Beauty 2013 – (partial) summary and outlook

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Bologna, 12/4/13

Dramatic events of the week

This week has seen plenty of important events in the outside world

Sombre news

Margaret Thatcher
1925-2013

Bad news

Man Utd 1-2 Man City

Good news

No World War III (yet)

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Sombre news

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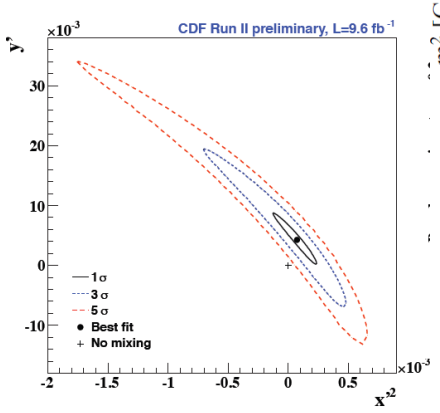
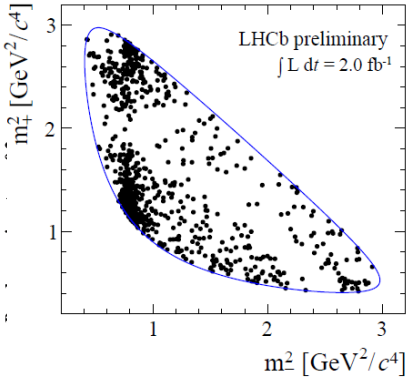
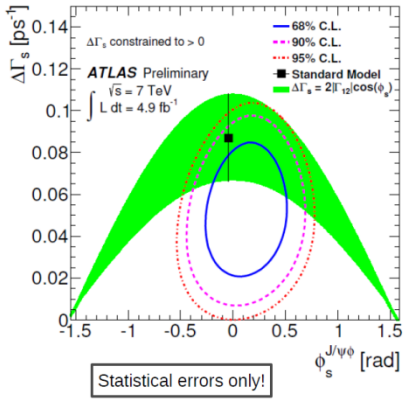
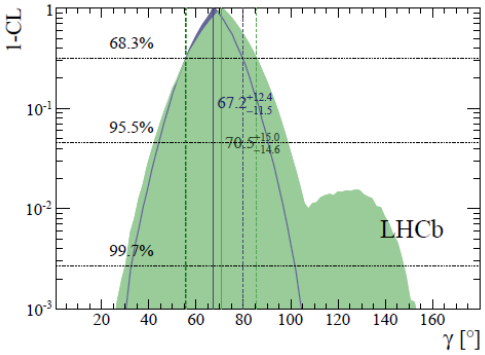
Dramatic events of the week

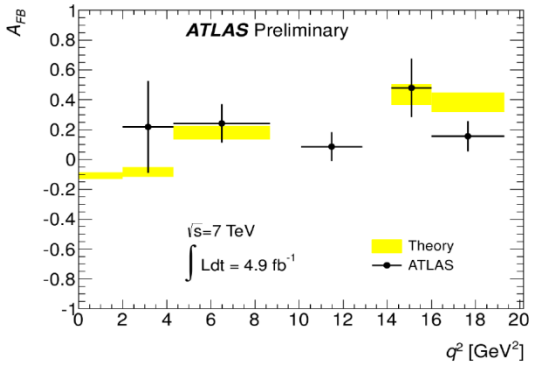
And also plenty of dramatic new results presented here in San Giovanni in Monte

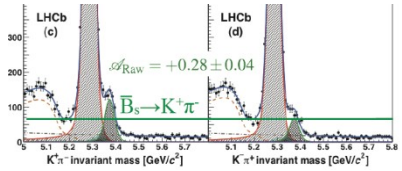


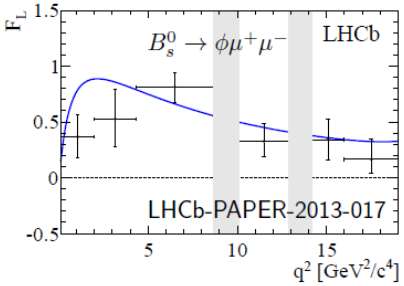


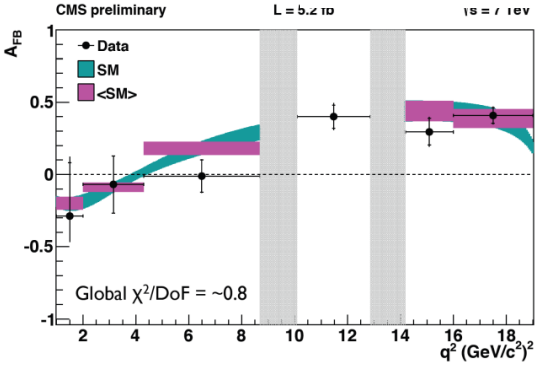








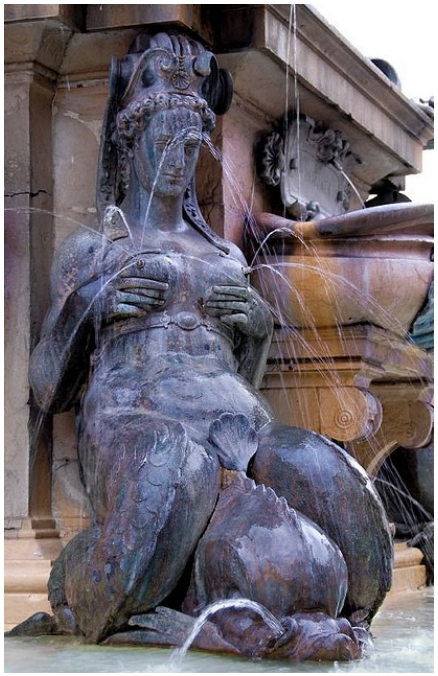




Outline

Let us pick out some selected topics from conference, and highlight new developments, open questions and prospects of progress

- Production and exotic spectroscopy
- B_s physics
- Precision CKM metrology
- Suppressed FCNC decays
- Charm mixing and CPV
- Loose ends
- Outlook

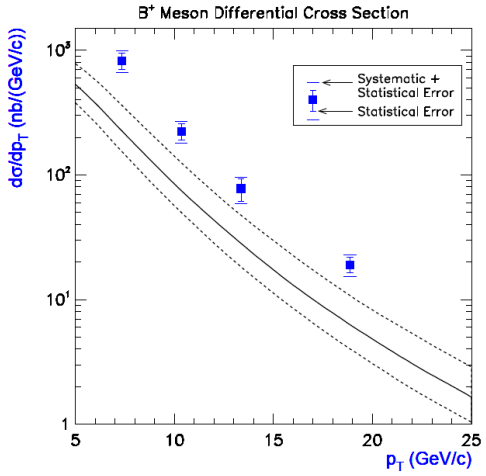


Production and
exotic spectroscopy

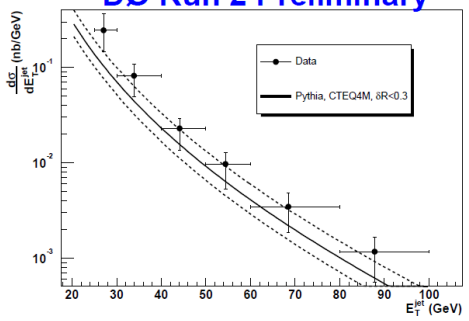
Progress on production

Description of open heavy flavour production a success [Forte] – great progress over the past ~10 years. Well developed and reliable tools (FONLL & NLO+PS) available.

DATA (CDF R,I) VS TH 2001

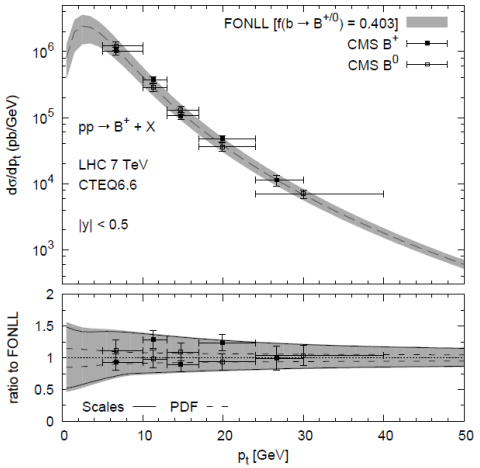


DATA (CDF R.II) VS TH 2003



(CDF, talk at Beauty 2003)

DATA (CMS) VS TH 2012



(Cacciari et al. 2012)

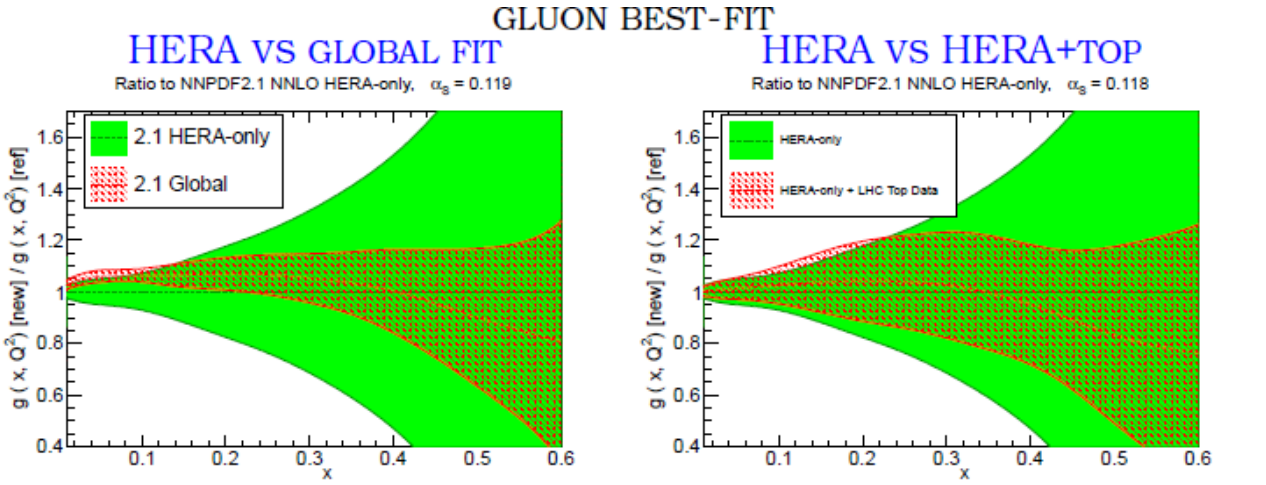
Emboldened by this, calculations and data can be used to inform other questions.

Parochial question of flavour physicist: can better predictions be made of production asymmetries at LHC. Measurements of increasing precision now arriving and issue very relevant for study of CP-asymmetries.

Heavy flavour production and impact on the 'bigger picture'

[Forte]

- Top production can be used to constrain gluon PDFs (and indeed α_s)



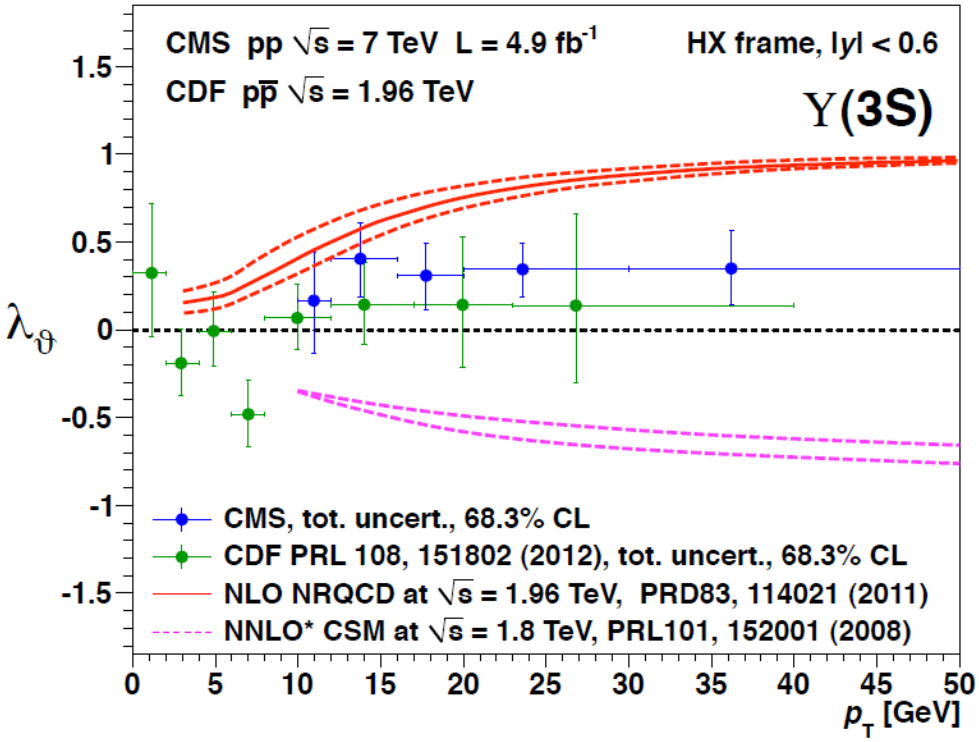
(Czakon, Mangano, Mitov, Rojo, 2013)

- Similarly, W + c data can tell us about on the strangeness content of proton
- Maybe ultimately top production can be used to measure m_t ? But current precision ~3%, to be compared with ~0.5% of direct measurement

Puzzles in polarisation

[Kratschmer]

Theory is less successful in describing onia production. In particular, recent results on upsilon polarisation from CDF and CMS stubbornly refuse to match predictions.

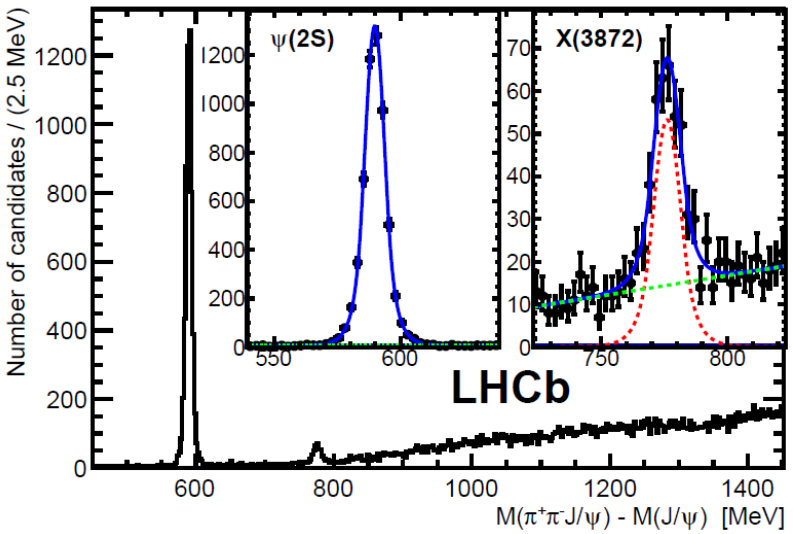


More results expected soon from other experiments + for J/ψ and ψ'.

Exotic spectroscopy

Just as one question is resolved

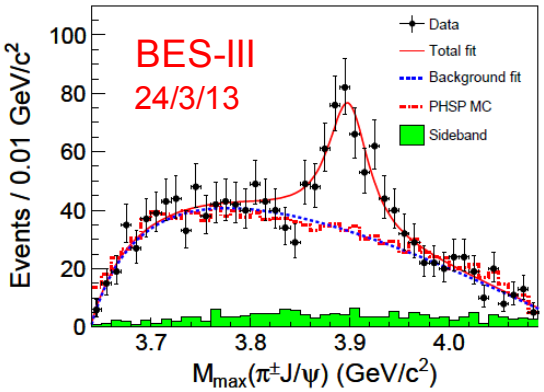
From analysis of LHCb
B→X(3872)K sample
it is determined that
X(3872) $J^{PC}=1^{++}$,not 2^{-+}



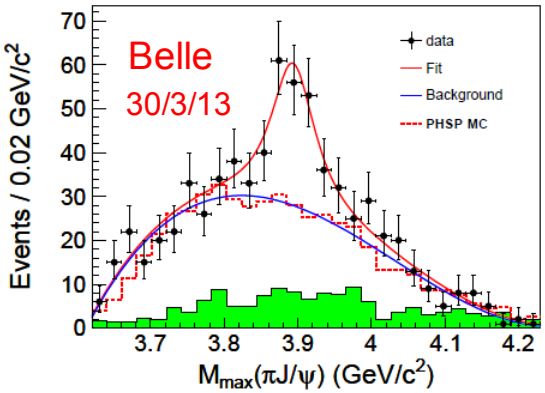
arXiv:1302.6269

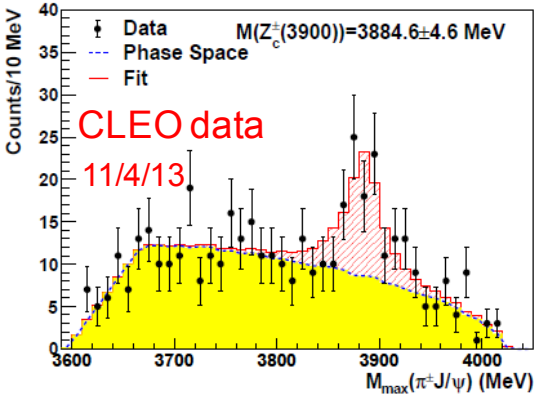
another one appears – what is the Z(3900)?

arXiv:1303.5949



arXiv:1304.0121





arXiv:1304.3036

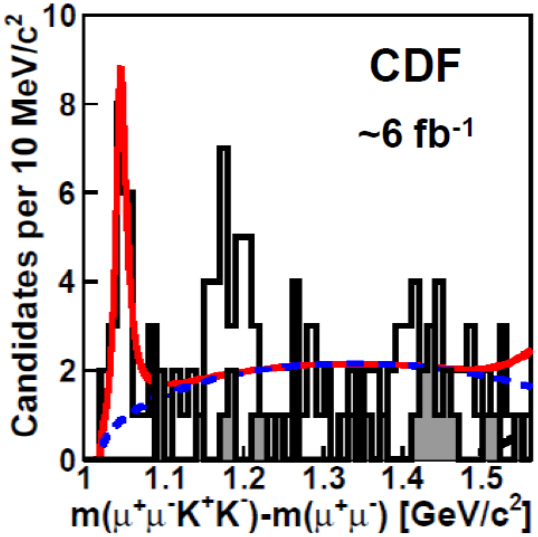
and still others remain…

[Hambrock, Fiorendi, Cuthbert, Needham, Fioravanti, Oswald]

Is there or is there not a X(4140) (+ other things) ?

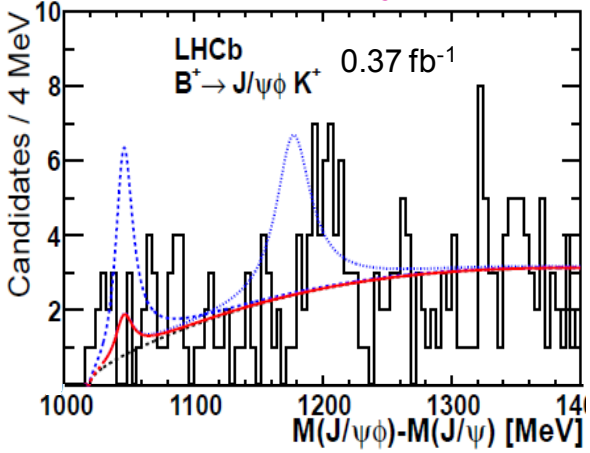
[Fiorendi, Needham]

Yes !



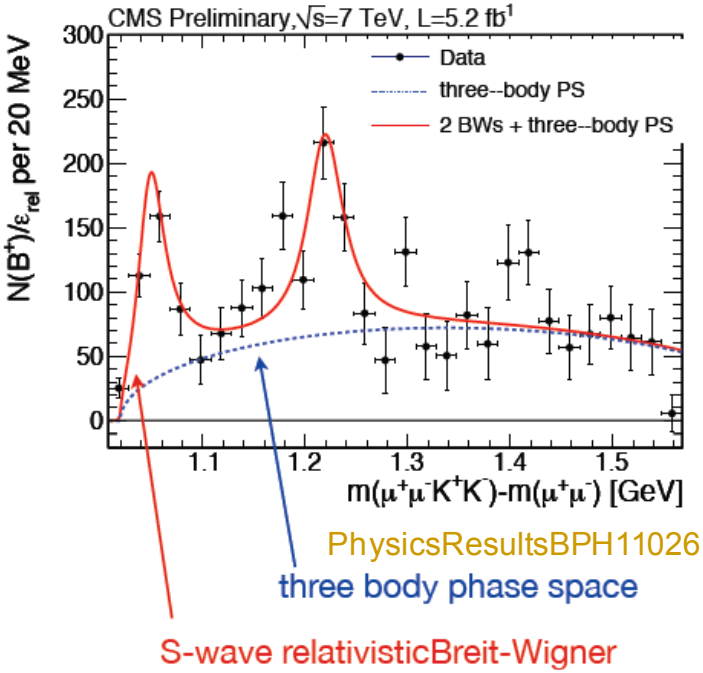
arXiv:1101.6058

Not really



PRD 85 (2012) 091103(R)

Yes !



PhysicsResultsBPH11026

three body phase space

S-wave relativisticBreit-Wigner

Wait for LHCb update and full amplitude analysis of spectrum

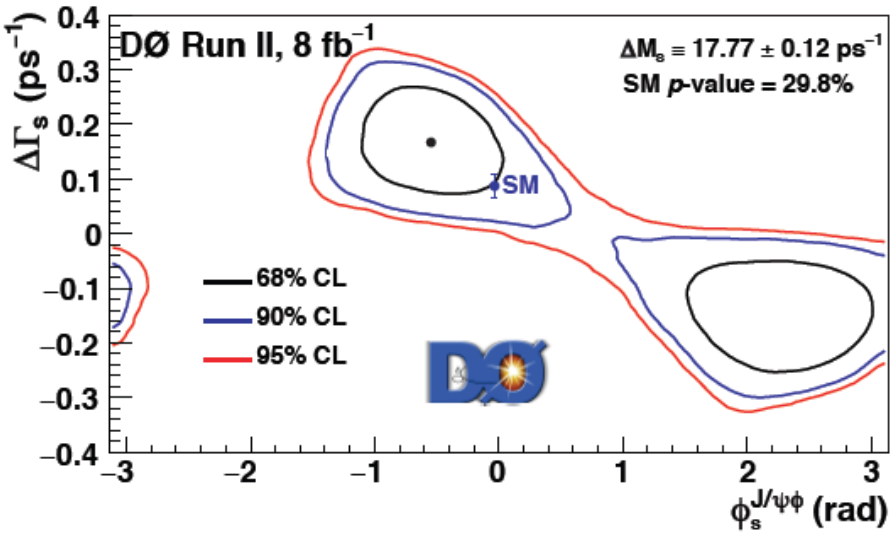
B_s physics

Mixing induced CPV in B_s system

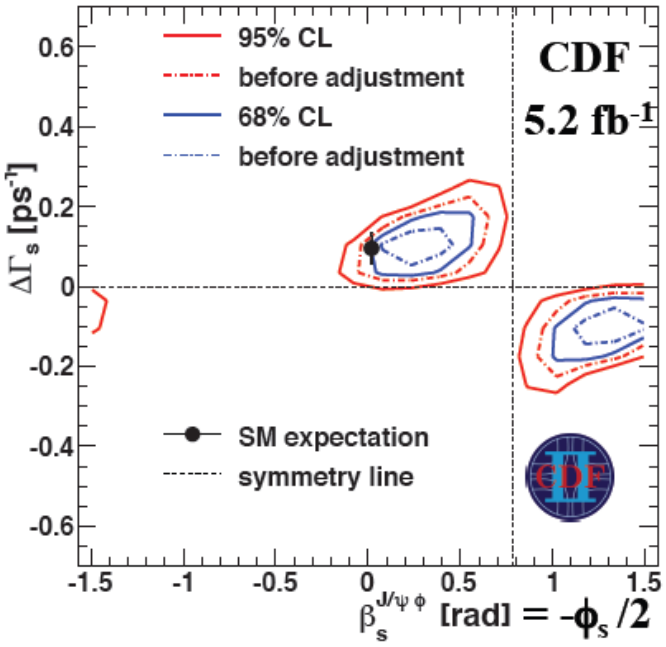
CPV phase, φ_s, in B_s mixing-decay interference, e.g. measured in $B_s \to J/\Psi\Phi$, very small & precisely predicted in SM. Box diagram offers tempting entry point for NP!

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.

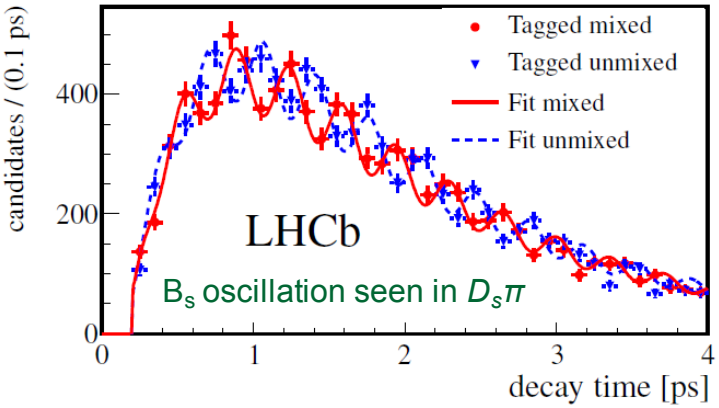
LHCb attributes/contributions:

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

- 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 $J/\Psi KK$ which resolves 2-fold ambiguity [PRL 108 (2012) 241801]

Final LHCb 2011 results made public this week [arXiv:1304.2600] and presented today [Dupertuis].



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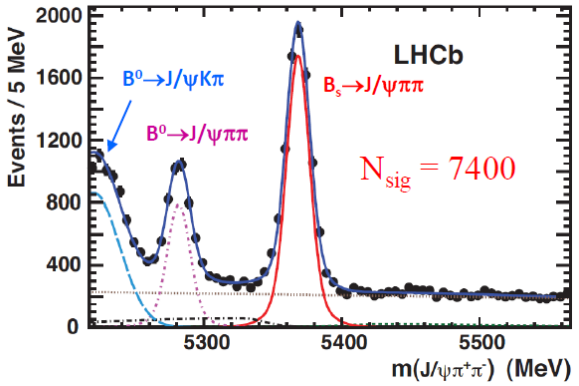
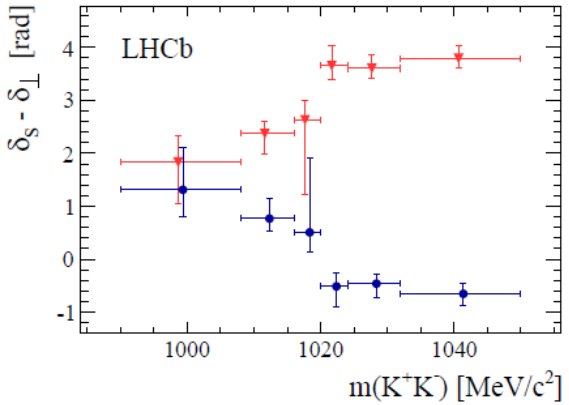
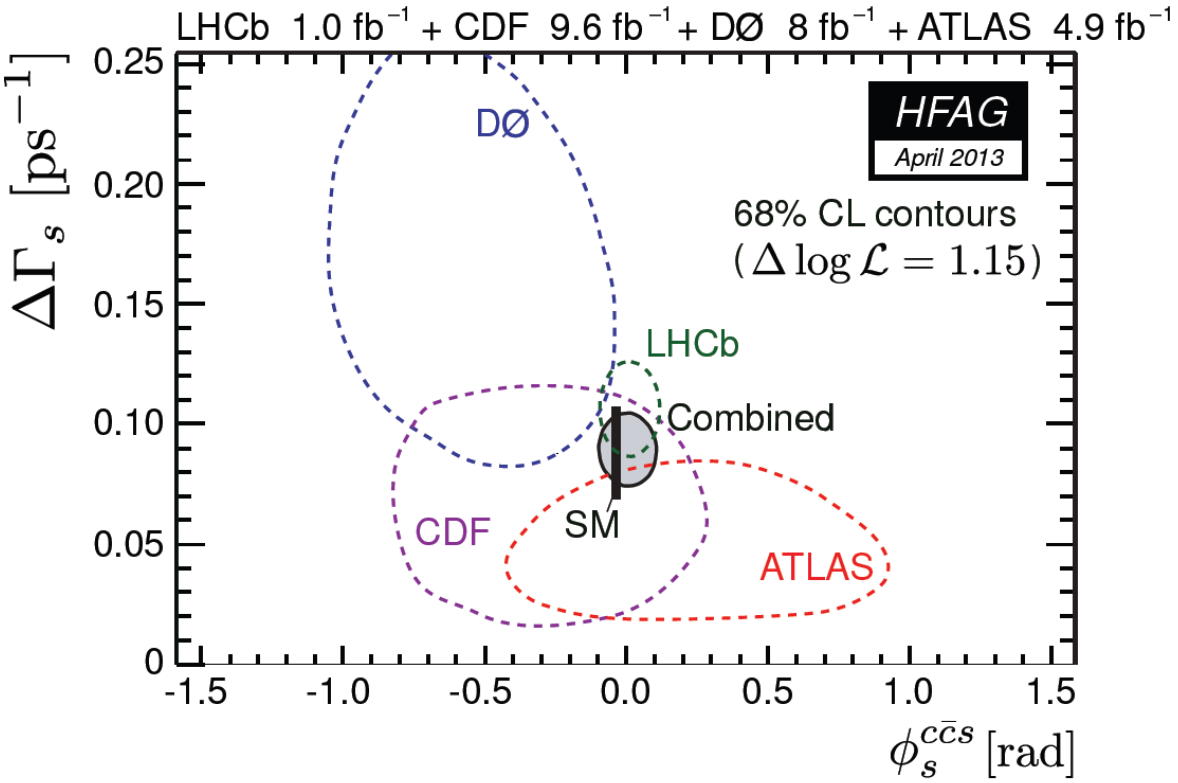




Precision studies of Φ_s

The LHC (firstly LHCb & now ATLAS/CMS) ha
LH

State of play (correct until 10:15 this morning):



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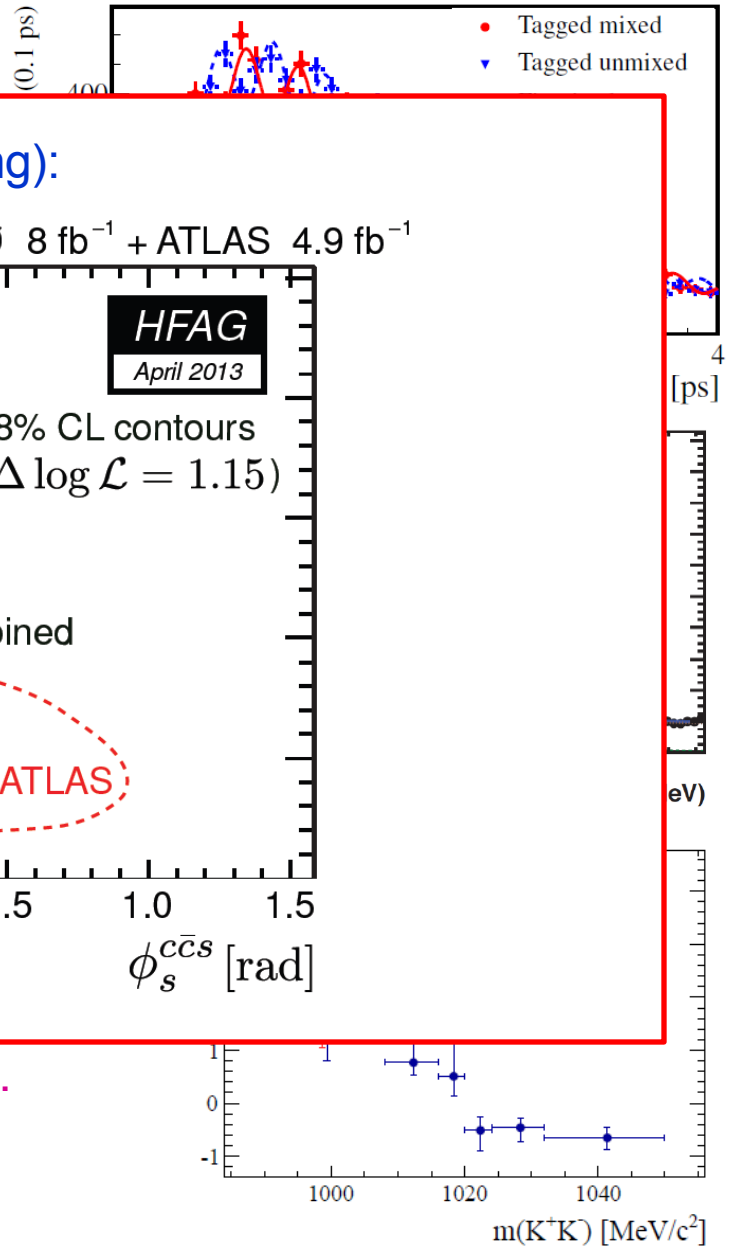
[arXiv:1304.2600] and presented today [Dupertuis].



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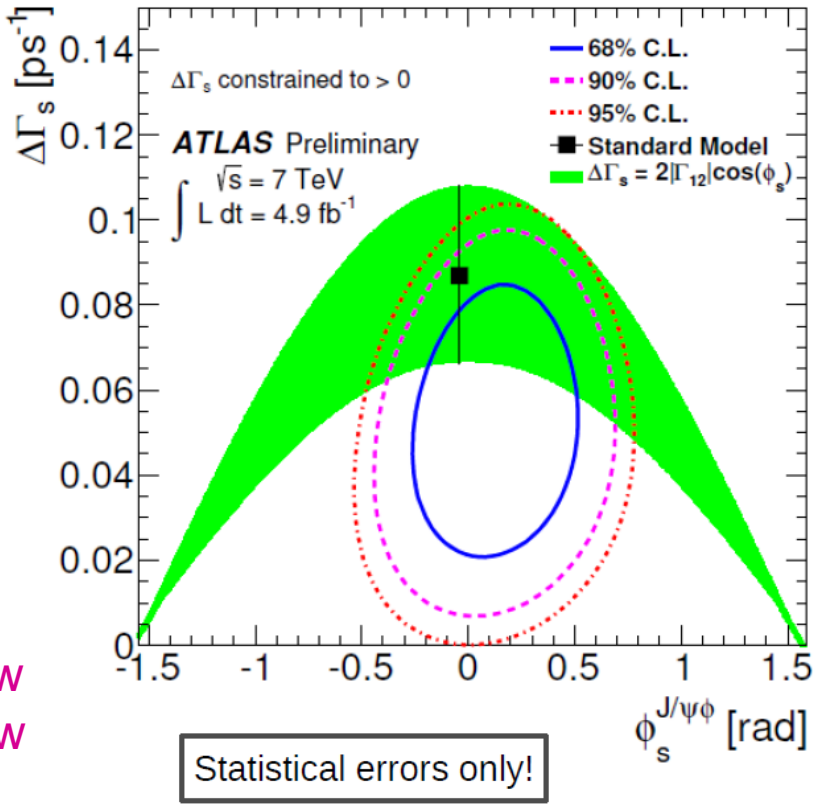
New kid on the block

[Heller]

A highlight of the conference has been to see first flavour tagged study from ATLAS

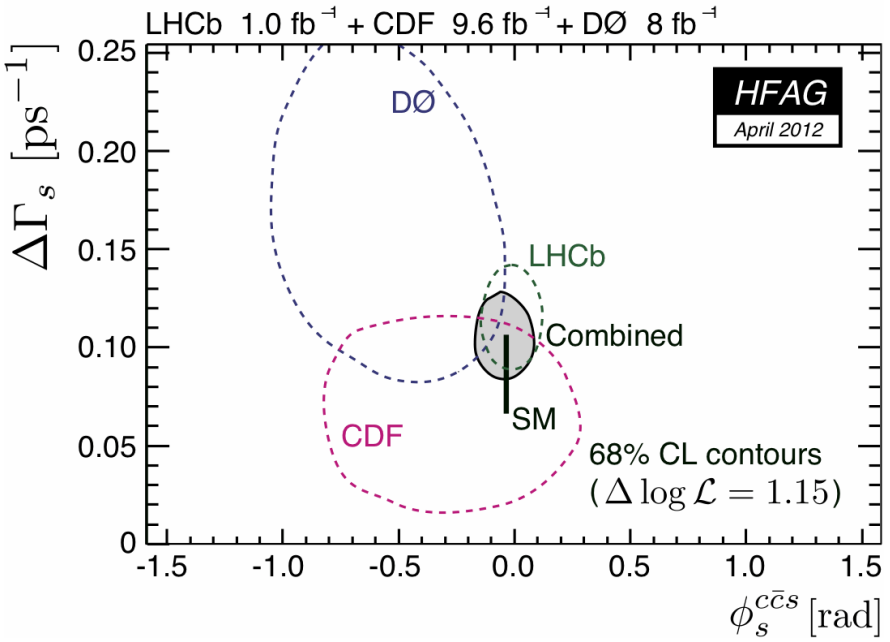
Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s(rad)	0.12	0.25	0.11
$\Delta\Gamma_s(\mathrm{ps}^{-1})$	0.053	0.021	0.009
$\Gamma_s(\mathrm{ps}^{-1})$	0.677	0.007	0.003
$\lvert A_\parallel(0)\rvert^2$	0.220	0.008	0.009
$\lvert A_0(0)\rvert^2$	0.529	0.006	0.011
$\lvert A_S\rvert^2$	0.024	0.014	0.028
$\delta_\perp$	3.89	0.46	0.13
$\delta_\parallel$	[3.04-3.23]		0.09
$\delta_\perp - \delta_S$	[3.02-3.25]		0.04

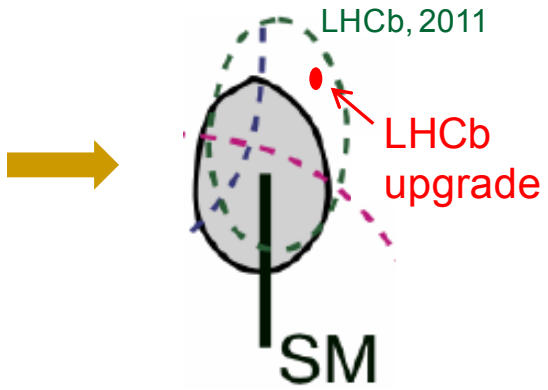


Great to see! Look forward to seeing how this develops and whether CMS will follow

Φ_s: conclusions & prospects

No big NP effect in B_s mixing-decay interference, but essential to improve precision as φ_s remains a priori *highly sensitive* to non-SM contributions.



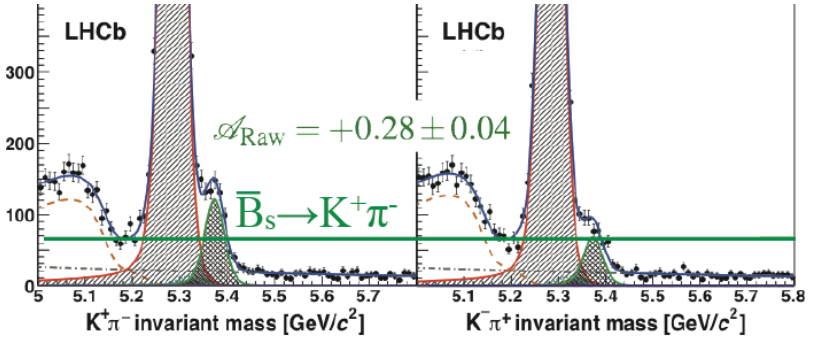


Good to see that LHCb (and also ATLAS/CMS) are well equipped for task

Results with charmless B_s decays

Satisfying news – first observation of CPV in the B_s system [Martens], seen in time-integrated $B_s \to K\pi$ decays…

$$\mathcal{A}_{CP}(B_s^0 \to K\pi) = 0.27 \pm 0.04\,(\text{stat.}) \pm 0.01\,(\text{syst.})$$



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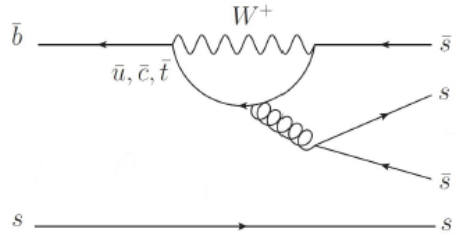
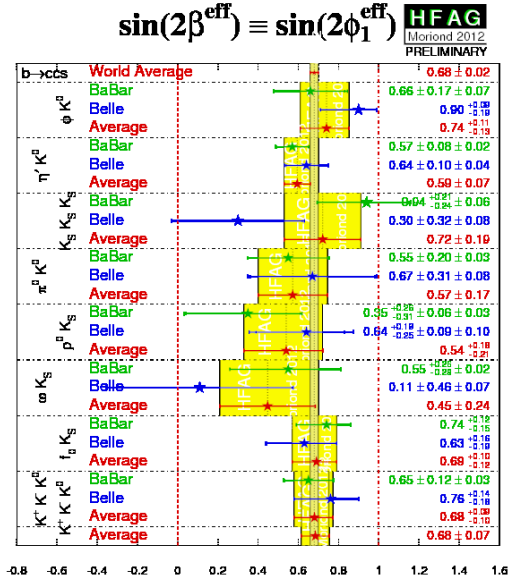
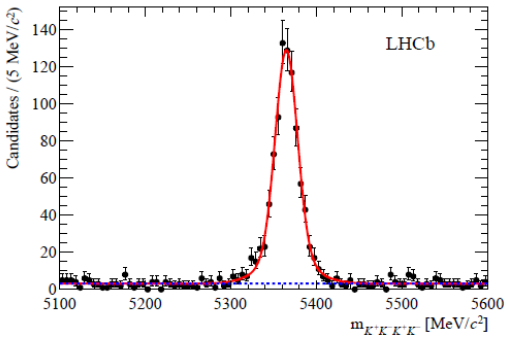
…and very promising for the future is first time-dependent study of gluonic Penguin $B_s \to \Phi\Phi$. Here a cancellation is expected between (small) phase in loop and box

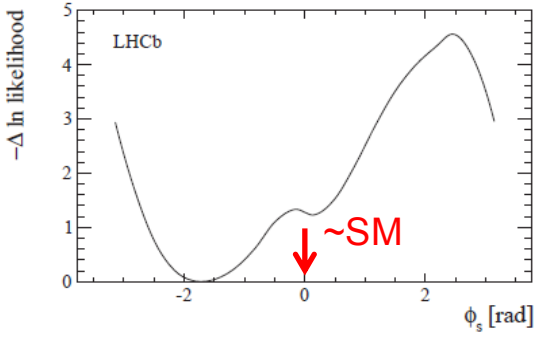


First result has p-value of 16% w.r.t. SM. Early days, but watch this space. Should help clarify 'sin2β^{eff}' picture



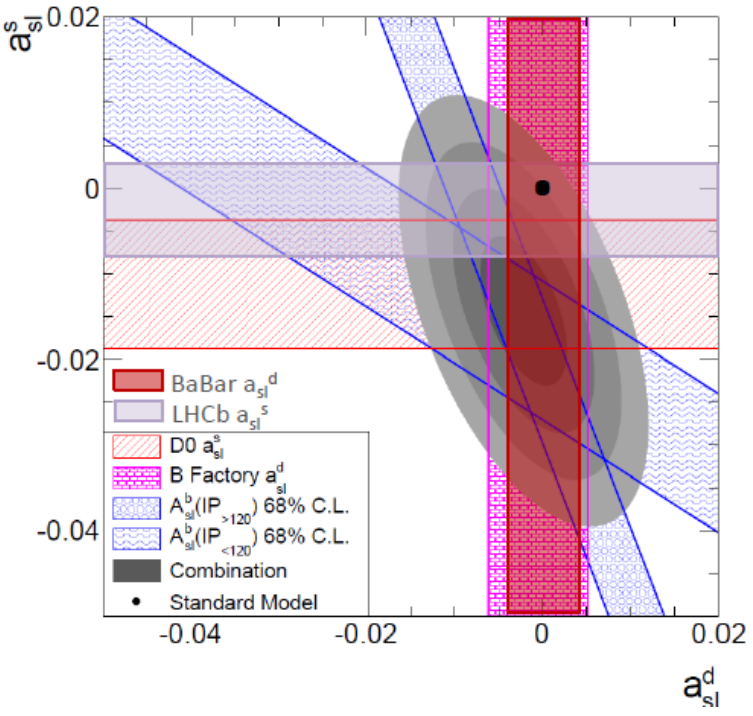
[Alvarez Castelle, arXiv:1303.7127]





Elephant in the room – the dimuon charge asymmetry

We heard reports from D0 [Bertram], LHCb [Vesterinen] and BaBar [Cartaro] on recent measurements of a^s_{sl} (LHCb, D0) and a^d_{sl} (D0, BaBar)



All these measurements are:

- not incompatible with the D0 dimuon result,
- entirely consistent with the SM,

hence, the picture is no clearer.

What's coming next?

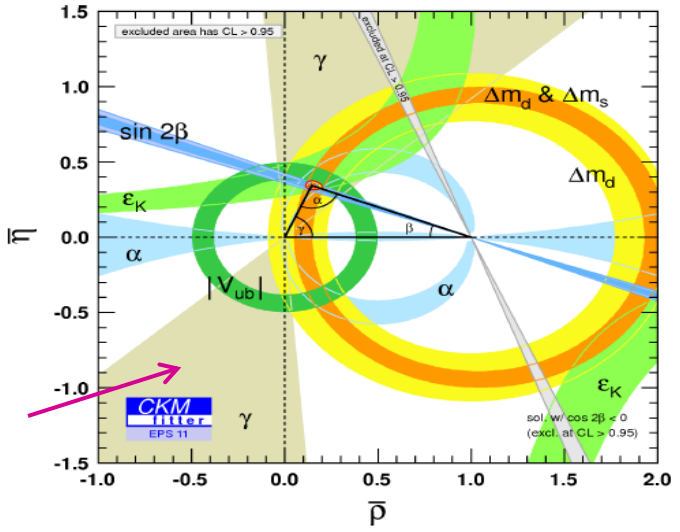
- final word on dimuons from D0, which will squeeze more IP info from measurement
- improved a^s_{sl} & a^d_{sl} results from LHCb

Guess for next Beauty: measurement will no longer be considered a 'problem', but this consensus will be achieved through audience exhaustion rather than experimental clarity.

Precision

CKM metrology

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

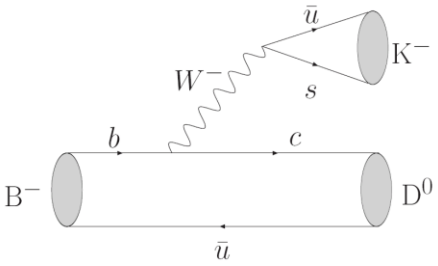
Look in $B^{\pm} \to DK^{\pm}$ decays using common mode for D^0 & $\bar{D}^0$

→ γ sensitive interference

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

Many possibilities: $K\pi$, KK, $K\pi\pi\pi$…

Favoured



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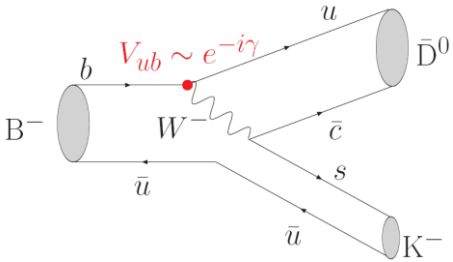


Tree-level decays: strategy very clean & yields result unpolluted by New Physics

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 $B \to hh$)

BaBar/Belle uncertainty ~ 16° ; indirect (*e.g.* loops) precision ~4° (& improving…)

[Cartaro]

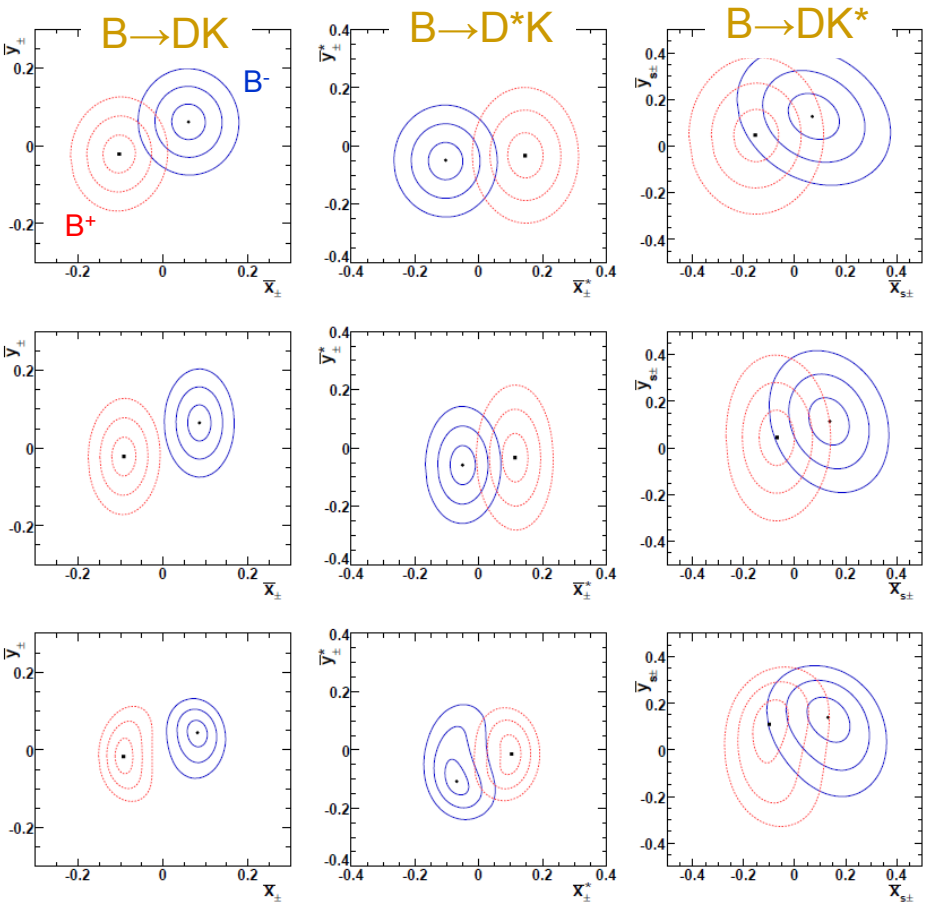
γ determination with B→D(*)K(*) requires combination of results from many modes

e.g. 'Cartesian coordinate' contours from BaBar combination [PRD 87 (2013) 052015]

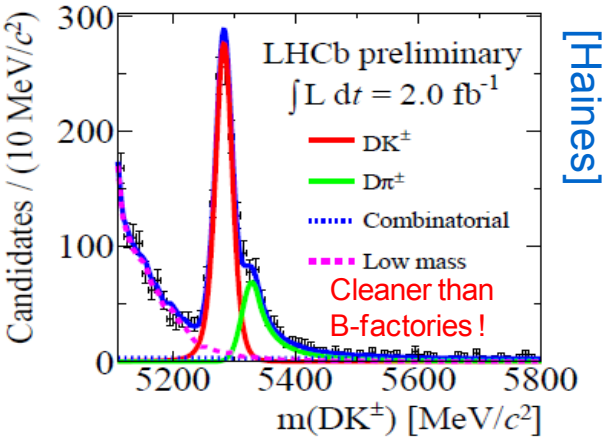
GGSZ ('Dalitz') alone

GGSZ+ GLW (CP-eigenstates)

GGSZ+GLW+ ADS (DCS-modes)

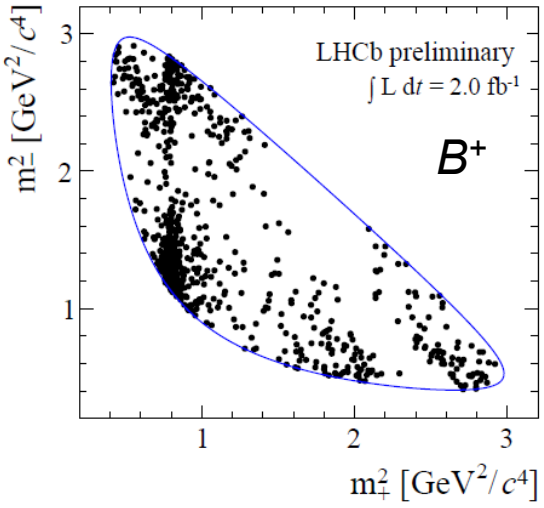


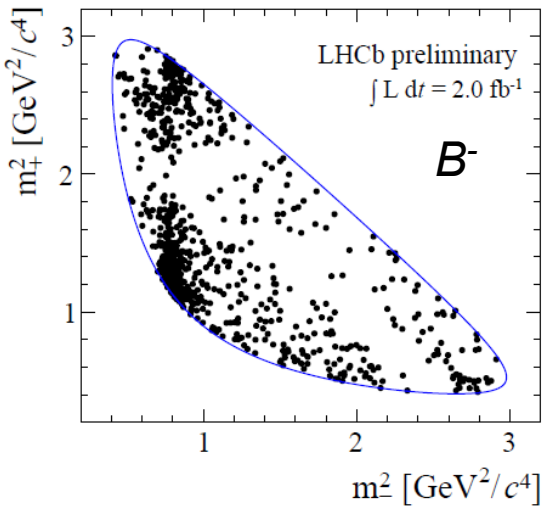
$B \to [K_S hh]_D K$ at LHCb: 2012 update

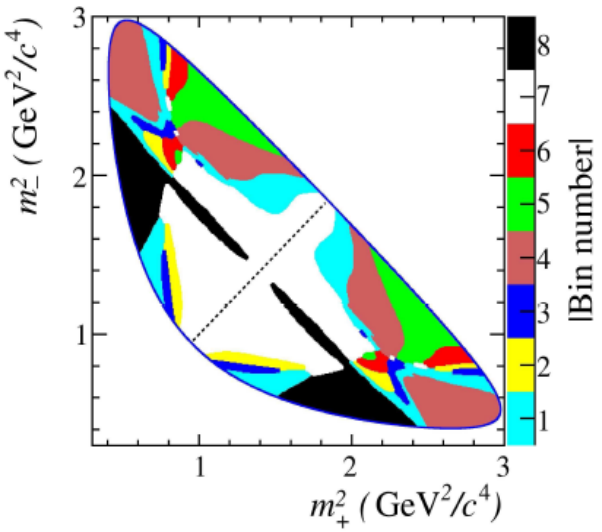


[Haines]

B→DK method has been applied by LHCb to *D→K*$_S$*ππ* and *K*$_S$*KK* using 2012 data. CPV leads to difference in *D* Dalitz plots for B^+ and B^- decays







[LHCb,CONF-2013-004]

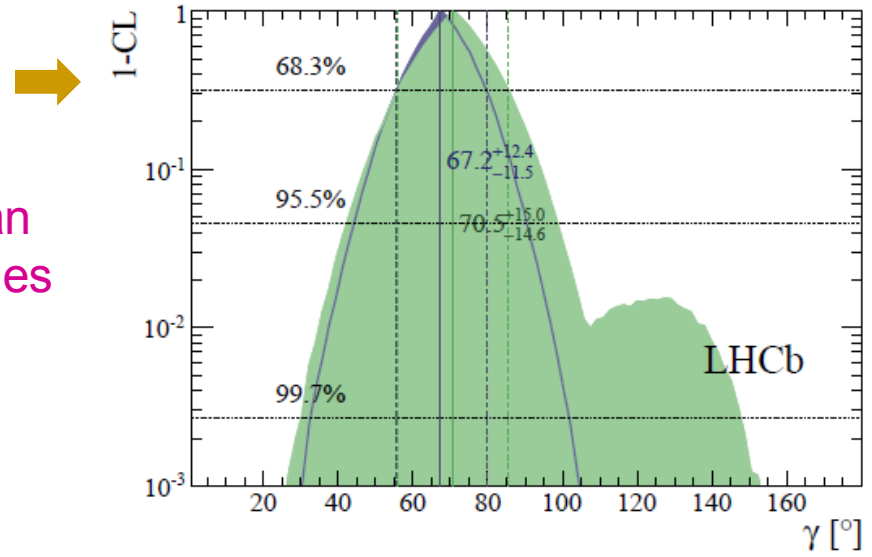
Data analysed in bins which have similar *D* decay strong-phase. To retain model independence these phases are taken from measurements of quantum-correlated *DD*bar pairs at CLEO-c [PRD 82 (2010) 112006] - will be improved by BES-III.

Cleanliness of measurement preserved exploiting synergy of facilities !

[Schiller]

LHCb: current precision on γ and future prospects

Combination of LHCb $B \to DK$ results obtained so far



LHCb-CONF-2013-006

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

Will improve steadily:

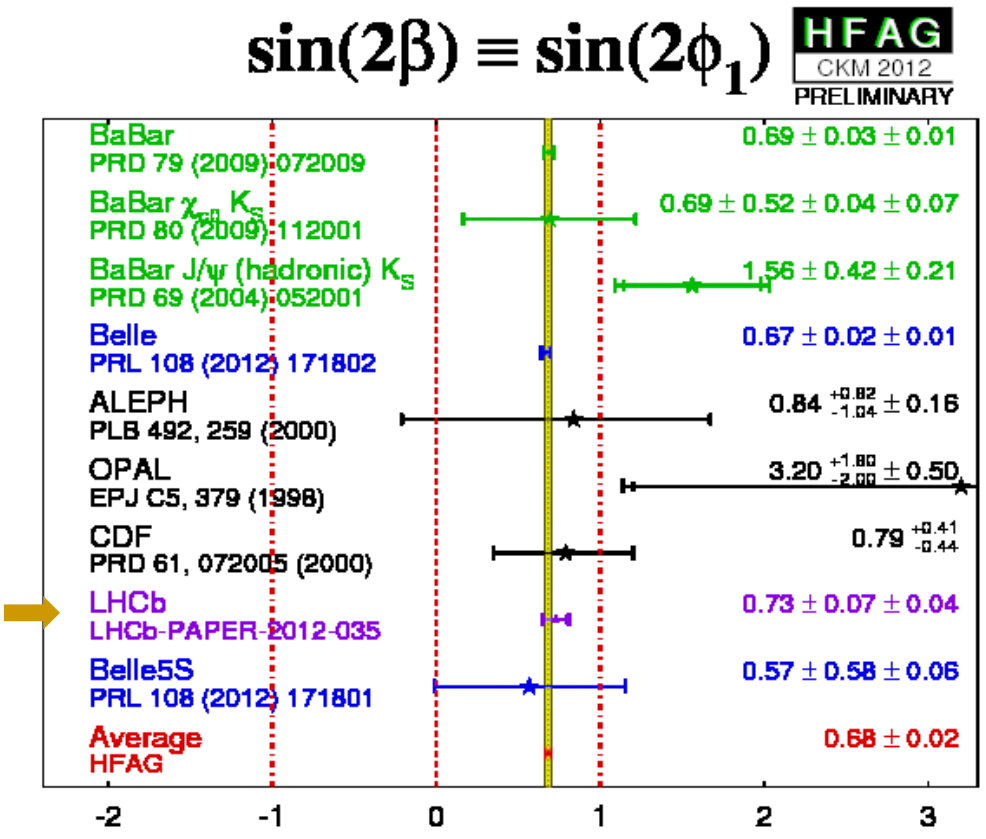
- more modes to be analysed (there are many...)
- Add ADS/GLW 2012 updates and post-LS1 data

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

Upgrade, with improved trigger and higher lumi, will allow this to be reduced to ~1°
Belle-II will aim for similar → true precision CKM-metrology !

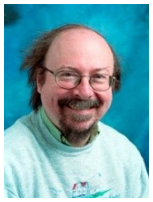
sin2β – the work is not yet done

Just because sin2β was measured so well at B-factories, it doesnt mean we should stop. It is very likely in this observable that New Physics is hiding.



LHCb has already entered the game and with 2011 data alone has error ~3x worse in $J/\psi K_S$ than B-factories.

Prospects are excellent, particularly at upgrade



'uncertainty of 0.01 is achievable'

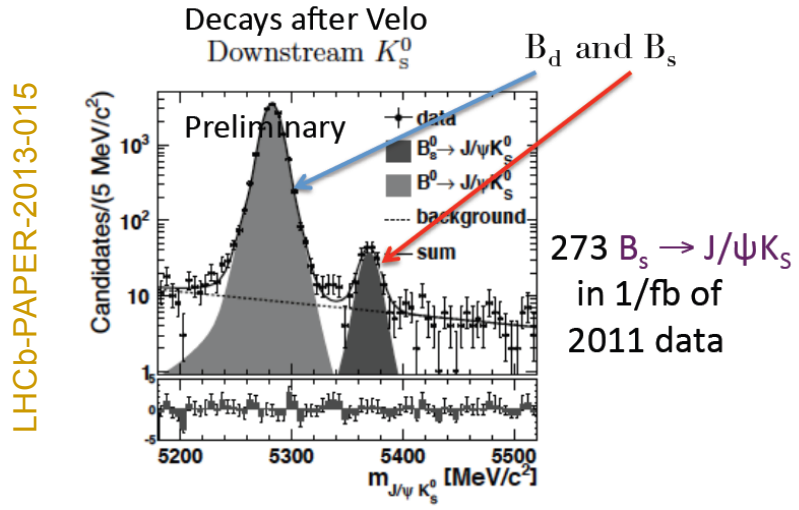
[Playfer]

and Belle-II will certainly raise bar.

It becomes increasingly important to worry about Penguin pollution.

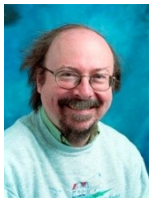
sin2β – the work is not yet done

Look at U-spin mirror mode $B_s \to J/\psi K_S$ [Playfer]



273 $B_s \to J/\psi K_S$ in 1/fb of 2011 data

$BF(B_s \to J/\psi K_S)/BF(B_d \to J/\psi K_S) = 0.044 \pm 0.003(stat) \pm 0.002(syst) \pm 0.003(f_s/f_d)$



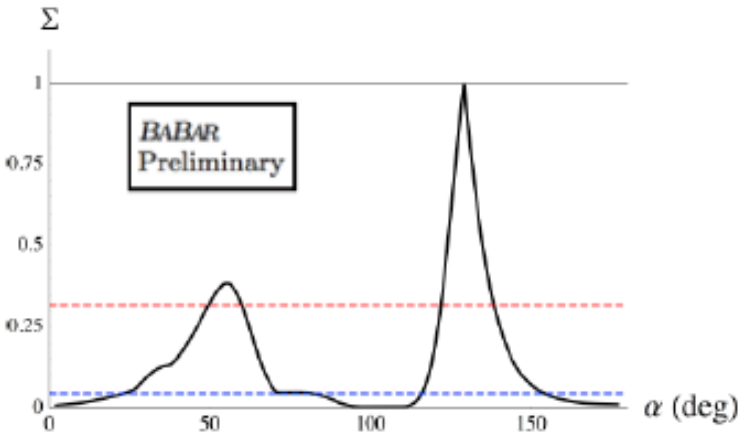
[Playfer]

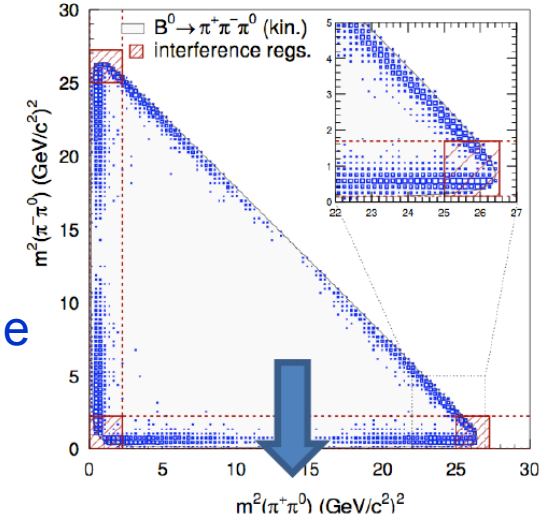
It becomes increasingly important to worry about Penguin pollution.

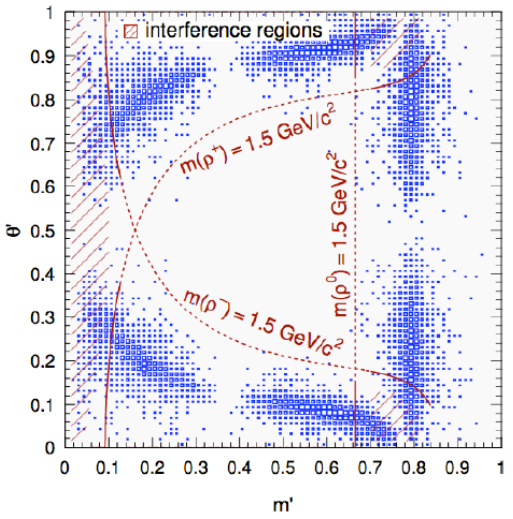
α extraction

Snyder and Quinn proposal to measure α in a Penguin-free manner through $B^0 \to \rho\pi$ [PRD 48 (1993) 2139] dates to year of first Beauty conference.

Preliminary 'last word' from BaBar [Cartaro] is that available statistics are not sufficient to obtain robust or precise fit







Most probably we will have to wait for Belle-II to see this method used with interesting power.

No matter – good constraints available from $B \to \rho\rho$.

Ultimately – how much do we really care about having independent α measurement?

Searching for in suppressed FCNC decays

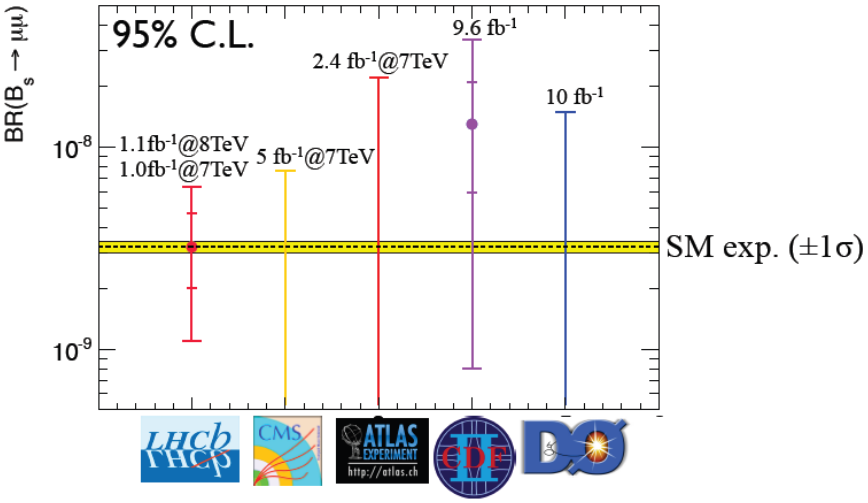
$B_s \rightarrow \mu\mu$ - current experimental status

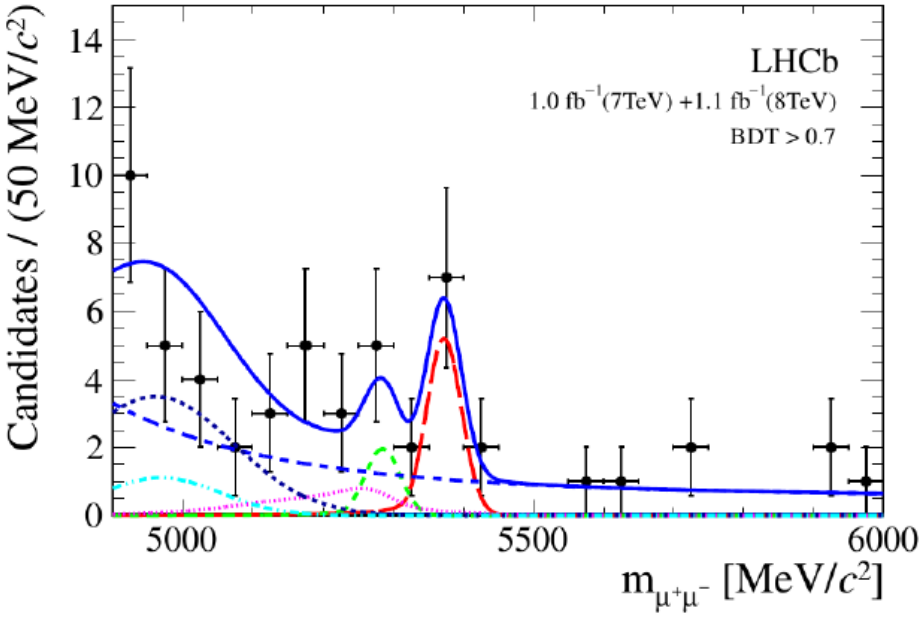
[Nobe, De Mattia, Dettori]

Results with 2.4 fb^{-1} shown by ATLAS, 5 fb^{-1} by CMS and 2.1 fb^{-1} by LHCb

Impressive limits set...

...and first evidence of decay at last seen





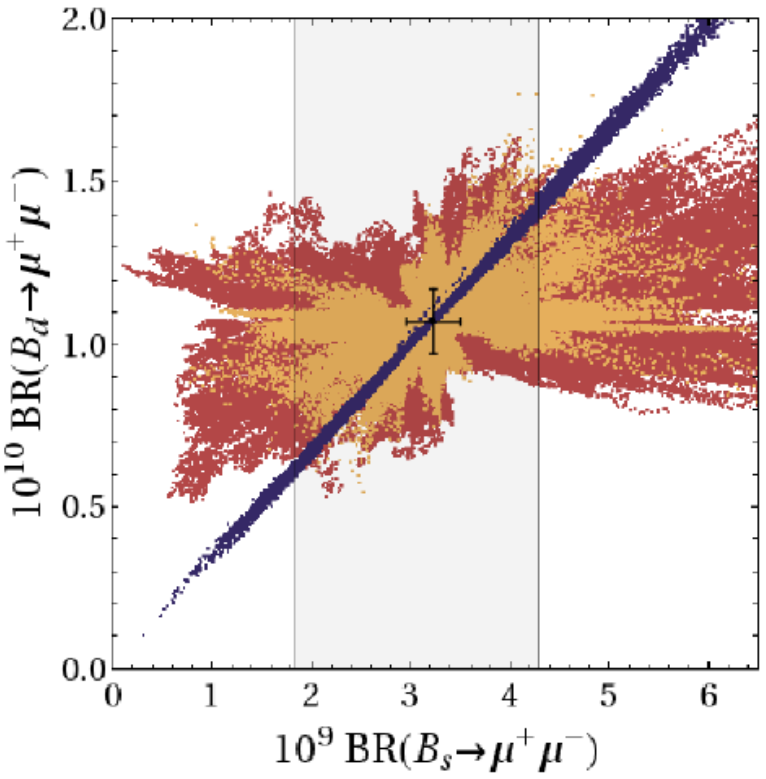
New updates expected soon, but given that decay is probably there at BR ~ BR_{SM}, and big New Physics effects are excluded, should we continue to care about this analysis ?

→ yes!

Next steps in $B_{(s,d)} \to \mu\mu$

[Altmannshofer, Knegjens]

Straub '13:
analysis of several models
with partial compositness



Important to measure BR ($B_s \to \mu\mu$) down to theoretical uncertainty (a few x 10^{-10})

- we have excluded spectacular effects, but are perhaps now in the regime where more 'natural' O(50%) NP effects can be probed
- excluding modest enhancement, or even suppression, w.r.t. SM will be important in further constraining e.g. high tanβ SUSY

Vital now to go after $B_d \to \mu\mu$ to test the 'golden' relation which holds in SM and MFV

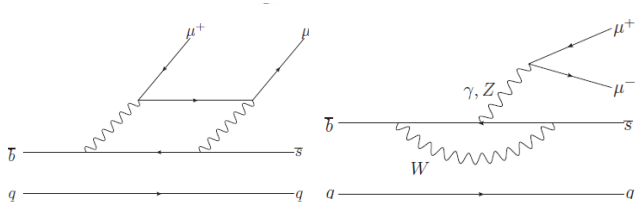
$$\frac{BR(B_s \to \mu^+\mu^-)}{BR(B_d \to \mu^+\mu^-)} \simeq \frac{f_{B_s}^2}{f_{B_d}^2}\frac{\tau_{B_s}}{\tau_{B_d}}\frac{|V_{ts}|^2}{|V_{td}|^2} \simeq 32$$

There is also important information to be accessed in lifetime and tagged time-dependent measurements

Lots to do over coming years and further future (e.g. LHCb upgrade)

LHC confronts electroweak Penguins

[van Dyk, Kreps]

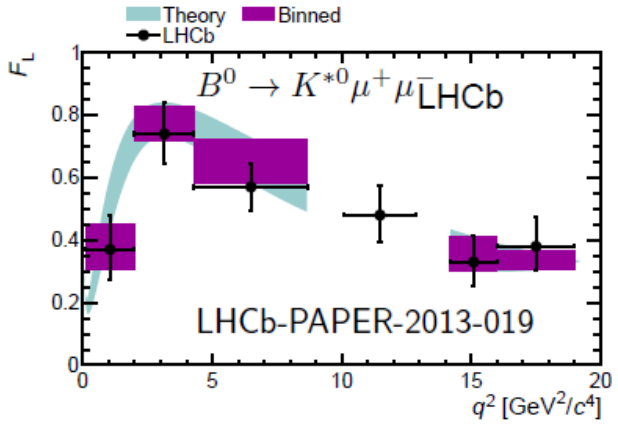


Such decays offer powerful way to probe helicity structure of New Physics.

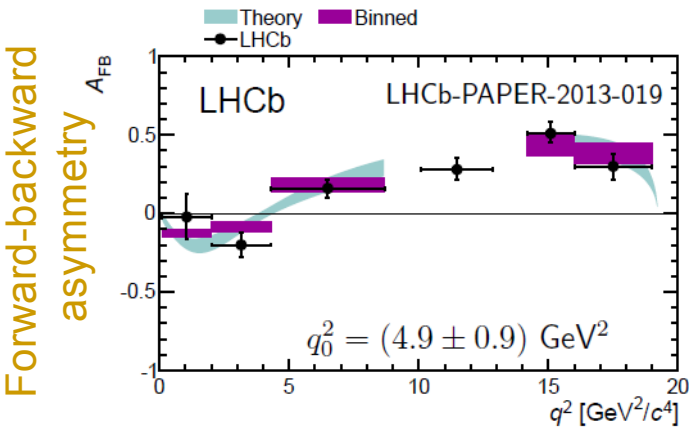
Flagship mode is $B^0 \to K^*\mu\mu$, and poster-child measurement is A_{FB}.

News from this week: LHCb is finalising its full 1 fb^{-1} 2011 measurement.

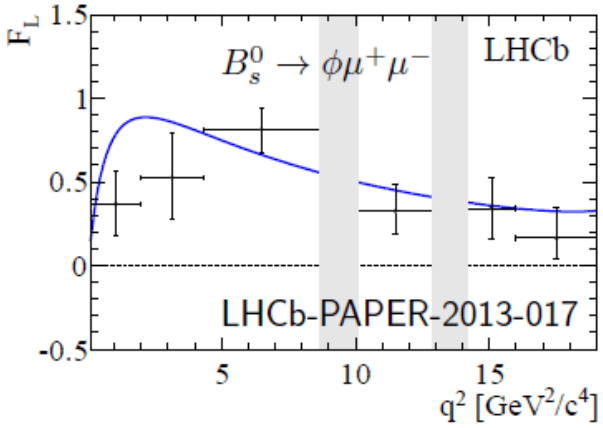
Polarisation



Forward-backward asymmetry



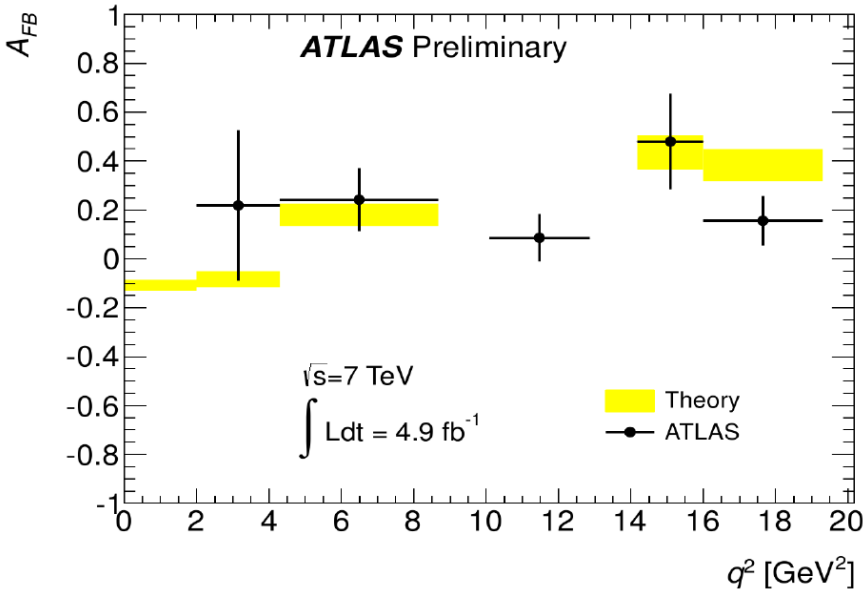
This is being accompanied by first meaningful studies of $B_s \to \Phi\mu\mu$

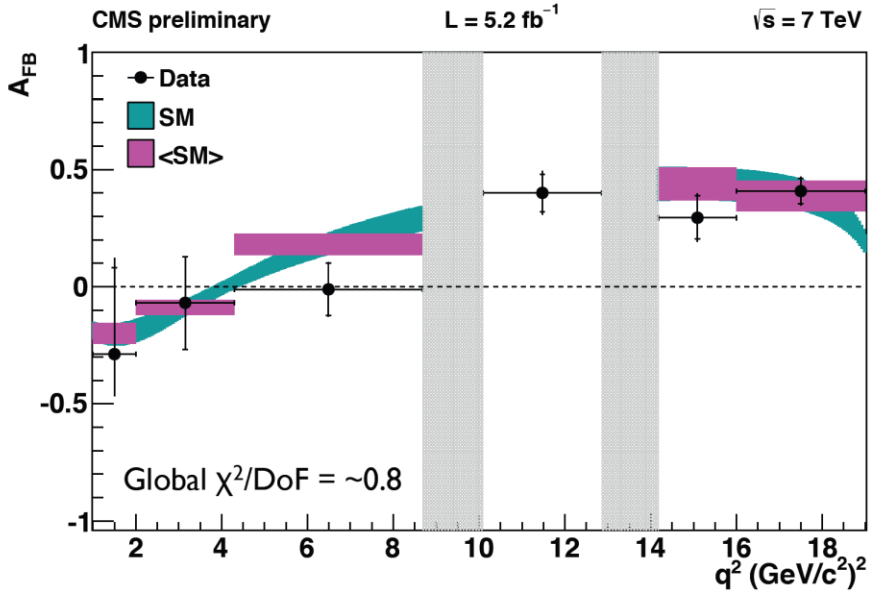


$B^0 \to K^* \mu\mu$ at ATLAS and CMS

[Dinardo, Usanova]

Very exciting news from the conference – ATLAS and CMS joining the game !



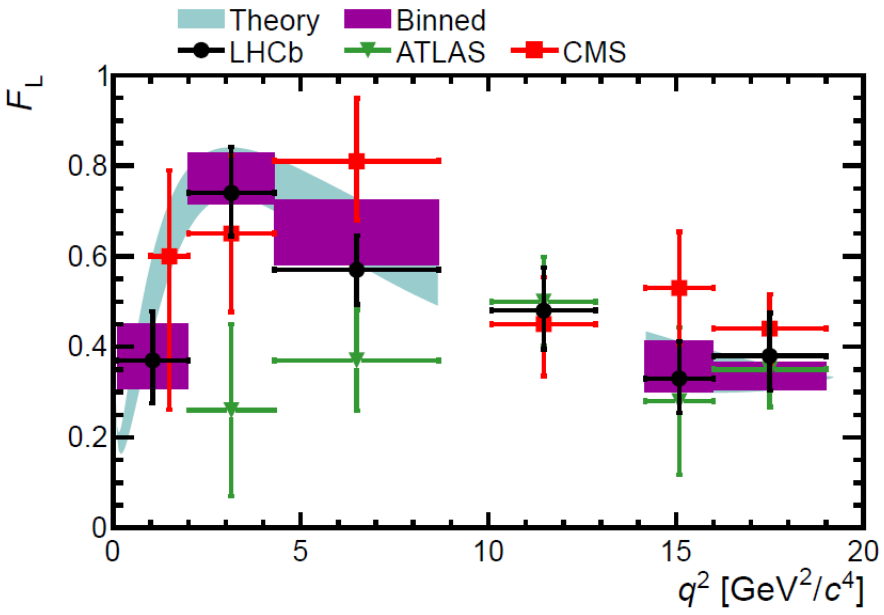


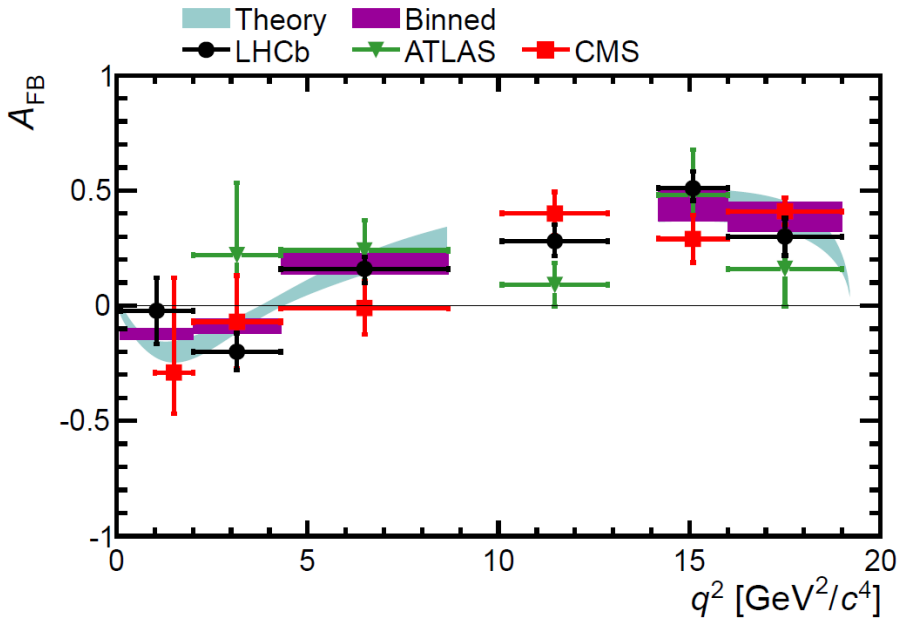
CMS-PAS-2011/009

The global LHC picture for K*μμ

[thanks to Tom Blake for plots]

Overlaying this week's K*μμ results, for F_L and A_{FB}





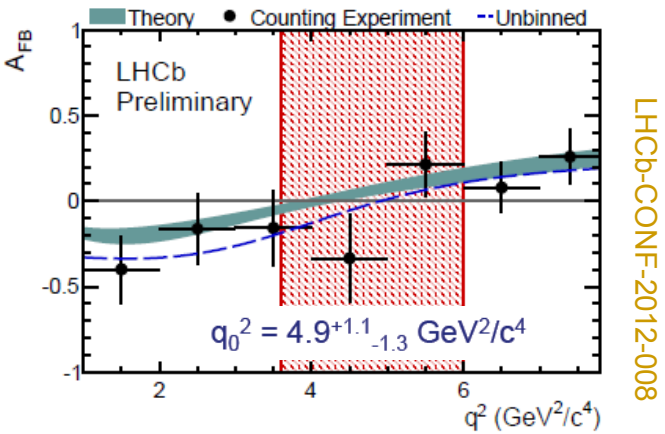
- LHCb and ATLAS/CMS complementary in low and high q^2 regions.
- Look forward to HFAG average.
- Time to revisit what is the optimal binning?

$B^0 \to K^* \mu\mu$ – the tasks ahead

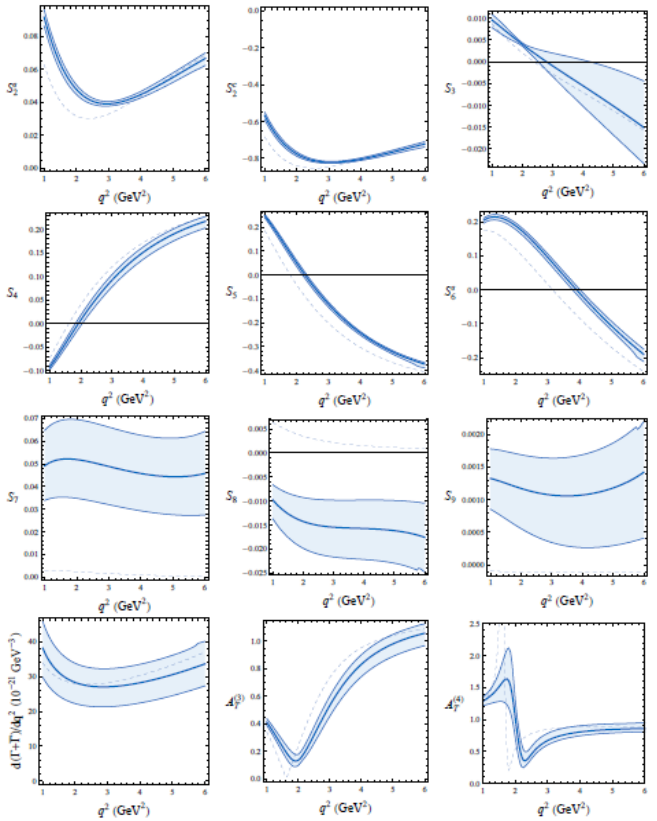
Bigger samples → more precise measurements & study of other observables

[Altmannshofer et al., JHEP 0901 (2009) 019]

- measure crossing point well – cleanly predicted within SM



LHCb-CONF-2012-008



- explore other observables, of which there are lots, many sensitive to different aspects of non-SM physics (first of these starting to appear)

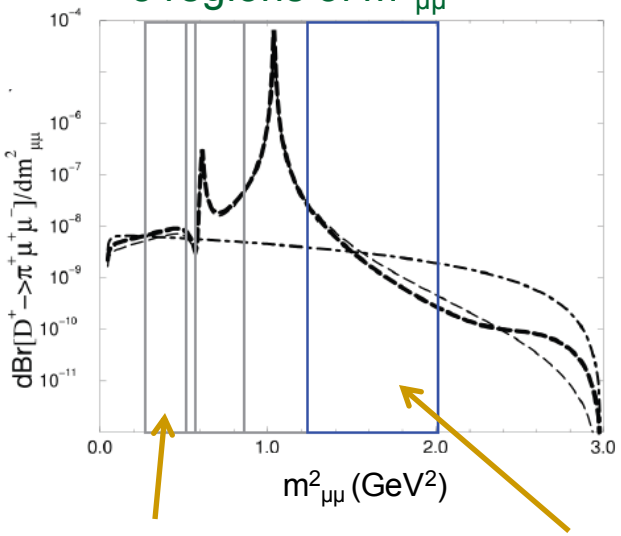
- enhance low q^2 region through study of $B^0 \to K^* e^+ e^-$

New results in searches for charm FCNC decays

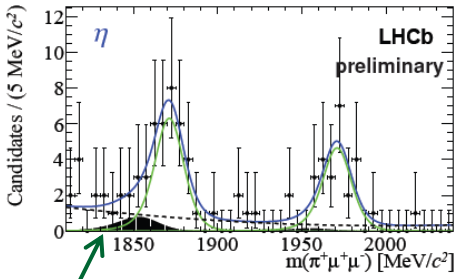
LHCb results shown for the first time for search for FCNC $D^+_{(s)} \to \pi^+\mu^+\mu^-$ [Thomas, LHCb-PAPER-2012-051]

5 regions of $m^2_{\mu\mu}$

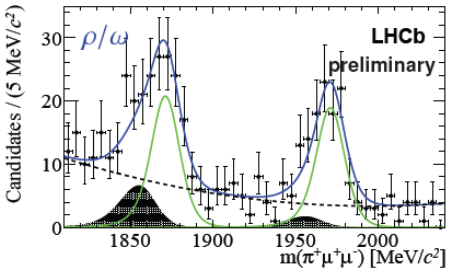
Figure adapted from PRD 64 (2001) 114009

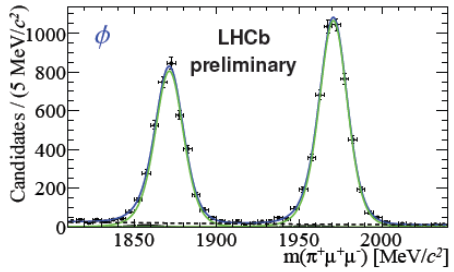


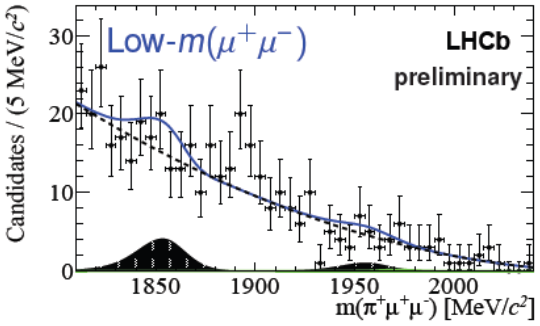
Clear peaks seen in resonance regions...

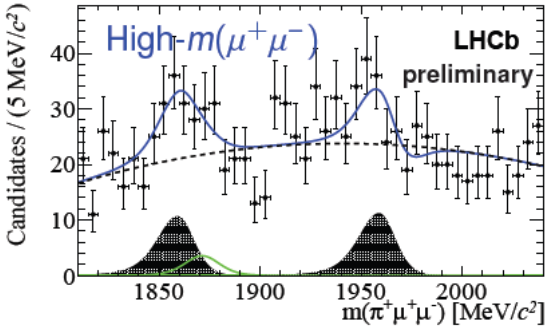


misidentified $\pi^+\pi^-\pi^+$









...but nothing (yet) in low and high mass non-resonance regions

New results in searches for charm FCNC decays

LHCb results shown for the first time for search for FCNC $D^+_{(s)} \to \pi^+\mu^+\mu^-$ [Thomas, LHCb-PAPER-2012-051]

Main results (preliminary):

$$\mathcal{B}(D^\pm \to \pi^\pm\mu^+\mu^-) < 8.3 \times 10^{-8}$$

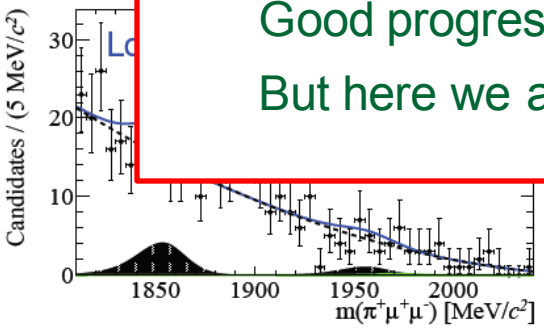
$$\mathcal{B}(D_s^\pm \to \pi^\pm\mu^+\mu^-) < 4.8 \times 10^{-7}$$

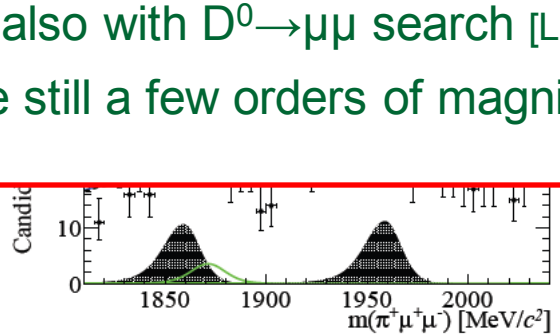
1-2 orders of magnitude more stringent than previous results. Now, not far from SM predictions. Exciting prospects for 2012/post-LS1 analysis and the upgrade.

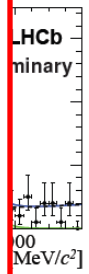
Good progress also with $D^0 \to \mu\mu$ search [LHCb-CONF-2012-005],

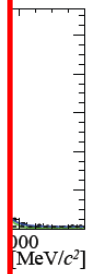
But here we are still a few orders of magnitude away from SM.

Figure adapted from PRD 64 (2001) 114009







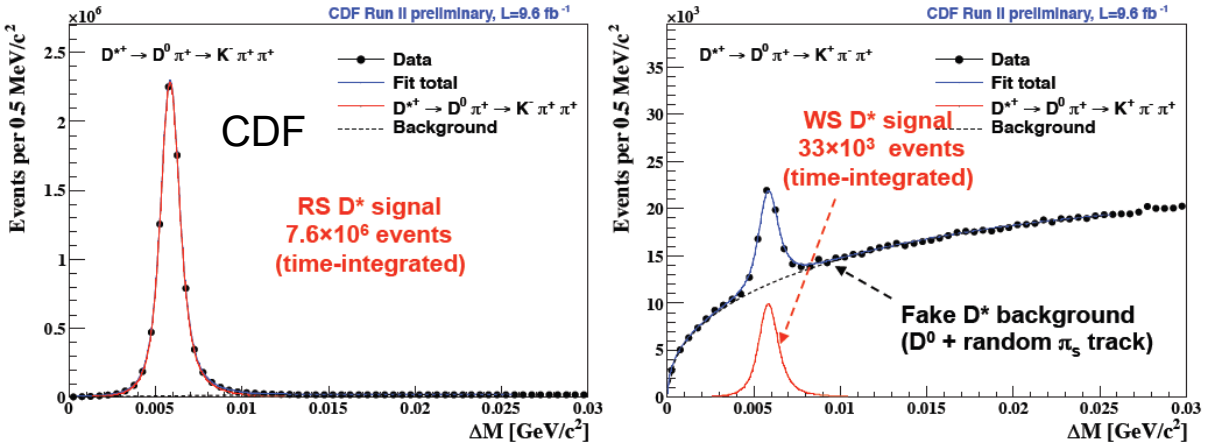


) in low and high mass non-resonance regions

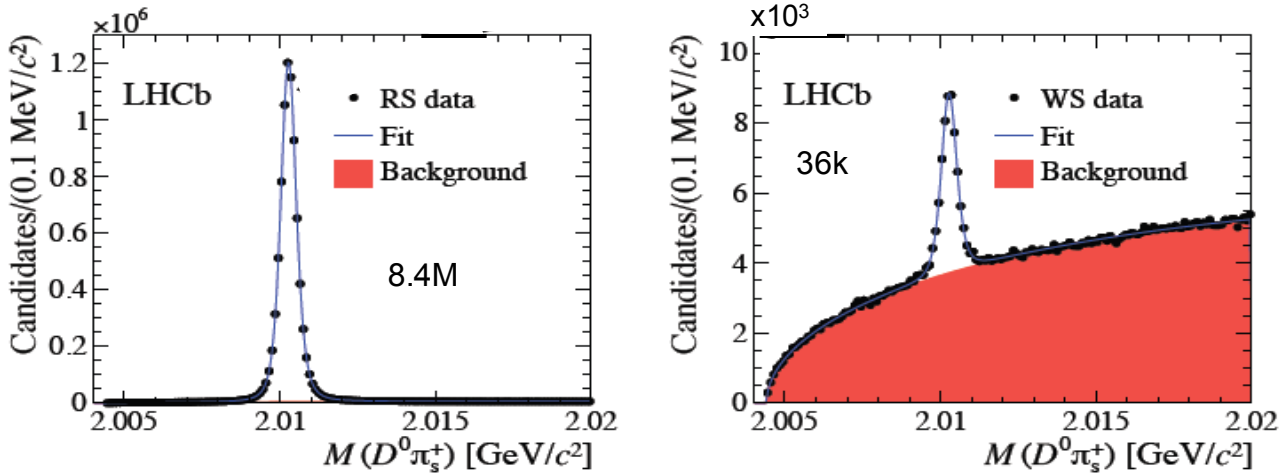
Charm mixing and CPV

New CDF results on D mixing (WS Kπ)

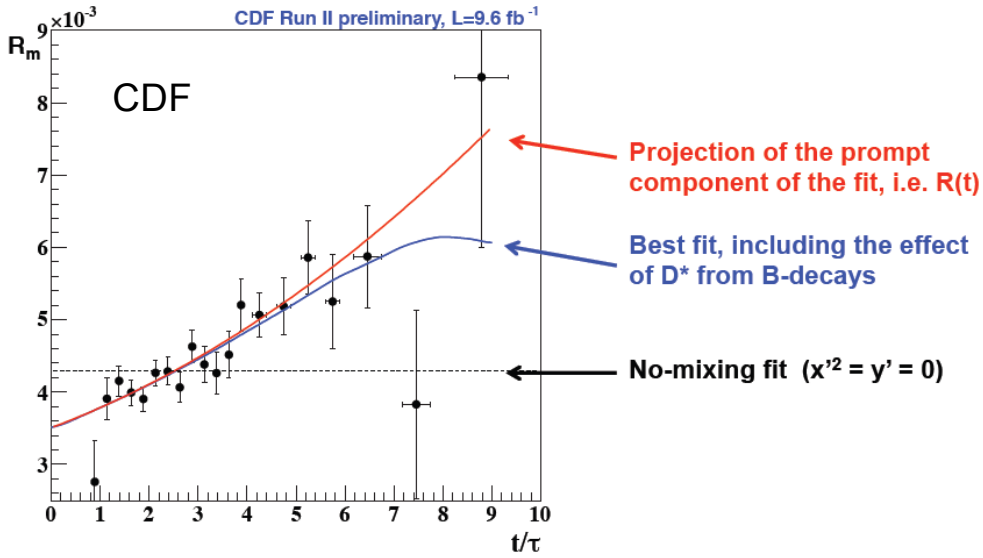
New result shown on Wednesday [Maestro]

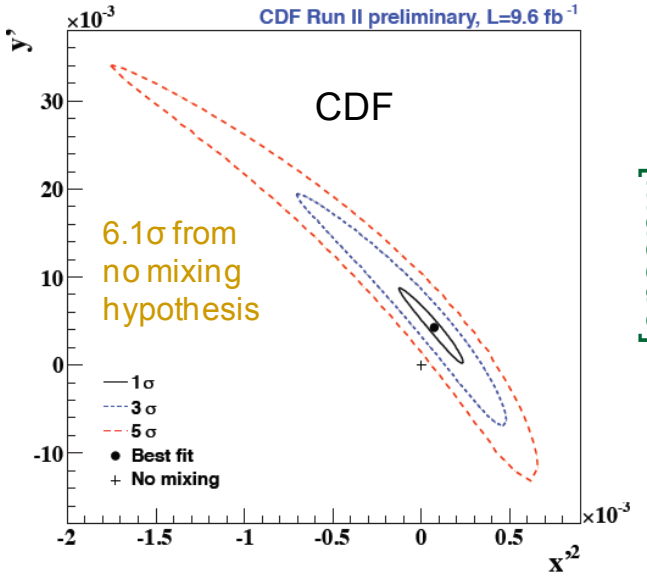


Yields similar to recent LHCb result [Ukleja] & *far* higher than seen at B-factories

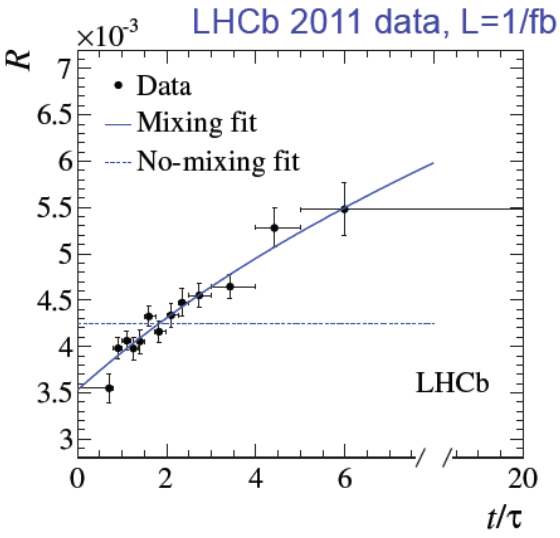


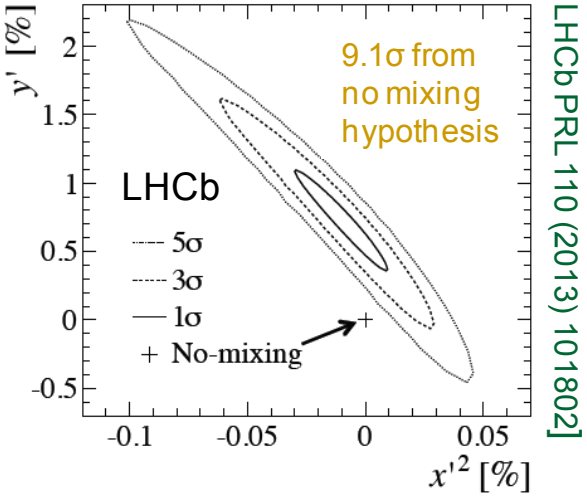
WS Kπ mixing results





[Maestro]





[Ukleja; LHCb PRL 110 (2013) 101802]

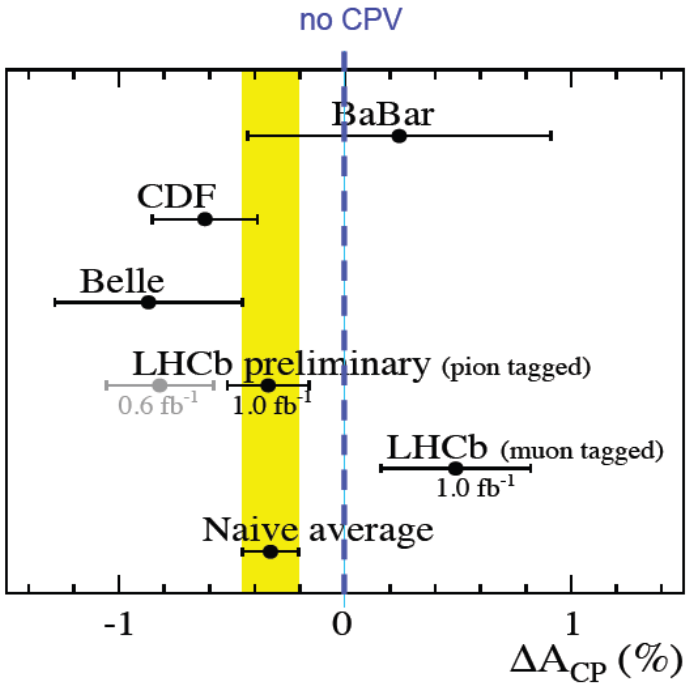
Direct CPV in charm – the ΔA_{CP} saga

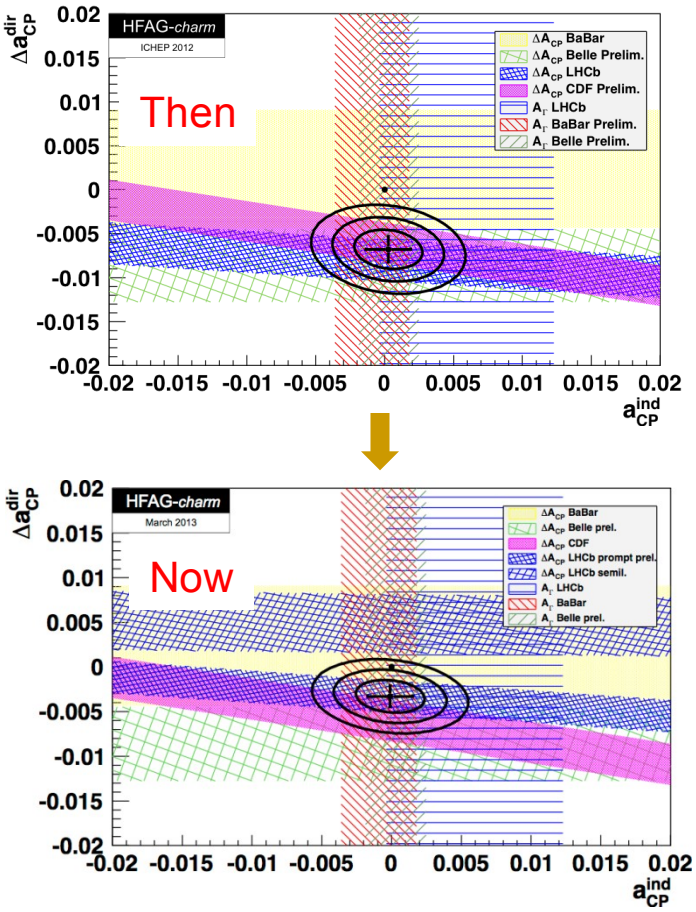
[Brod, Ukleja]

By last summer a consistent picture had emerged of ~0.5% direct CPV in SCS charm decays (thanks to LHCb, CDF, Belle)

This caused the theory community to re-evaluate their position (next slide).

Recent LHCb results (prompt update and semileptonic B) has muddied the picture,



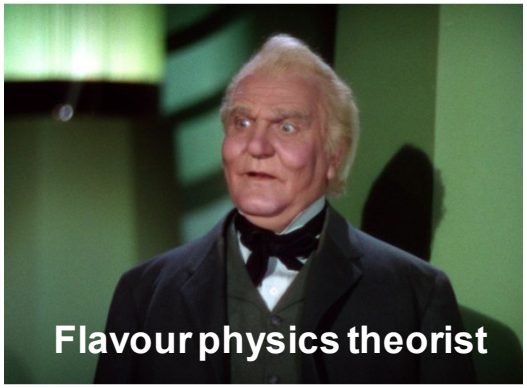


Wish list:
- results from 2012 data set (& beyond)
- results in other modes
- results on indirect CPV (theoretical interpretation less ambiguous)

ΔA_{CP}: Informing the theory community

Please, sir. We've done what you told us. We've brought you the broomstick of the Wicked Witch of the West. We melted her.

Oh... You liquidated her, eh? Very resourceful!



Yes, sir. So we'd like you to keep your promise to us, if you please sir.

Not so fast! I'll have to give the matter a little thought. Go away and come back tomorrow.

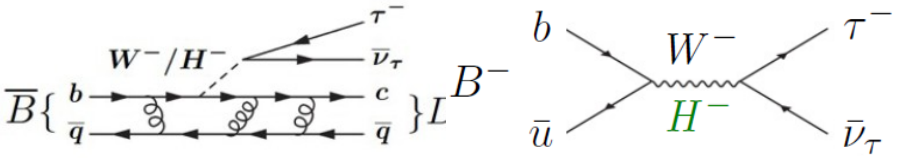
Loose ends

We have seen several examples of studies that have an unclear (or suspicious) experimental status

- Spectroscopy: X(4140)
- D0 dimuon anomaly
- Charm CPV: ΔA_{CP}

Here is one more...

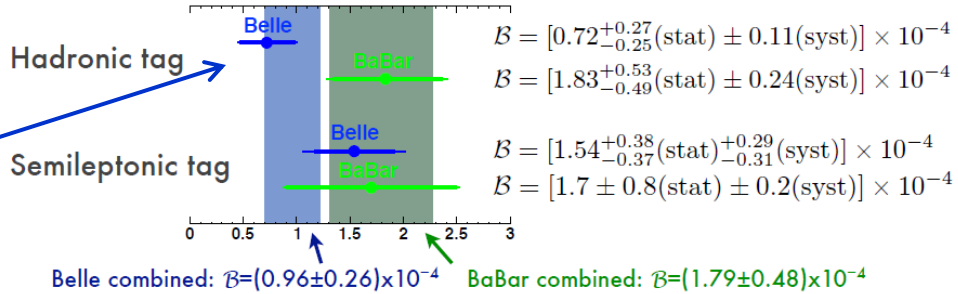
$B \to \tau\nu$, $B \to D^{(*)}\tau\nu$



Intriguing offsets in BRs / relative BRs in these modes may be telling us about charged Higgs sector. Situation nicely summarised this week [Horii].

$B \to \tau\nu$

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



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

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

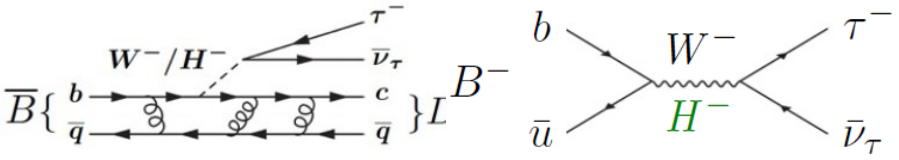
	R(D)	R(D*)
BaBar	+2.0σ	+2.7σ
Belle	+1.4σ	+3.0σ

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

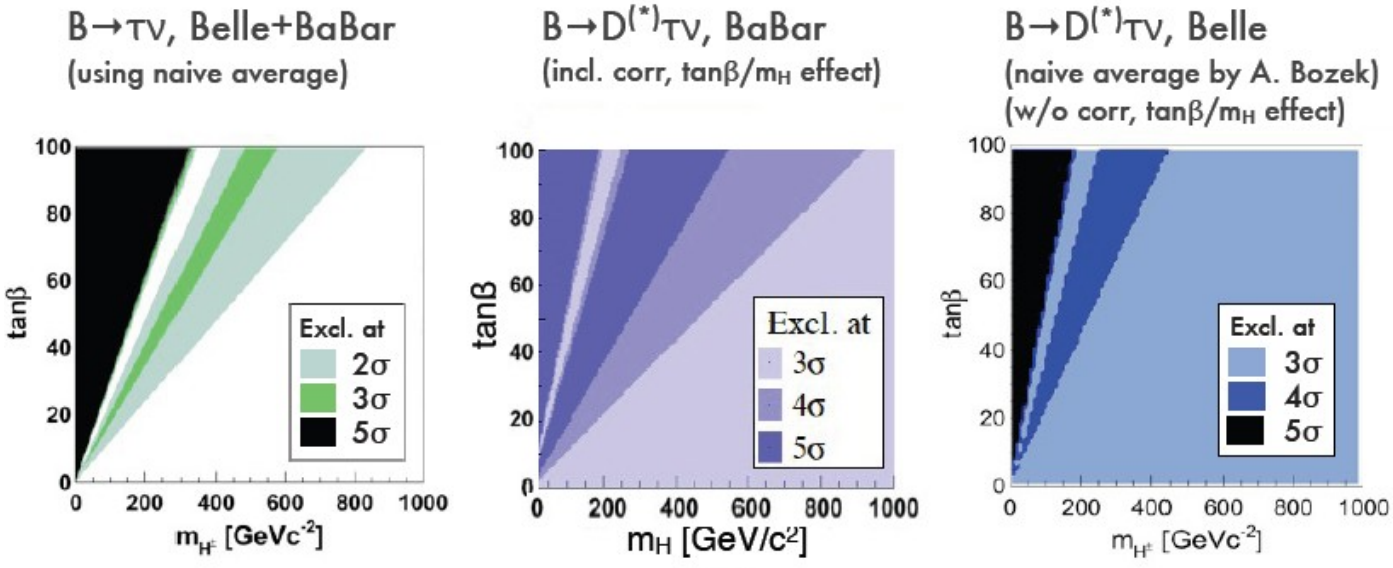
Watch this space – Belle will soon update

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

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

Outlook and conclusions

Barking up the wrong tree?

Curious that after thorough programme of flavour studies at the B-factory & Tevatron, after first exploration of key flavour observables at the LHC there is still no sign of effects coming from the New Physics at the TeV scale which we are all expecting.

Sometimes the absence of a signal is the critical clue:

Policeman: "Is there any other point to which you would wish to draw my attention?"

Holmes: "To the curious incident of the dog in the night-time."

Policeman: "The dog did nothing in the night-time."

Holmes: "That was the curious incident."

(Conan Doyle, 'Silver Blaze', 1892)

The dog did not bark because the stranger they were looking for did not exist.

But it is still too early to reach an analogous conclusion...

Another way to look at it

Although there appears to be no 'low hanging New Physics fruit' (in neither flavour nor direct searches)...

...we have an excellent opportunity to climb much higher

Additional data from 2012 run, post-L1 statistics and samples to be collected at LHCb upgrade will give *enormous* increase in knowledge w.r.t. now

- factor >10 reduction in γ uncertainty
- true precision measurement of Φ_s
- extensive exploration of electroweak Penguins with thorough exploration of $B^0 \to K^* \mu\mu$ decays
- measure BR($B_s \to \mu\mu$) to better than theory uncertainty and also measure BR($B_d \to \mu\mu$).
- sensitivity to direct CPV in charm down to SM expectation, and ultra-precise probing of indirect CPV in charm
- etc etc...


Let’s get climbing, so we can enjoy the view!

Many, many thanks to Vincenzo, Umberto, Angelo and friends, and the fantastic support team for such a wonderful conference

Beautiful physics results,

great company,

a fascinating environment,

and magnificent food!

Let's get climbing, so we can enjoy the view!