUSY)

[Straub, arXiv:1012.3893]



This is very impressive... but perhaps a little disappointing. But much still to do!

- measure BR precisely – maybe it *is* lower than SM?
- measure $\mathrm{BR}(B^0 \rightarrow \mu\mu)/\mathrm{BR}(B_s \rightarrow \mu\mu)$
- measure lifetime and CP asymmetries

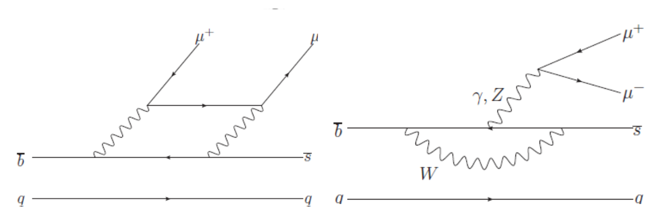
Beauty physics – current concerns

Five *selected* topics with genuine New Physics discovery potential...

- CKM metrology – the quest for precise knowledge of γ
- CPV in B_s mixing-related phenomena
- In search of the super-rare: $B^0_{(s)} \rightarrow \mu\mu$
- LHC data confronts electroweak Penguins: $B \rightarrow K^{(*)}\mu\mu$
- Loose ends (?) from the B-factories: $B \rightarrow \tau\nu$, $D^{(*)}\tau\nu$

...for which results have recently become available &/or progress is soon expected

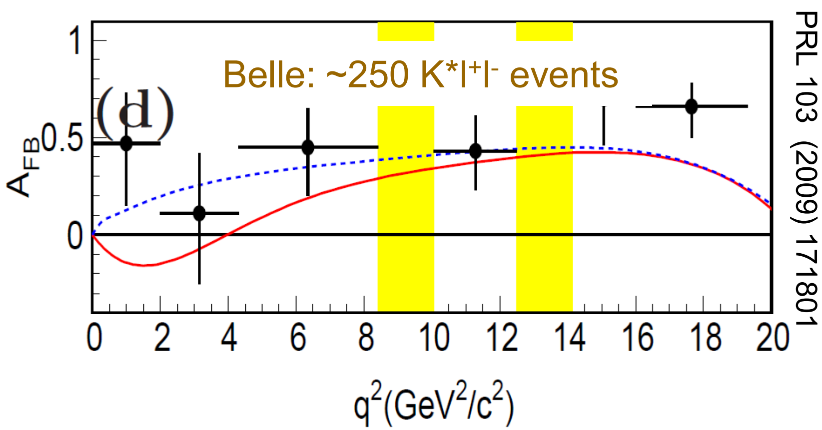
LHC confronts electroweak Penguins

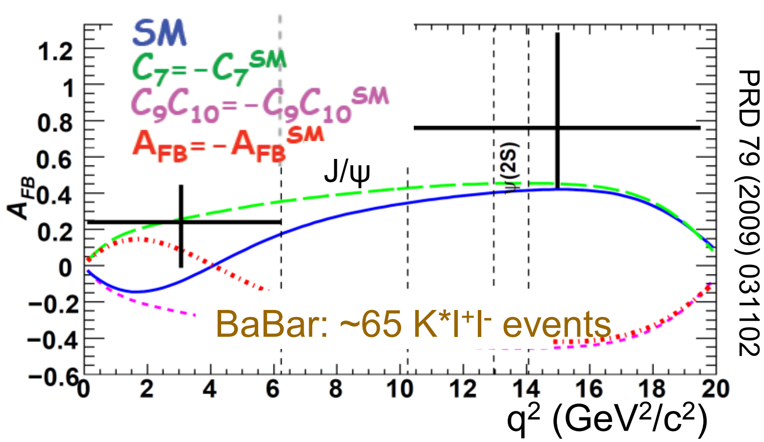


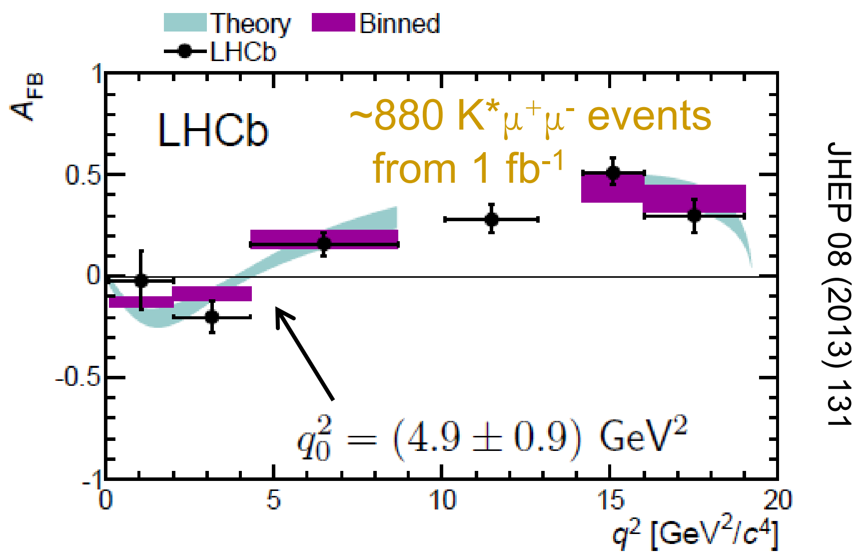
Such decays offer powerful way to probe helicity structure of New Physics.

Flagship mode is $B^0 \to K^*\mu\mu$, and poster-child measurement is A_{FB}.

Pioneering measurements from B-factories intriguing – LHCb brought clarity





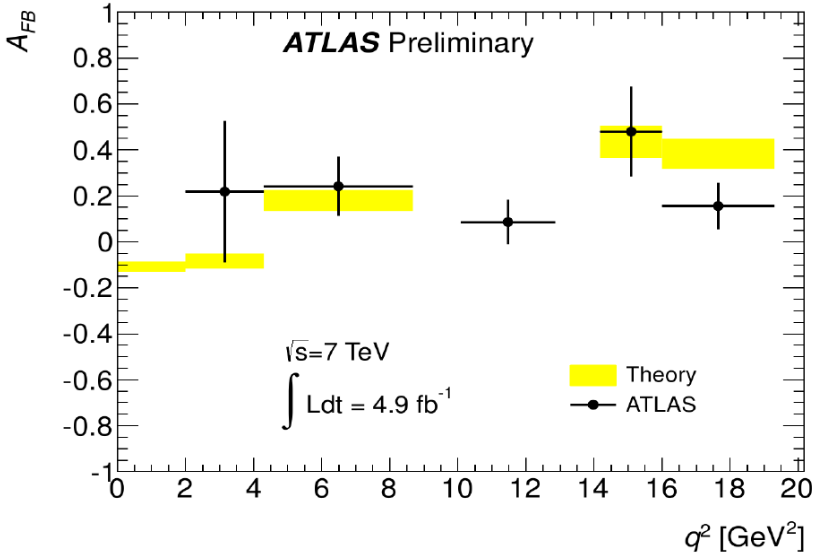


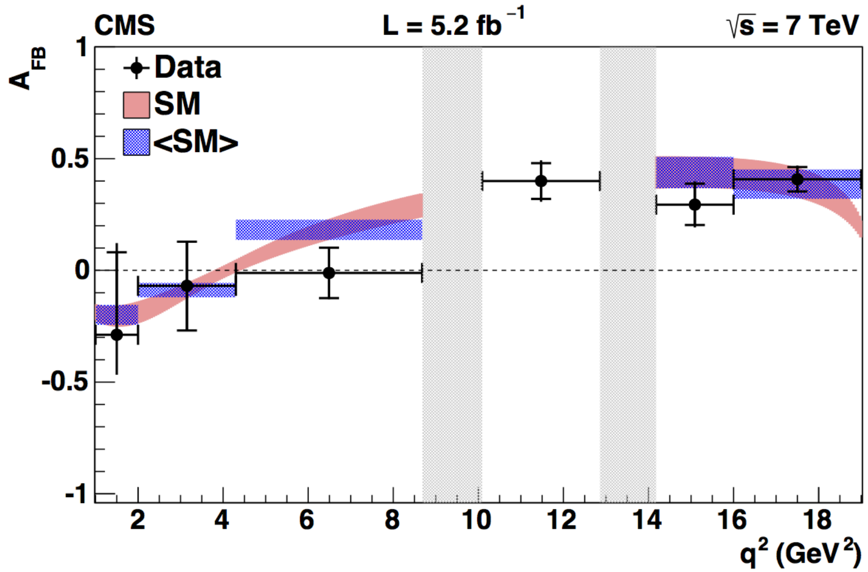
Particularly important to measure crossing point (q_0^2), as this is theoretically clean

$B^0 \to K^*\mu\mu$ at ATLAS and CMS

This is a measurement where there is also a strong contribution from the GPDs

ATLAS-CONF-2013-038





arXiv:1309.6920

Complementary to LHCb because they have particular sensitivity at high q^2

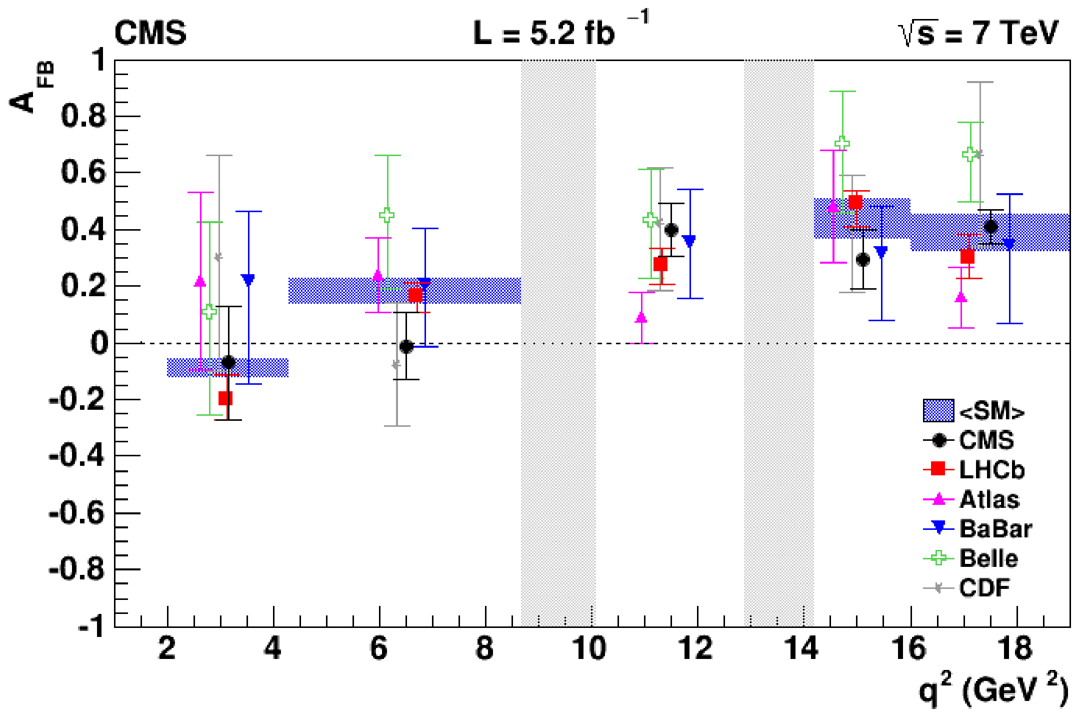
$B^0 \rightarrow K^*\mu\mu$ at ATLAS and CMS

Thi… …s

ATLAS-CONF-2013-038

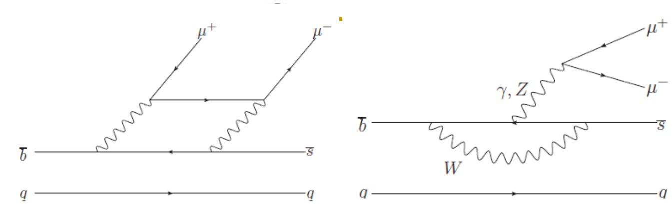
arXiv:1309.6920

Overall, there seems to be excellent agreement with SM expectation



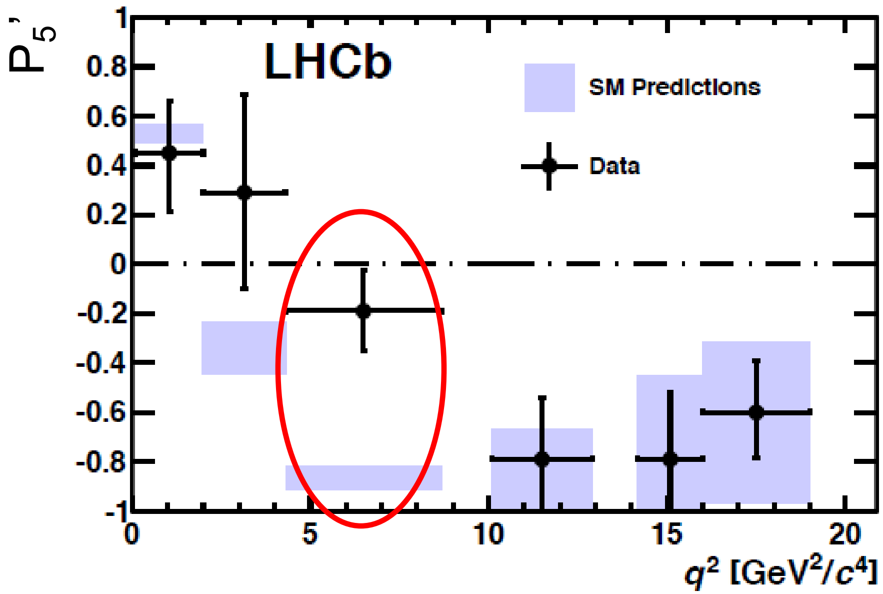
Co…

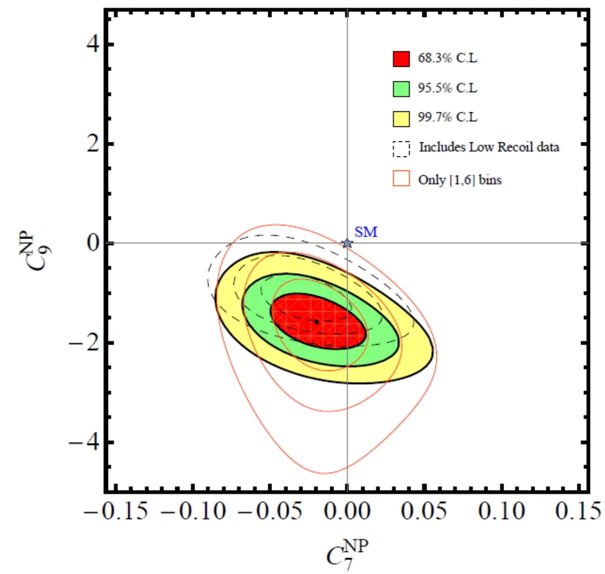
LHC confronts electroweak Penguins



But, there are many other $B^0 \to K^* \mu\mu$ observables which can be measured from angular analysis, and not all of these behave as expected

arXiv:1308.1707



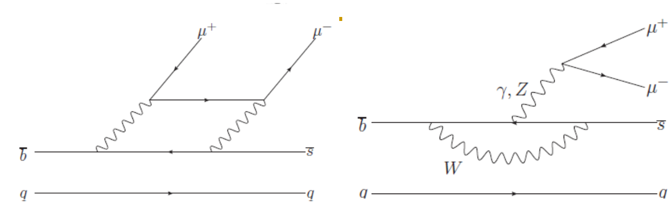


Descotes-Genon, Matias & Virto, PRD 88 (2013) 074002

Observables can be related to underlying Wilson coefficients, & some commentators have found correlated behaviour from (smaller) discrepancies in other observables.

Others believe tension is overstated...

LHC confronts electroweak Penguins



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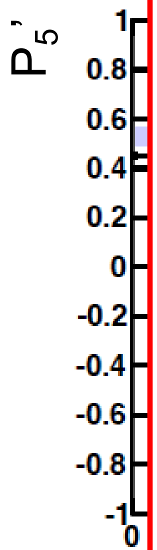


Wait a little - the truth will out soon...

...there is twice as much data on tape to be analysed.

But this isn't the only surprise in $B \rightarrow K^{(*)}\mu\mu$ measurements...

Descotes-Genon, Matias & Virto, PRD 88 (2013) 074002

Observables can be related to underlying Wilson coefficients, & some commentators have found correlated behaviour from (smaller) discrepancies in other observables.

Others believe tension is overstated...

Isospin asymmetries in B→K$^{(*)}$μμ

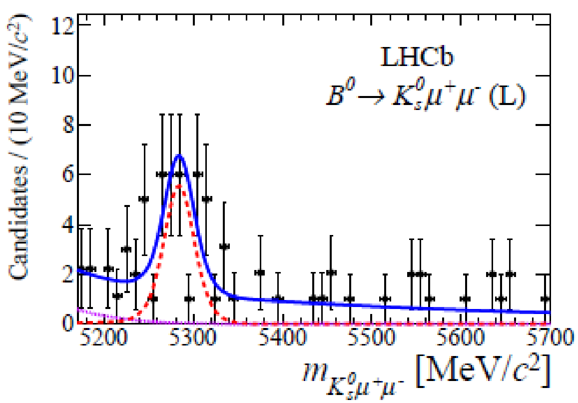
The isospin asymmetry
$$A_I = \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - \frac{\tau_0}{\tau_+}\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + \frac{\tau_0}{\tau_+}\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}$$

is expected to be very close to zero in SM (but rises for $q^2 < 1$ GeV^2 in B→K*μμ)

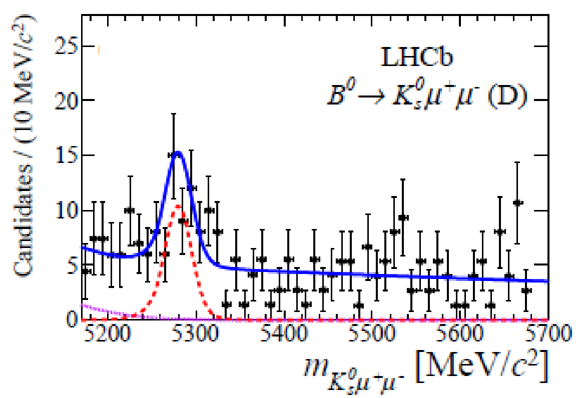
Recently measured by LHCb [JHEP 07 (2012) 133] making use of K_S final states

e.g. for B→Kμμ

$B^0 \to K_S\mu\mu$

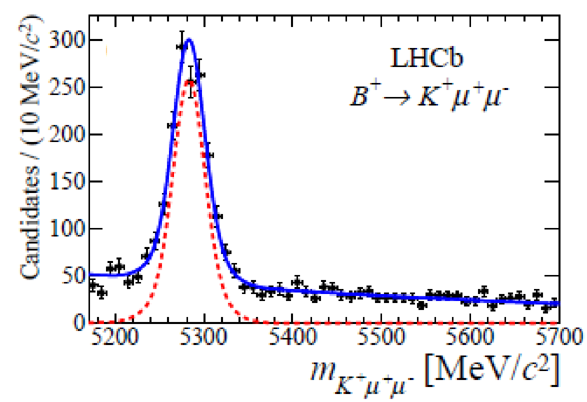


K_S decaying in VELO detector



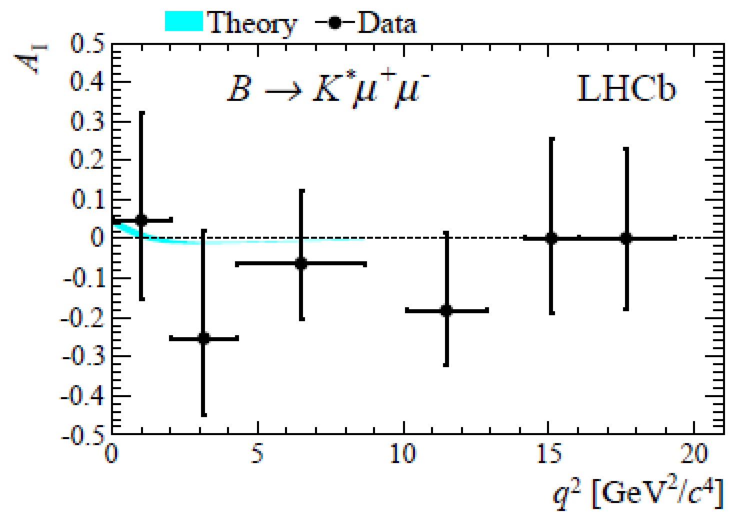
K_S decaying after VELO detector

$B^+ \to K^+\mu\mu$

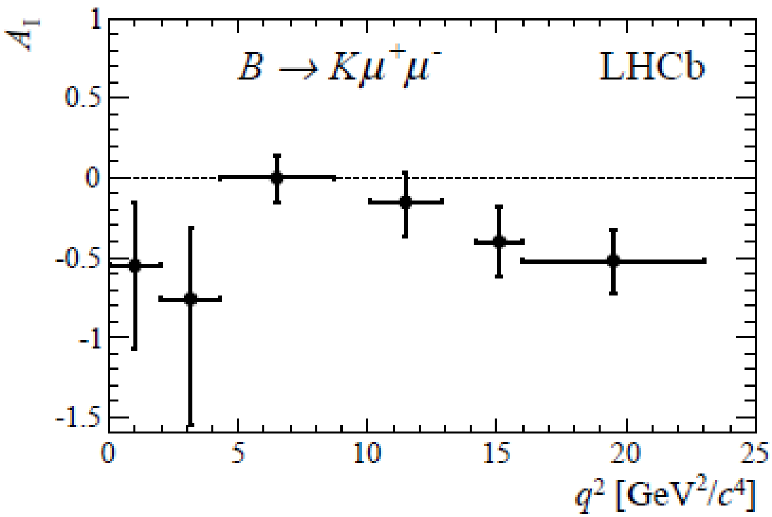


Isospin asymmetries in B→K$^{(*)}$μμ

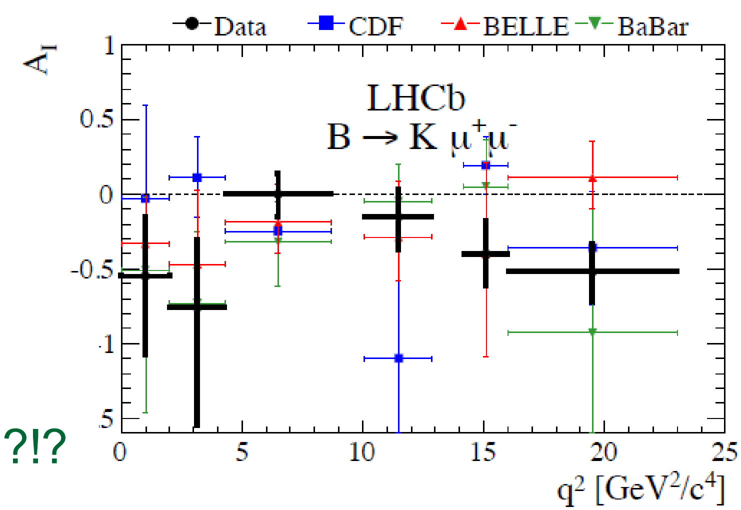
Results for B→K*μμ vs q^2 of di-muons consistent with 0, as expected



But that for B→Kμμ is systematically low !
Naive average over q^2 gives 4.4σ effect,...



...one hinted at by previous experiments



Looks real but doesnt smell like New Physics (*e.g.* why is effect seen only in B→Kμμ?) but certainly unexpected. What is going on here ?!?

Beauty physics – current concerns

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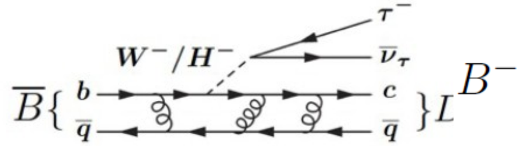
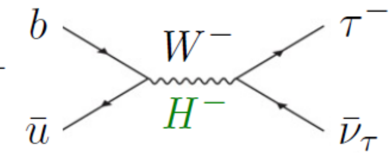
...for which results have recently become available &/or progress is soon expected

B→τν, B→D(*)τν

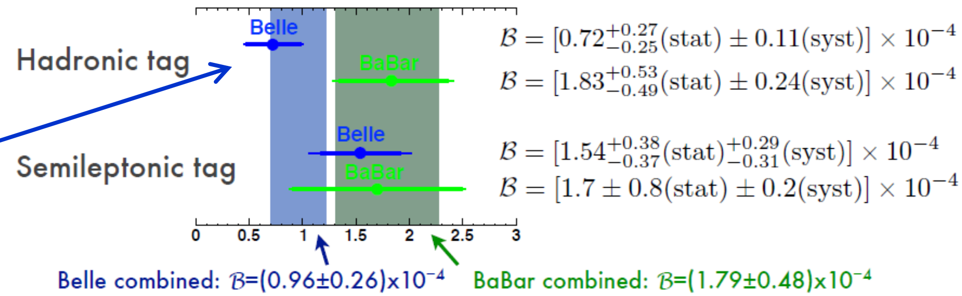




Intriguing offsets in BRs / relative BRs in these modes may be telling us about charged Higgs sector.

B→τν

All results were high w.r.t. SM.
Recent Belle update softens tension,
but degrades internal consistency



B→D(*)τν

$$\mathcal{R}(D) = \frac{\mathcal{B}(\overline{B} \to D\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D\ell^-\overline{\nu}_\ell)}, \quad \mathcal{R}(D^*) = \frac{\mathcal{B}(\overline{B} \to D^*\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^*\ell^-\overline{\nu}_\ell)}$$

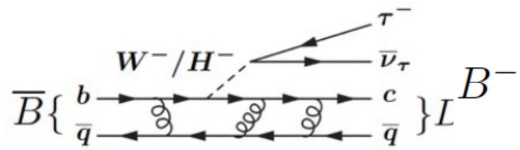
	R(D)	R(D*)
BaBar	+2.0σ	+2.7σ
Belle	+1.4σ	+3.0σ

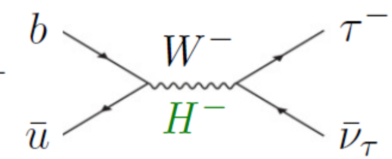
Definite pattern emerging – but, beware, this measurement is hard!

Watch this space – Belle will soon update

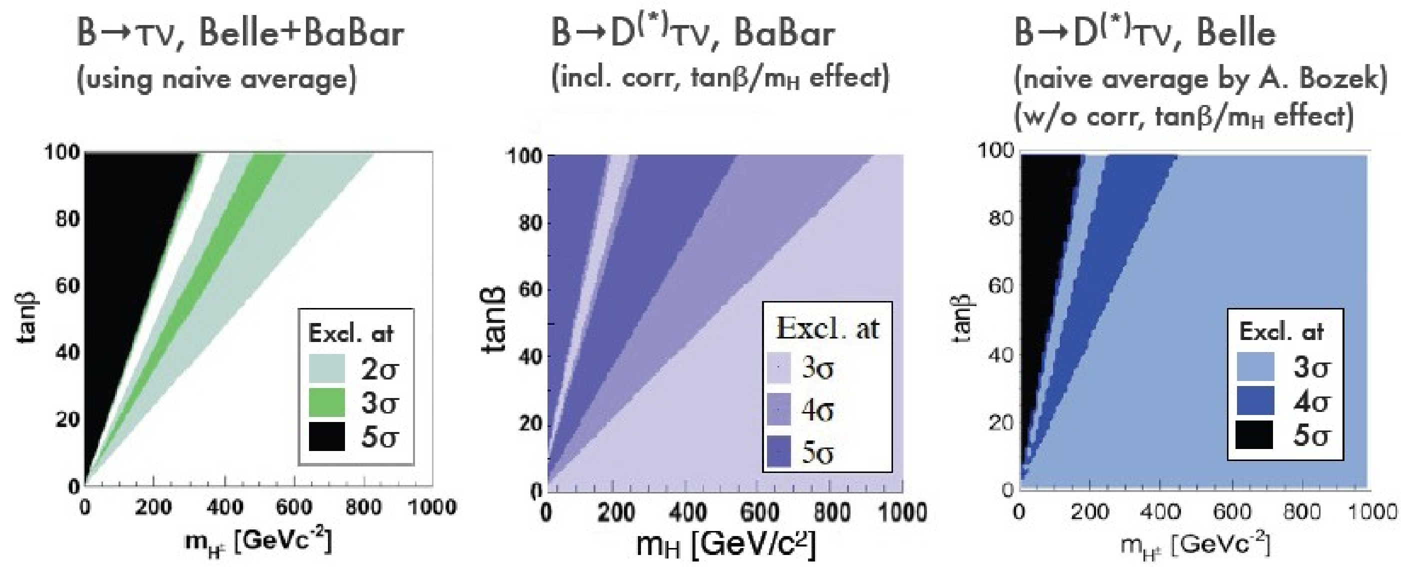
Question: are all these hints pointing in the same direction ?

$B \to \tau\nu$, $B \to D^{(*)}\tau\nu$





Answer: it seems not – rather different regions in parameter space favoured



Needed urgently, better measurements of :

- $B \to \tau\nu$ from Belle-II
- $B \to D^{(*)}\tau\nu$ from Belle, Belle-II and (?) LHCb

Question: are all these hints pointing in the same direction ?

Message from flavour searches after LHC run 1

There are some fascinating anomalies to ponder & follow-up from published run 1 flavour analyses (would it were so from the high p_T studies!), but nonetheless there seems to be no 'low hanging fruit' - so we'll have to climb higher.

That's OK, as the view will be better !

Dreaming about ultra-high statistics

Big improvements foreseen before 2018-19 long shutdown (e.g. ~8 fb^{-1} at LHCb, ~ doubling in x-sec from E_{CM} w.r.t. 2012, improved analysis methods) but we can dream of what could be achieved with a very large increase in sample sizes *e.g.*

- CKM metrology

  Determine γ with sub-degree precision to match anticipated improvements in indirect precision coming from lattice QCD. Improve β down to ~0.02^o.

- CPV in B_s mixing

  Measurement of φ_s with precision much better than SM central value, to probe for sub-leading contributions from NP.

- $B^0_{(s)} \rightarrow \mu\mu$

  True precision measurement of BR down to theory uncertainty and first measurement of ultra-suppressed $B^0 \rightarrow \mu\mu$ BR.

- $B^0 \rightarrow K^*\mu\mu$

  Precision studies of all observables of interest through full angular analysis

- Charm

  Extensive study of direct CPV across wide range of modes.
  Sensitivity to indirect CPV down to SM expectation.

Plus great improvements in precision, & *new* measurements, in many other topics!

Realising the dream – the LHCb upgrade

LHCb collaboration plans an upgrade, to be installed in 2018-19 shutdown

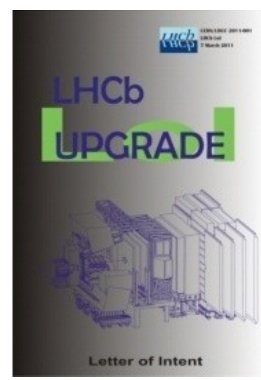
Essential features:

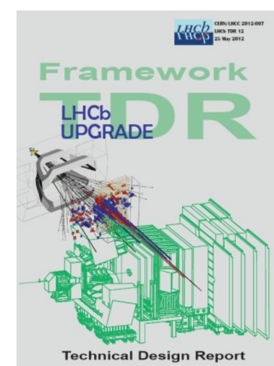
- Full software trigger: will readout into DAQ all subdetectors at 40 MHz (c.f. 1 MHz at present). This will improve efficiency compared with current hardware trigger, giving factor of two improvement for hadronic final states
- Increase operational luminosity to 1-2 x10^{33} cm^{-2}s^{-1}

Annual yields in muonic final states will increase 10x w.r.t. most published analyses, and 20x for hadronic decays. Aim to collect ~50 fb^{-1} in total.

LoI (March 2011) and ‘Framework TDR’ (May 2012) approved by LHCC.

First detector TDRs (VELO and particle identification) to be submitted *this* month !



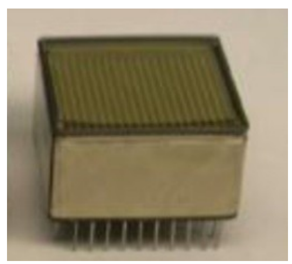


UK leadership in detector upgrades

UK physicists are leading players in upgrade activities in RICH and VELO.
Bid for full participation in building these detectors is now under review.

RICH

Photodetectors must be changed from HPD, as readout chips encapsulated inside tubes. Commercial MaPMTs a strong candidate.

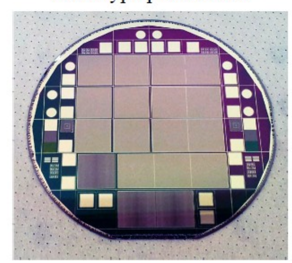


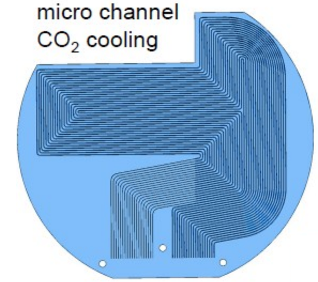
Optics of RICH 1 will be modified to spread out rings & combat the occupancy increase that would otherwise come from higher lumi.

VELO

Will switch from strips to a pixel detector, cooled with micro-channel technology

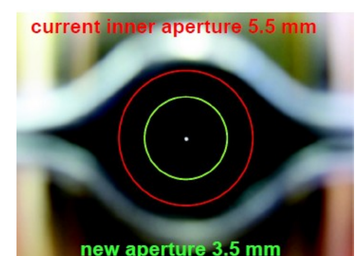
Prototype pixel sensor





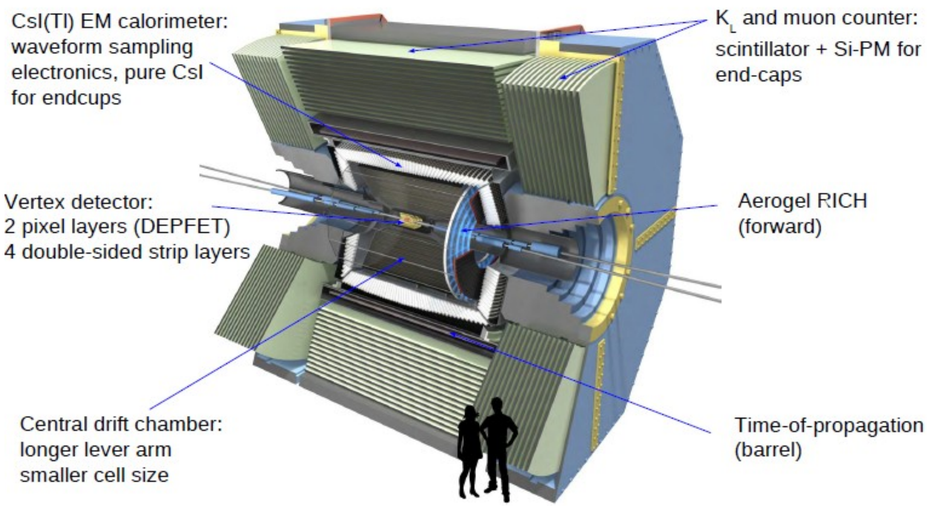
Pixel readout: Timepix3 → Velopix

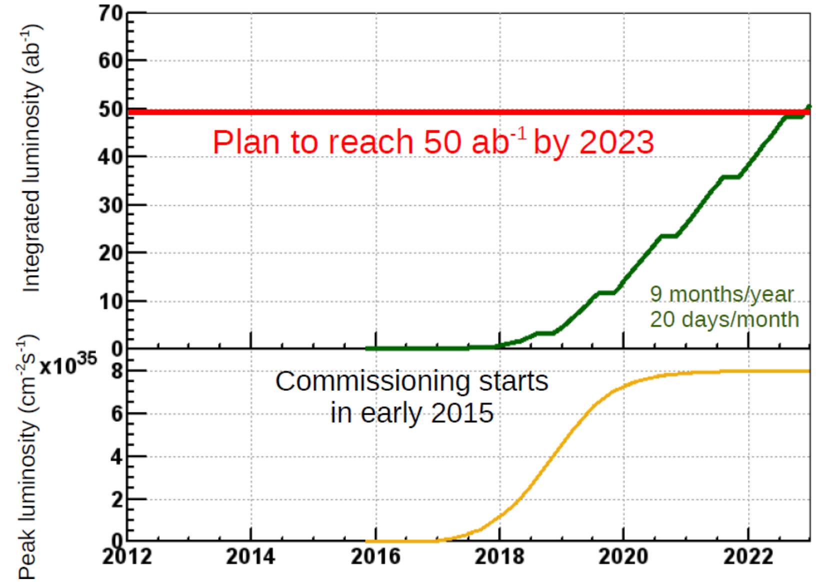
In addition thin RF foil and go even closer to the beam to help in proper-time resolution.



The e^+e^- frontier: Belle-II

Looking forward, the LHC is not the only show in town. The e^+e^- programme will resume with SuperKEKb (accelerator) & Belle-II (detector) aiming for x50 Belle yield.





Capabilities highly complementary to LHCb, with particular strengths in:

- final states with soft neutrals and neutrinos
- inclusive studies
- tau physics

Conclusions

Thanks to the LHC, we have crossed a new frontier in flavour physics. LHCb has exceeded expectations, & ATLAS/CMS have also contributed in some key areas.

Alas, no sign of large New Physics effects. We have to work harder!
Thus in certain key topics (*e.g.* $B_s \to \mu\mu$) the game is now switching from exploration to precision measurement

Nonetheless, not everything is following the SM script, e.g.:

- dilepton charge asymmetry
- P5' anomaly and isospin asymmetry in $B \to K^{(*)}\mu\mu$
- BRs of $B \to \tau\nu$, $D^{(*)}\tau\nu$

What do these mean? More measurements required!

Plenty of scope for the picture to change over the next ~5 years

LHCb upgrade will bring an added order of magnitude in precision, and make many new studies possible. Belle-II will bring complementary strengths.

Backups