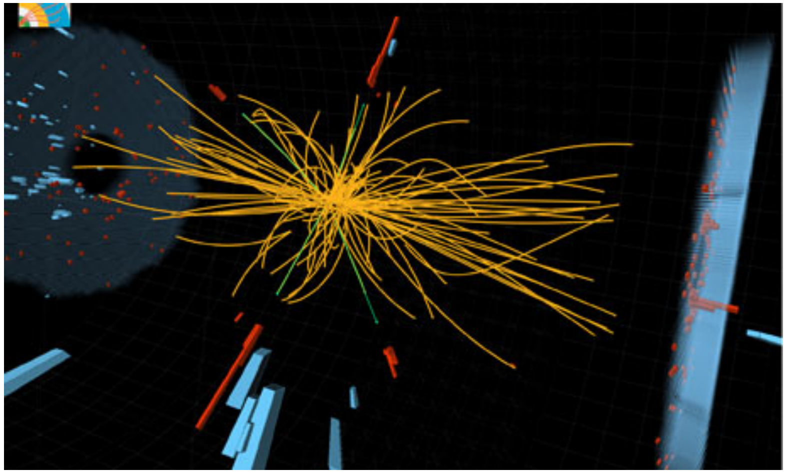
Seminar at Birmingham University

Recent Highlights from LHCb

Yuehong Xie

University of Edinburgh

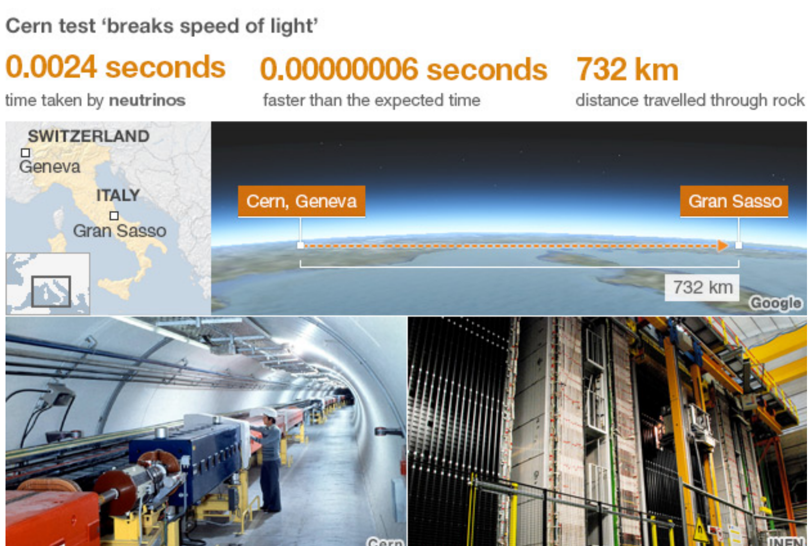
Hot off the press



Intriguing hints for the Higgs boson?

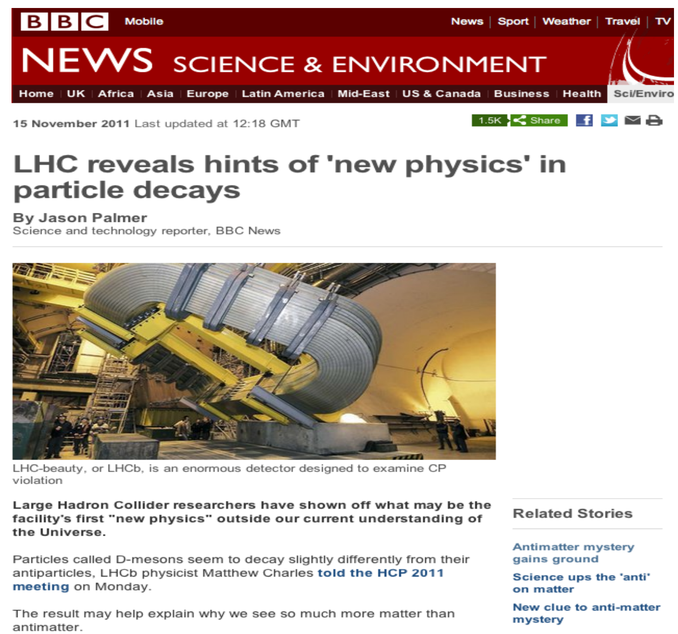
Faster than light neutrinos?

"Hints of new physics" in charm decays?



Cern, Switzerland: A beam of neutrino particles is sent through rock towards Italy

Gran Sasso, Italy: Bricks with ultrasensitive covering at underground laboratory detect arrival



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15 November 2011 Last updated at 12:18 GMT

LHC reveals hints of 'new physics' in particle decays

By Jason Palmer
Science and technology reporter, BBC News

LHC-beauty, or LHCb, is an enormous detector designed to examine CP violation

Large Hadron Collider researchers have shown off what may be the facility's first "new physics" outside our current understanding of the Universe.

Particles called D-mesons seem to decay slightly differently from their antiparticles, LHCb physicist Matthew Charles told the HCP 2011 meeting on Monday.

The result may help explain why we see so much more matter than antimatter.

Related Stories

Antimatter mystery gains ground

Science ups the 'anti' on matter

New clue to anti-matter mystery

In flavour physics we aim to understand if

Yukawa coupling to the Higgs field is the (only) origin of flavour and CP violation.

We currently believe

Einstein's special relativity is valid.

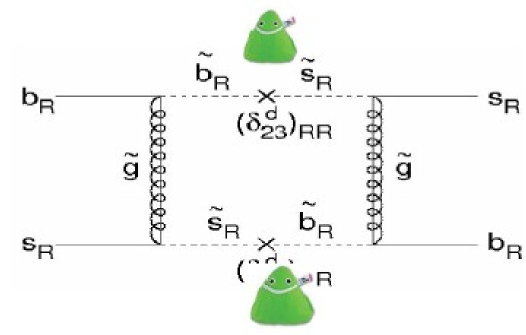
Outline of the talk

- Flavour physics
- LHCb and physics program
- LHCb highlights
  - ϕ_s measurement
  - Charm CP violation
  - Rare decay results
- Conclusions

Flavour physics

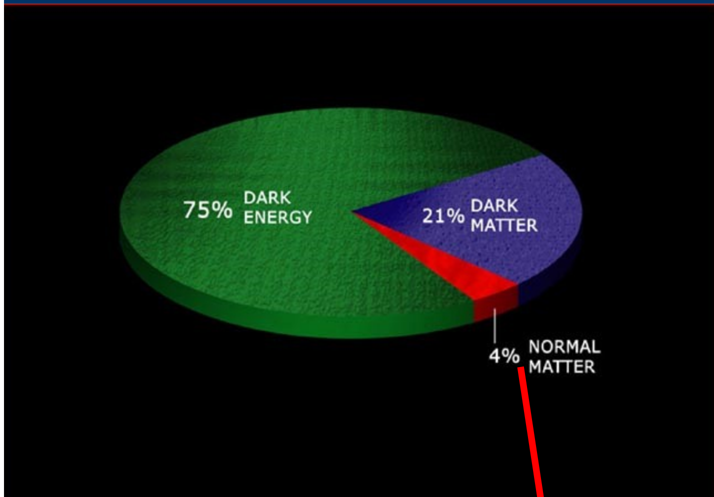
- Search for and study quantum effects of new particles in loop-mediated processes
  - can probe much higher mass scale (up to 100 TeV) than √s (7TeV at current LHC)
  - E.g. predictions of charm and top quarks

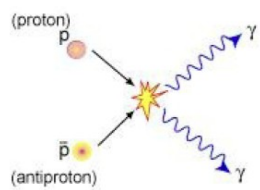
Indirect searches

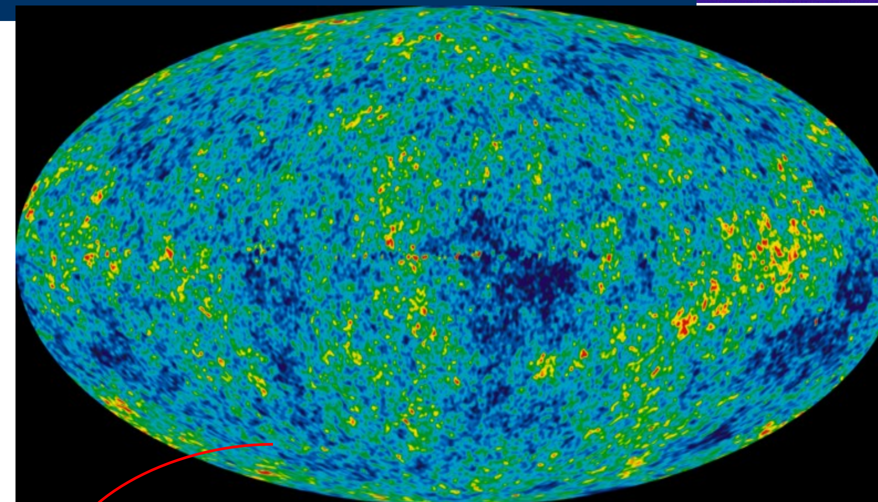


- Many flavour observables provide a model-independent search and help discriminating new physics scenarios
  - SUSY, technicolor, extra dimensions, 4th generation…
- Provide information about magnitudes and phases of NP couplings needed for full understanding of underlying theory
- Interesting in its own right: need new source of CP violation to explain matter-antimatter asymmetry

CPV and Baryogenesis







$$\frac{\Delta n_{\text{baryon}}}{n_\gamma} = \frac{n_{\text{baryon}} - n_{\overline{\text{baryon}}}}{n_\gamma} \sim O\left(10^{-10}\right)$$

The source of current matter domination over antimatter is unknown.
CPV is one of the three necessary conditions (Sacharow 1967)

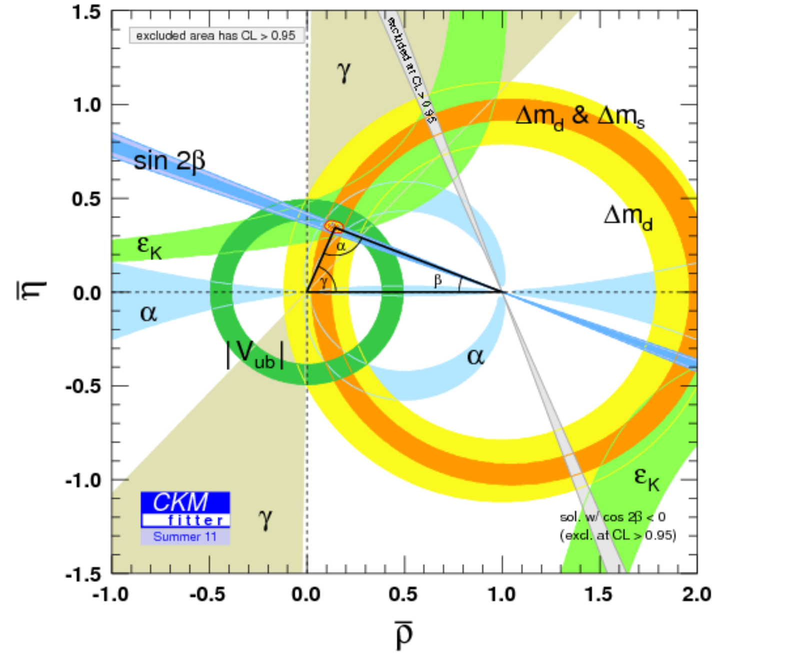
The unique source of CPV in Standard Model is a single phase in the CKM matrix

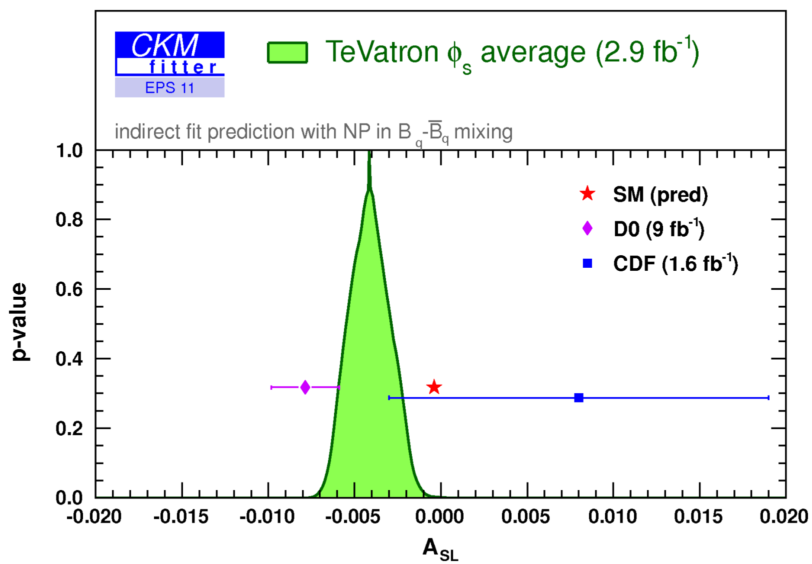
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = \hat{V}_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

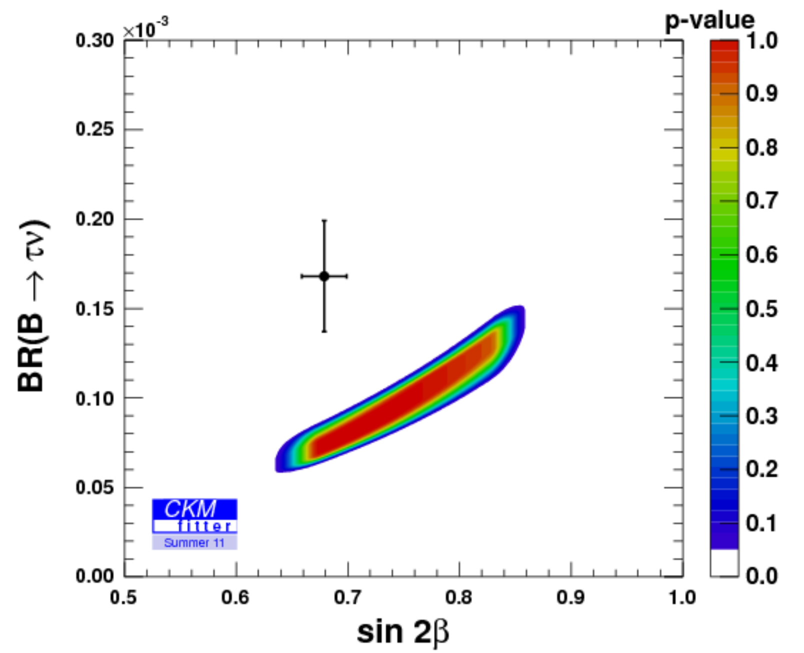
CPV predicted in SM gives $\Delta n_{baryon}/n_\gamma \sim O(10^{-20})$. It is 10^{10} too small.
There must be come other CPV beyond SM

CKM unitarity test

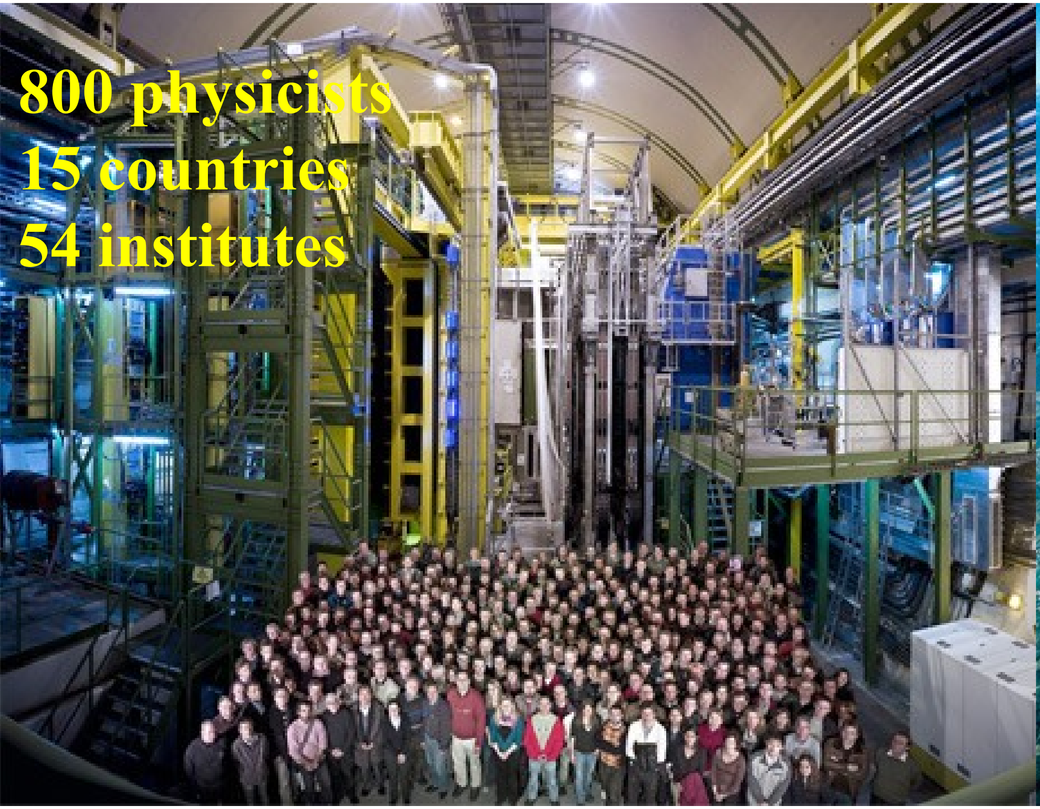
- CKM is basically at work
- 10% level NP in b→d and b→s transitions still allowed
- Some quantities not very well measured: γ, $|V_{ub}|$
- Some interesting "anomalies" $\sin 2\beta$ vs $B \to \tau\nu$, D0 A_{SL}

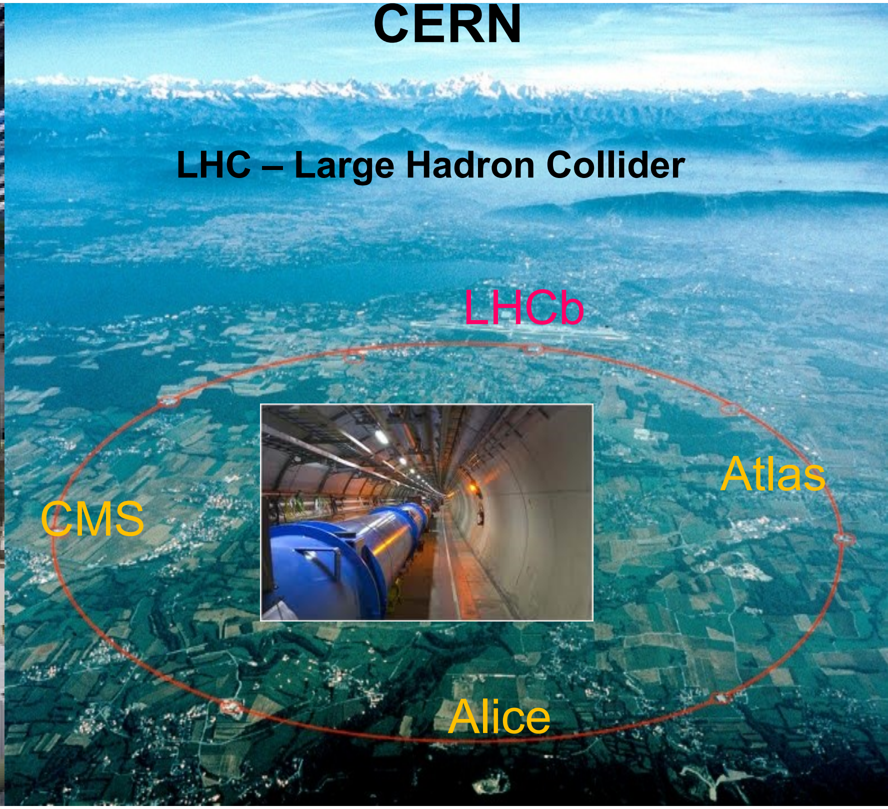






LHCb: an experiment dedicated to beauty and charm physics





Ideal place to perform indirect search for new physics

LHCb physics program

- Major physics objective: indirect search for new physics effects in loop-mediated processes
  - New physics in B_s mixing: ϕ_s, Γ_s, A_{SL}
  - New physics in $b \to s$ loop decays: $B_s \to \mu^+\mu^-$, $B^0 \to K^*\mu^+\mu^-$, $B_s \to \phi\gamma$, $B_s \to \phi\phi$ ...
  - New physics in D^0 mixing or decays: direct CPV in $D^0 \to K^+K^-/\pi^+\pi^-$, mixing parameters from $\tau(K^+K^-)$, $\tau(\pi^+\pi^-)$ and $\tau(K^+\pi^-)$, …
  - Precision test of CKM mechanism: γ measurements
- Also EW, exotics, spectroscopy, LFV, QCD …

An example of "DNA test"

LHCb

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ε_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\mathrm{CP}}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	★★

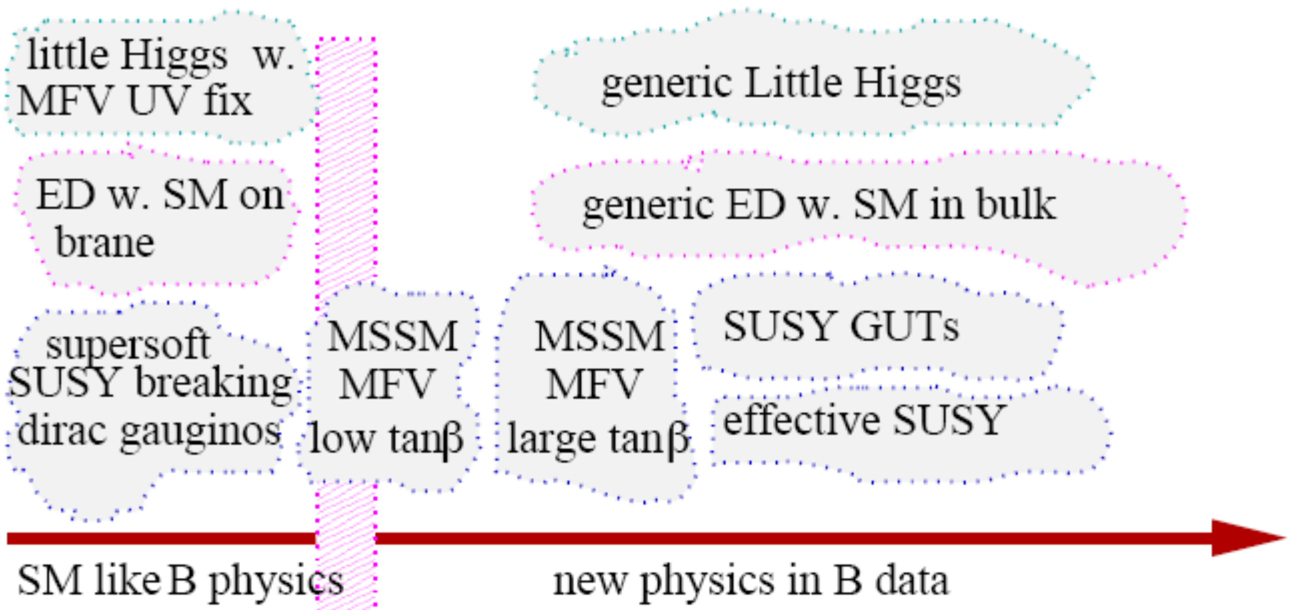
Table 2: "DNA" of flavour physics effects [55] for the most interesting observables in a selection of SUSY and non-SUSY models. ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

Buras, arXiv:0910.1032v1

Bear in mind the limit

models of EWKSB with NP @ TeV

Fig from hep-ph/0207121



reach in indirect signals depends on beyond the SM flavor/CP violation (minimal=CKM), large parameters such as $\tan\beta$ and theoretical and experimental uncertainties

(Courtesy of G. Hiller)

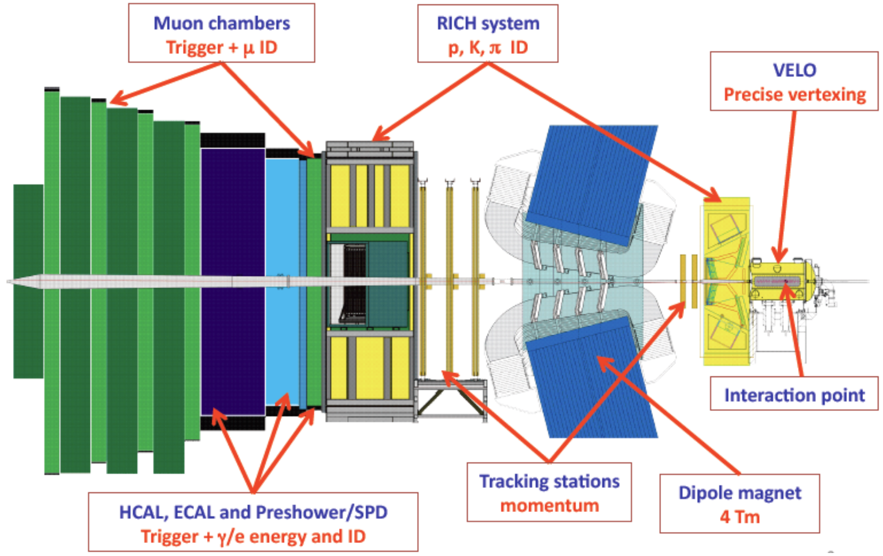
The LHCb detector

Single arm forward spectrometer optimized for flavour physics

Precise tracking

Good mass and IP resolution to suppress background

Good vertex resolution for time dependent analysis



Excellent particle identification

π/K separation over 2-100 GeV

Powerful muon identification

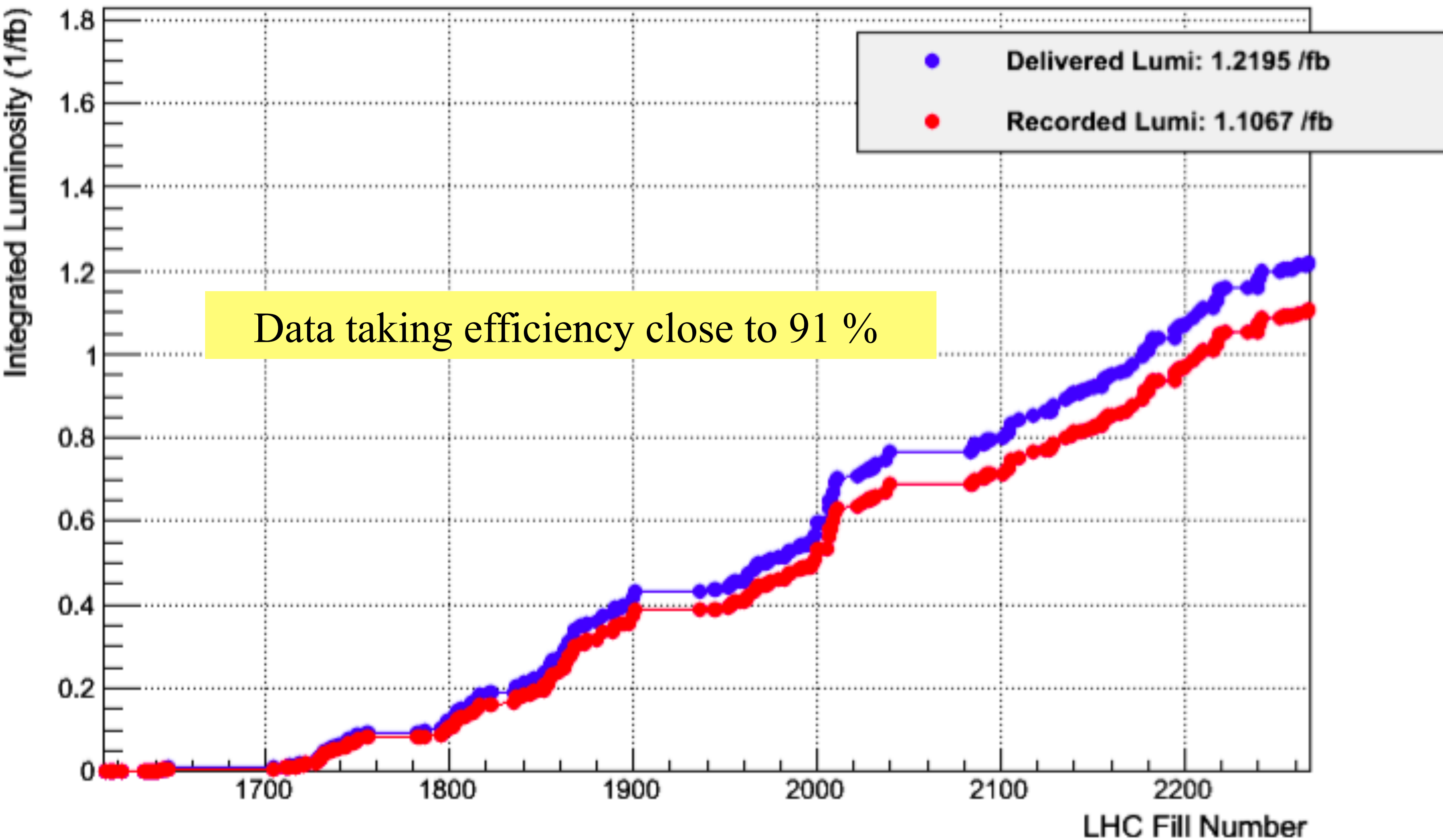
Efficient trigger

Low P_T thresholds for lepton, γ/π^0 and hadron

All B species produced

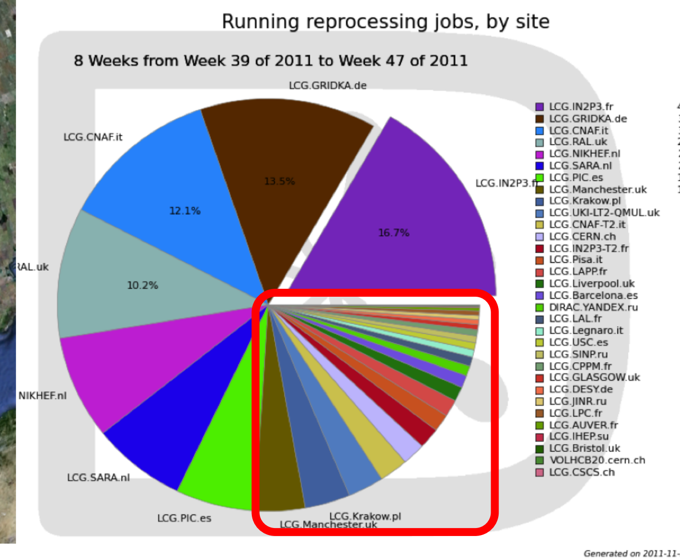
B^-, B_s, B^0, B_c, Λ_b, …, +c.c.

2011 running

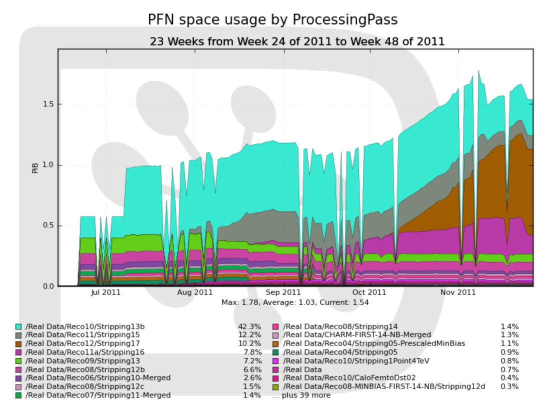


Analyses presented today based on 2010 and early 2011 datasets

Data processing



- Only 2 months to reprocess all of our 2011 data!
  - Over 2PB of data on disk.
- Using resources all over Europe to do this.
- Data ready in plenty of time for the winter conferences - expect great results.



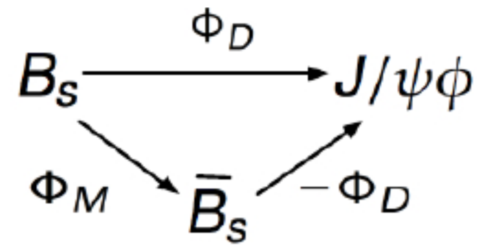
Stay tuned!

Search for new physics in B_s mixing

$$B_s \to J/\psi\phi$$
$$B_s \to J/\psi f_0$$

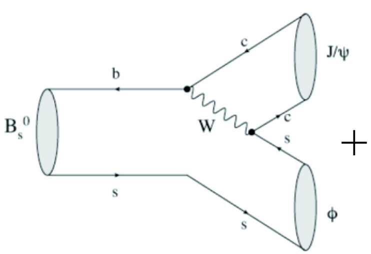
New physics in B_s mixing

- Measure CP violation through interference of decays with and without mixing: $\phi_s = \phi_M - 2\phi_D$

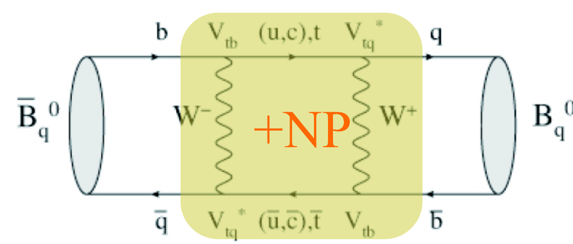


- Precise SM prediction [A. Lenz, arXiv: 1102.4274]

$$\phi_s \stackrel{\text{SM}}{=} -2\beta_s \equiv -2\arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -0.036 \pm 0.002 \text{ rad}$$



+ penguin diagrams



Tree decay diagram immune to NP

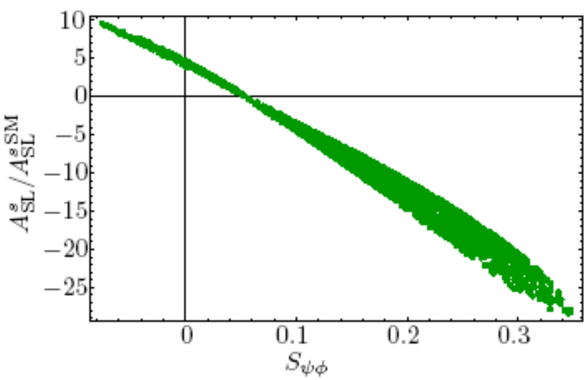
Mixing affected by NP

- New physics can significantly enhance ϕ_s : SUSY, Little Higgs, extra dimension, 4th generation, extra Z', …

Examples of NP effects

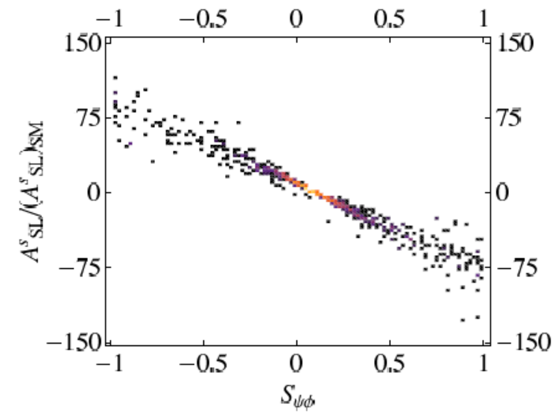
Little Higgs Model with T-Parity

[M. Blanke *et al.*, Acta Phys.Polon.B41:657, 2 010]

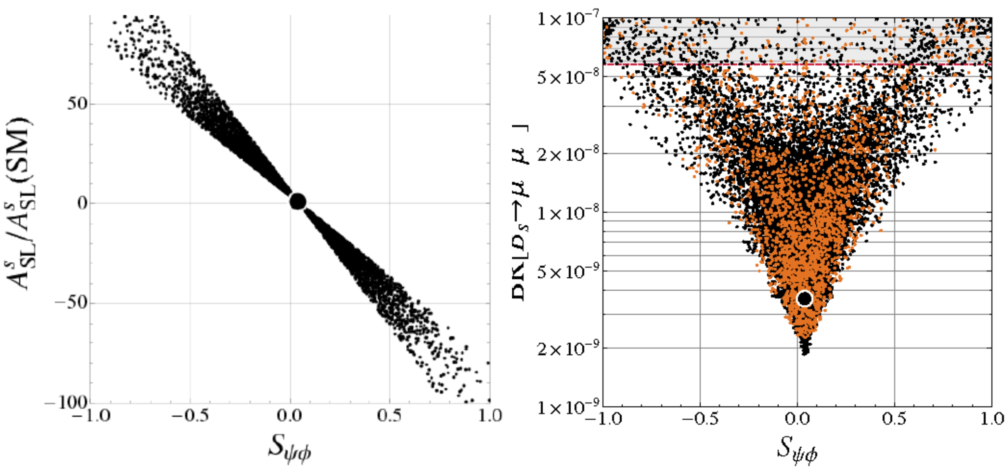


Warped Extra Dimension Model

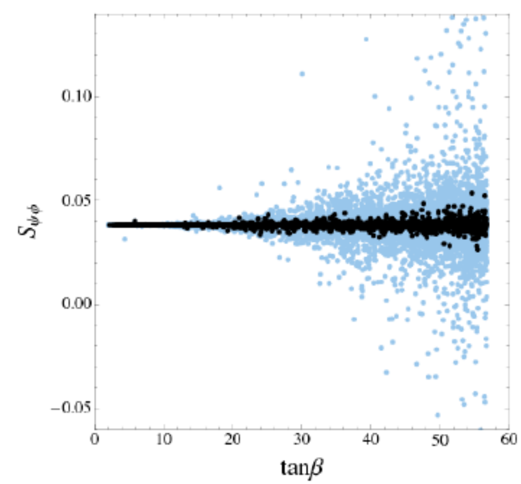
[M. Blanke *et al.*, JHEP 0903:001,2009]



SUSY "AC" Model



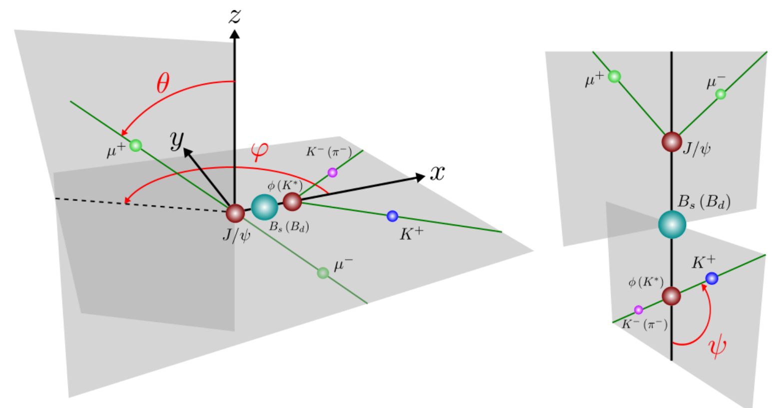
MFV SUSY Model



[W. Altmannshofer *et al.*, arXiv:0909.1333]

Describing $B_s \to J/\psi K^+K^-$

- $B_s \to J/\psi K^+K^-$ is mixture of 4 CP eigenstates
  - 3 K^+K^- P-waves and 1 S-wave
- Described in 4D space
  - 3 angles (θ, ϕ, ψ) and proper time t
- 10 physics parameters
  - 6 amplitudes and strong phases
  - ϕ_s, $\Delta\Gamma_s$, Δm_s, Γ_s



$$\frac{d^4\Gamma(B_s^0 \to J/\psi\phi)}{dt\, d\cos\theta\, d\varphi\, d\cos\psi} \equiv \frac{d^4\Gamma}{dt\, d\Omega} \propto \sum_{k=1}^{10} \boxed{h_k(t)}\, \boxed{f_k(\Omega)}$$

(+ descriptions of background, efficiency, resolution, mistag rate.)

Need flavour-tagged, time-dependent angular analysis.

Extracting ϕ_s in $B_s \rightarrow J/\psi K^+K^-$

ϕ_s is obtained from time evolution of B_s ($\overline{B}_s$) to CP eigenstates

e.g., B_s ($\overline{B}_s$) to longitudinal final state

$$|A_0|^2(t) = |A_0|^2 e^{-\Gamma_s t}[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \pm \sin\phi_s \sin(\Delta m t)]$$

+ for B_s
- for $\overline{B}_s$

- Analysis requirements
  - Separate signal and background
  - Separate different CP eigenstates
  - Identify the initial B flavour and know mistag probability
  - Resolve the fast B_s oscillation and know time resolution

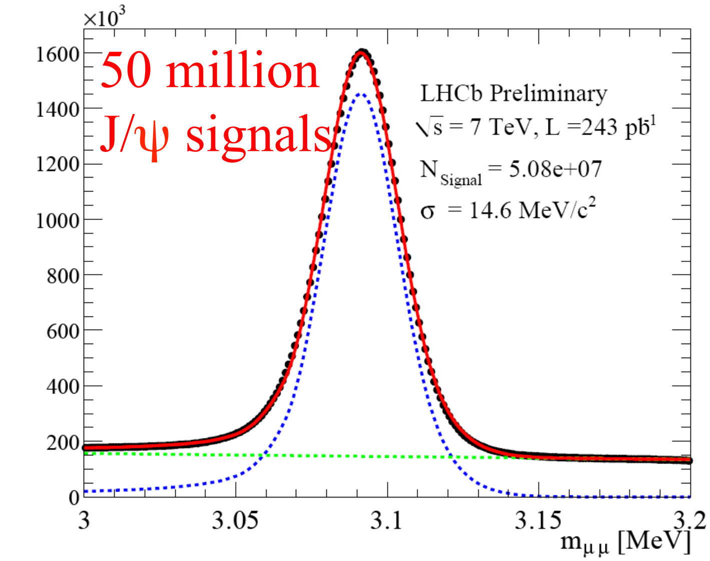
Time evolution for refernece

$$
\begin{aligned}
|A_0|^2(t) &= |A_0|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) + \sin\phi_s \sin(\Delta m t)\right], \\
|A_\parallel(t)|^2 &= |A_\parallel|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) + \sin\phi_s \sin(\Delta m t)\right], \\
|A_\perp(t)|^2 &= |A_\perp|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) - \sin\phi_s \sin(\Delta m t)\right], \\
\Im(A_\parallel(t)\,A_\perp(t)) &= |A_\parallel||A_\perp| e^{-\Gamma_s t}\left[-\cos(\delta_\perp - \delta_\parallel)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. - \cos(\delta_\perp - \delta\_\|)\cos\phi_s \sin(\Delta m t) + \sin(\delta_\perp - \delta_\parallel)\cos(\Delta m t)\right], \\
\Re(A_0(t)\,A_\parallel(t)) &= |A_0||A_\parallel| e^{-\Gamma_s t}\cos(\delta_\parallel - \delta_0)\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. + \sin\phi_s \sin(\Delta m t)\right], \\
\Im(A_0(t)\,A_\perp(t)) &= |A_0||A_\perp| e^{-\Gamma_s t}\left[-\cos(\delta_\perp - \delta_0)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. - \cos(\delta_\perp - \delta_0)\cos\phi_s \sin(\Delta m t) + \sin(\delta_\perp - \delta_0)\cos(\Delta m t)\right], \\
|A_s(t)|^2 &= |A_s|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) - \sin\phi_s \sin(\Delta m t\right], \\
\Re(A_s^*(t)A_\parallel(t)) &= |A_s||A_\parallel| e^{-\Gamma_s t}\left[-\sin(\delta_\parallel - \delta_s)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) - \sin(\delta_\parallel - \delta_s)\ \cos\phi_s \sin(\Delta m t)\right. \\
&\quad \left. + \cos(\delta_\parallel - \delta_s)\cos(\Delta m t)\right], \\
\Im(A_s^*(t)A_\perp(t)) &= |A_s||A_\perp| e^{-\Gamma_s t}\sin(\delta_\perp - \delta_s)\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. - \sin\phi_s \sin(\Delta m t)\right], \\
\Re(A_s^*(t)A_0(t)) &= |A_s||A_0| e^{-\Gamma_s t}\left[-\sin(\delta_0 - \delta_s)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. - \sin(\delta_0 - \delta_s)\cos\phi_s \sin(\Delta m t) + \cos(\delta_0 - \delta_s)\cos(\Delta m t)\right].
\end{aligned}
$$

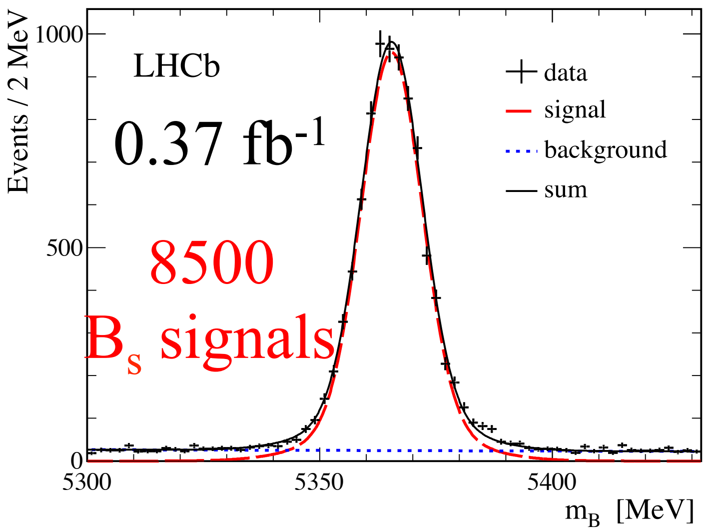
Major source of sensitivity to ϕ_s

Separating signal and background

- Very clean $B_s \rightarrow J/\psi\phi$ signal
  – powerful muon trigger
  – excellent kaon identification
  – require $t(B_s)>0.3$ ps to remove dominant background from prompt J/ψ

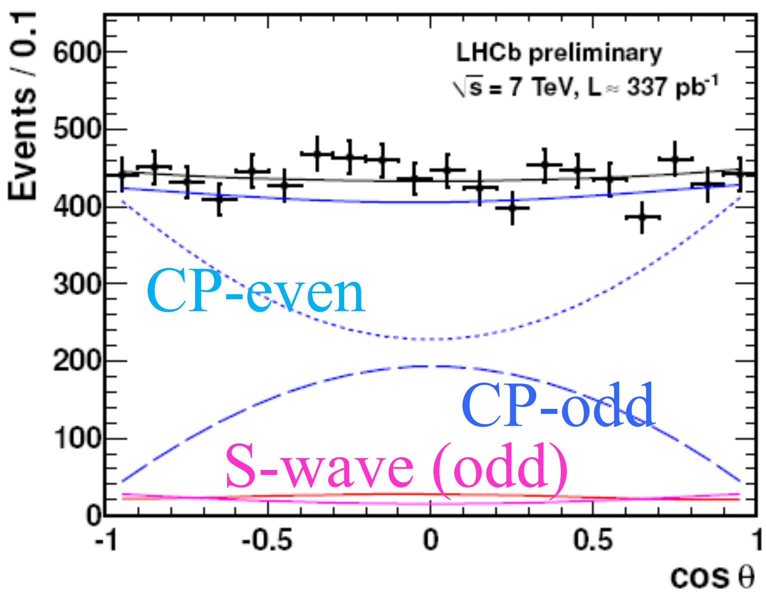


- Use B_s candidate mass variable to statistically separate signal and background in fit



Separating CP eigenstates

Different CP eigenstates are statistically separated in maximum likelihood fit using angular information

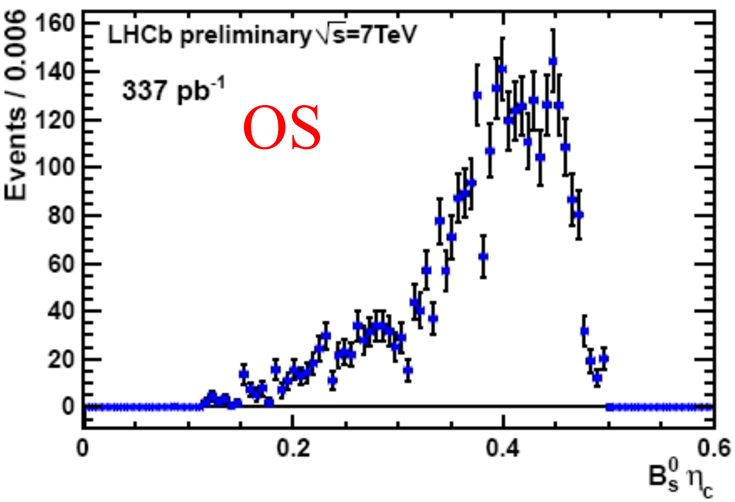


k	$h_k(t)$	$f_k(\theta,\psi,\varphi)$
1	$\lvert A_0\rvert^2(t)$	$2\cos^2\psi\left(1-\sin^2\theta\cos^2\phi\right)$
2	$\lvert A_\parallel(t)\rvert^2$	$\sin^2\psi\left(1-\sin^2\theta\sin^2\phi\right)$
3	$\lvert A_\perp(t)\rvert^2$	$\sin^2\psi\sin^2\theta$
4	$\Im(A_\parallel(t)\,A_\perp(t))$	$-\sin^2\psi\sin 2\theta\sin\phi$
5	$\Re(A_0(t)\,A_\parallel(t))$	$\frac{1}{2}\sqrt{2}\sin 2\psi\sin^2\theta\sin 2\phi$
6	$\Im(A_0(t)\,A_\perp(t))$	$\frac{1}{2}\sqrt{2}\sin 2\psi\sin 2\theta\cos\phi$
7	$\lvert A_s(t)\rvert^2$	$\frac{2}{3}(1-\sin^2\theta\cos^2\phi)$
8	$\Re(A_s^*(t)A_\parallel(t))$	$\frac{1}{3}\sqrt{6}\sin\psi\sin^2\theta\sin 2\phi$
9	$\Im(A_s^*(t)A_\perp(t))$	$\frac{1}{3}\sqrt{6}\sin\psi\sin 2\theta\cos\phi$
10	$\Re(A_s^*(t)A_0(t))$	$\frac{4}{3}\sqrt{3}\cos\psi(1-\sin^2\theta\cos^2\phi)$

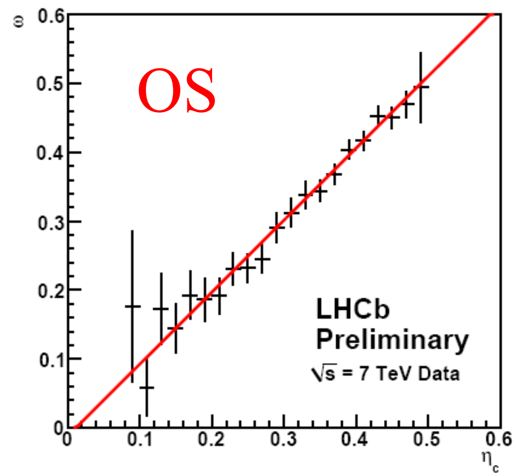
Relative variation of angular efficiency <5% and accounted for according to full MC simulation

Identifying initial B flavour

- Initial flavour of B inferred from
  - Opposite Side: products of the other B meson
  - Same Side: fragmentation particles associated to signal B
- Currently use OS, fully optimized and calibrated on data
  (SS tagging will be used in next round of analysis)



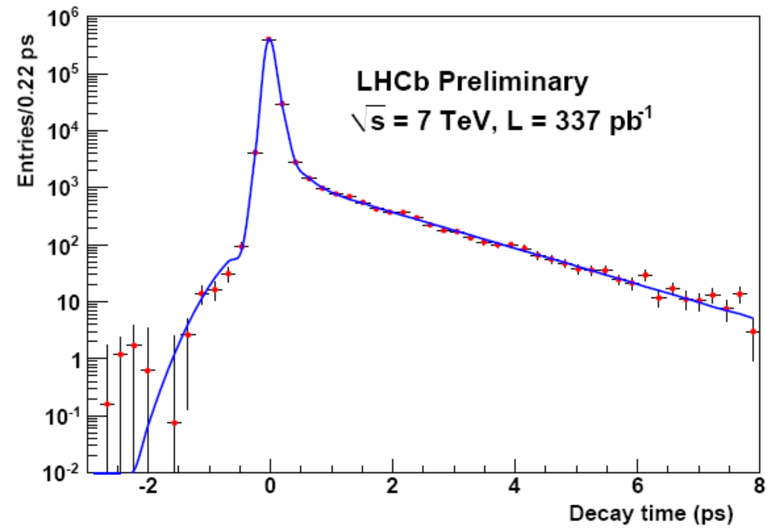
Effective tagging efficiency
(1.91 ±0.23)%



Wrong tagging probability very well calibrated with $B^+ \to J/\psi K^+$

Time resolution and acceptance

- Time resolution model obtained from prompt events



LHCb-CONF-2011-049

- Effective proper time resolution 50 fs

- Compared with B_s oscillation period of about 350 fs

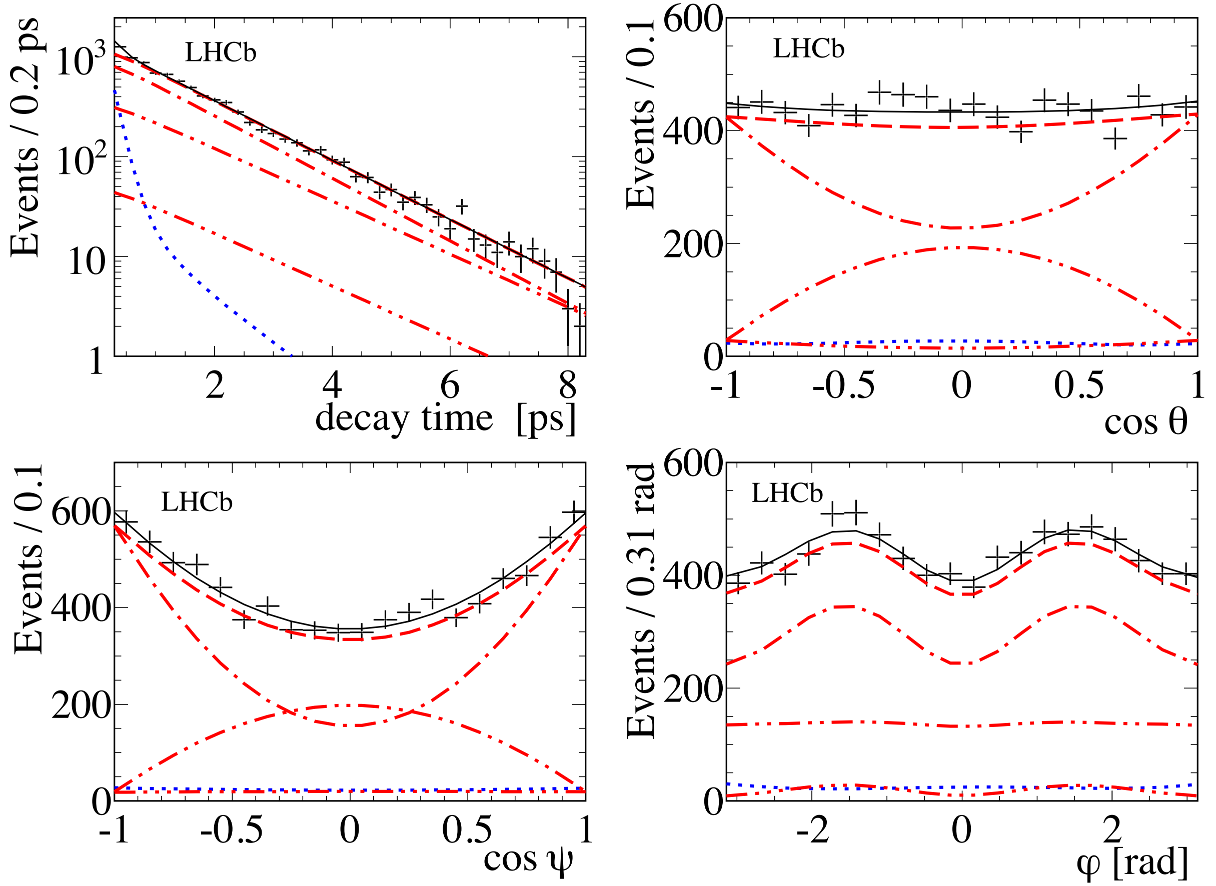
$$\Delta m_s = 17.63 \pm 0.11 \pm 0.02 \text{ ps}^{-1}$$

LHCb-CONF-2011-010

- Efficiency as a function of proper time obtained from data

$B_s \to J/\psi K^+K^-$ fit projections

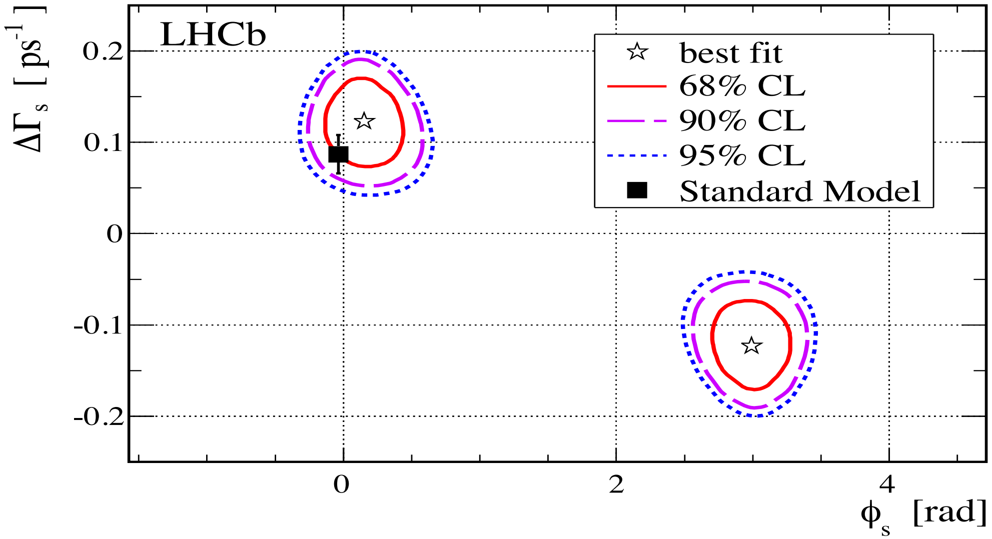
arXiv:1112.3183



Goodness-of-fit: p-value 0.68 based on point-to-point dissimilarity test [M. Williams, JINST 5 (2010) P09004]

ϕ_s results from $B_s \rightarrow J/\psi K^+K^-$

arXiv:1112.3183, submitted to PRL



- Two ambiguous solutions $\phi_s \leftrightarrow \pi\text{-}\phi_s$; $\Delta\Gamma_s \leftrightarrow -\Delta\Gamma_s$
- World's most precise measurement of ϕ_s

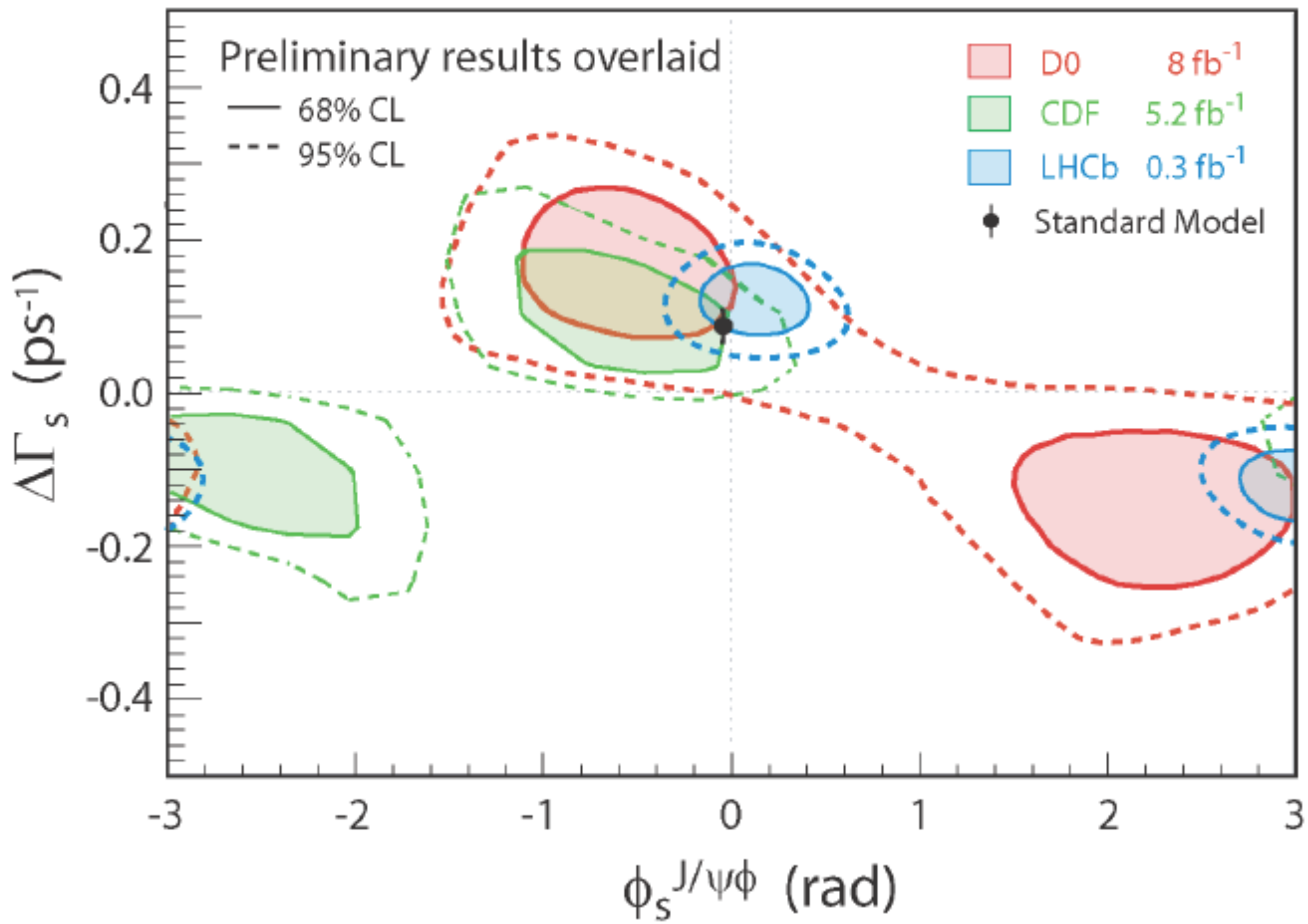
$$\phi_s = 0.13 \pm 0.18\ (\text{stat}) \pm 0.06\ (\text{syst})\ \text{rad}$$

consistent with SM prediction $\phi_s^{SM} = -0.036 \pm 0.002$ rad

- 4σ evidence for $\Delta\Gamma_s \neq 0$

$$\Delta\Gamma_s = 0.123 \pm 0.029\ (\text{stat}) \pm 0.011\ (\text{syst})\ \text{ps}^{-1}$$

“artist’s view”



http://lhcb-public.web.cern.ch/lhcb-public/

Method to resolve the ambiguity

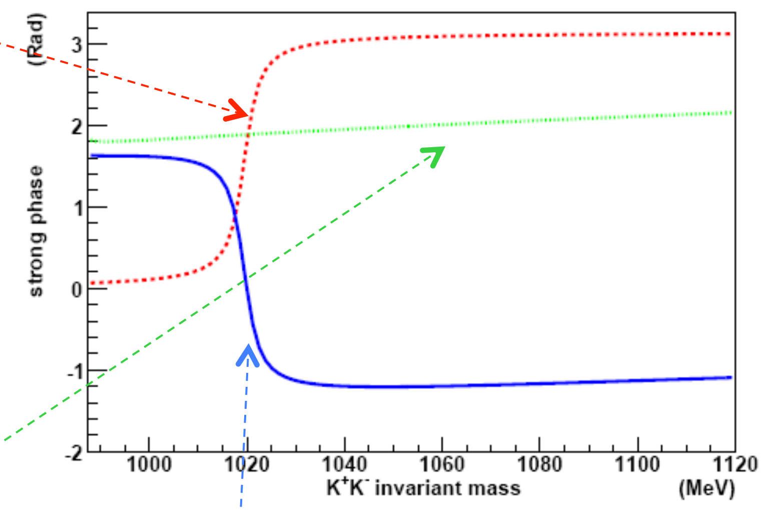
[Y. Xie et al., JHEP 0909:074, 2009]

Similar to Babar measurement of sign of cos(2β), PRD 71, 032005 (2007)

K^+K^- P-wave:

Phase of Breit-Wigner amplitude increases rapidly across φ(1020) mass region

$$BW(m_{KK}) = \frac{F_r F_D}{m_\phi^2 - m_{KK}^2 - i m_\phi \Gamma(m_{KK})}$$



K^+K^- S-wave:

Phase of Flatté amplitude for $f_0(980)$ relatively flat (similar for non-resonance)

Phase difference between S- and P-wave amplitudes

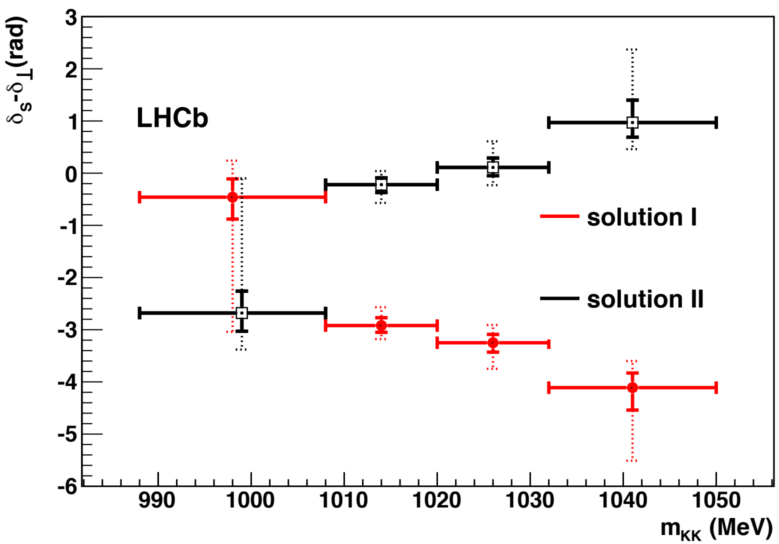
Decreases rapidly across φ(1020) mass region

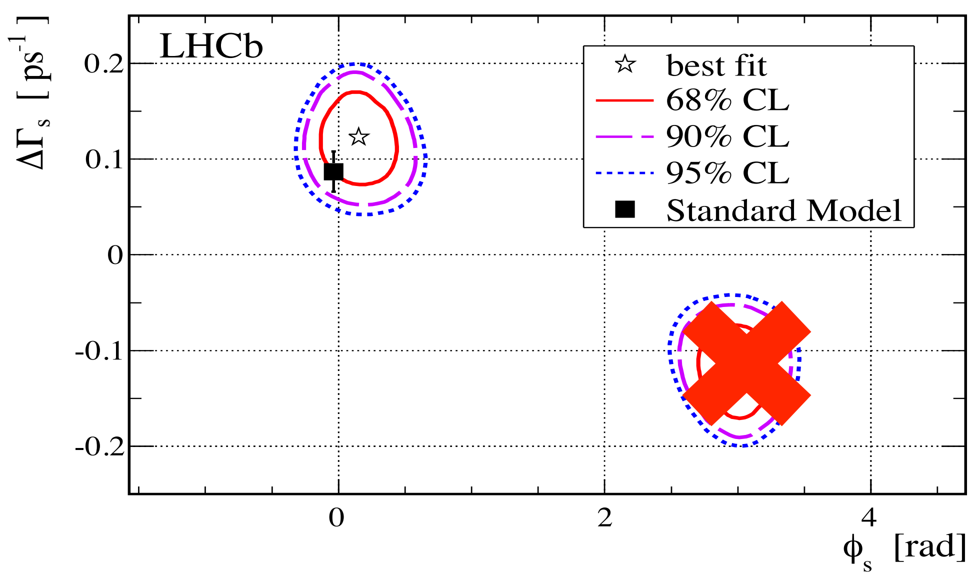
Resolution method: choose the solution with decreasing trend of δ_S-δ_P vs m_{KK} in the φ(1020) mass region

Ambiguity resolution

Paper in preparation, to be submitted to PRL

- Winner solution is consistent with the SM predictions
- The other solution is excluded at 4.5σ CL

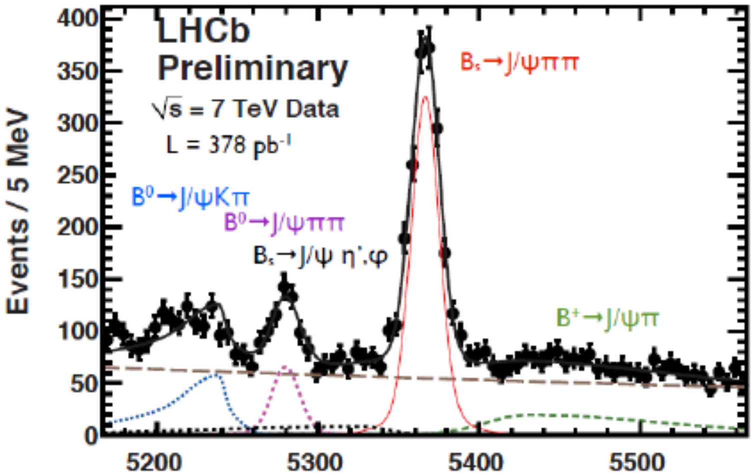


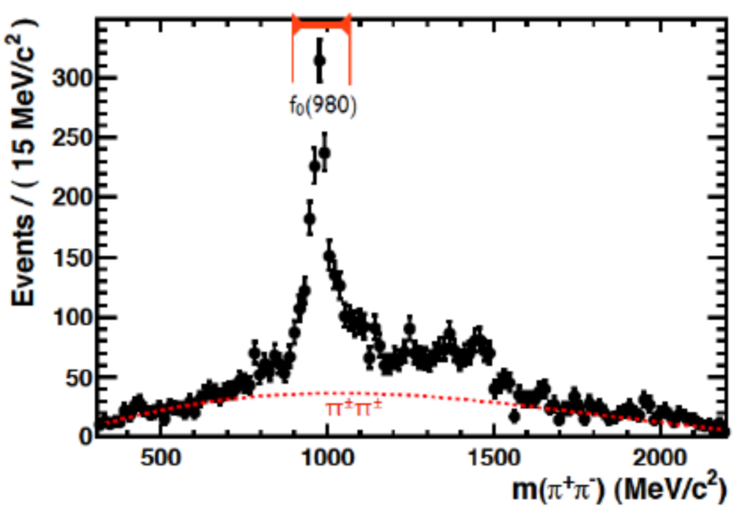


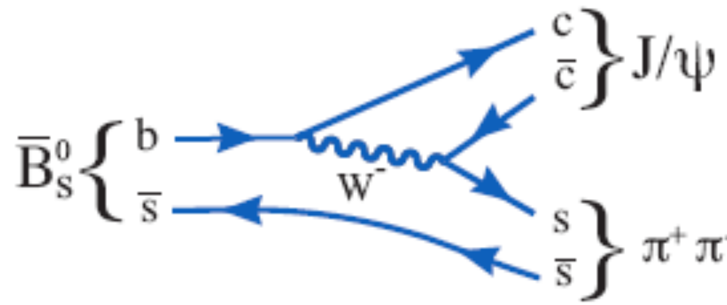
$B_s \rightarrow J/\psi f_0$

arXiv:1112.3056 , submitted to PLB

LHCB-CONF-2011-051







CP odd final state alone cannot determine Γ_s and $\Delta\Gamma_s$

Using $\Delta\Gamma_s$ and Γ_s from $B_s \rightarrow J/\psi\phi$

$\phi_s = -0.44 \pm 0.44 \pm 0.02$ rad

Combined fit of $B_s \rightarrow J/\psi f_0$ and $B_s \rightarrow J/\psi\phi$

$\phi_s = 0.07 \pm 0.17 \pm 0.06$ rad

Prospects for ϕ_s

- Improve statistical error $\sigma(\phi_s)$ from $B_s \rightarrow J/\psi\phi$
  - Expect 2 fb^{-1} by end of 2012 → $\sigma(\phi_s) \sim 0.07$ from simple scaling
  - Using same side kaon tagging will give further improvement
- Reduce systematic error significantly
  - Use better method to treat background and angular acceptance
- Control theoretical uncertainties
  - Main issue: effect of penguin contribution on ϕ_s needs to be controlled to match the experimental accuracy of ϕ_s with 2 fb^{-1} or more
  - Expect using 2011+2012 data sample to measure $A_{CP}(B_s \rightarrow J/\psi K^*)$ and exploit the U-spin relation between $B_s \rightarrow J/\psi K^*$ and $B_s \rightarrow J/\psi\phi$

    [S. Faller *et al.*, PRD 79:014005, 2009]
- Exploit more channels: $B_s \rightarrow J/\psi\eta$, $J/\psi\eta'$ and D_sD_s
- Measure A_{SL} which probes the same physics

Search for new physics in charm sector

$$\Delta A_{CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$$

CP violation in Charm

SM charm physics is almost CP conserving,
CPV up to O(10^{-3}) plausible, being revisited!

Unitary triangle for charm

$$V_{ud}V_{cd}^{*} + V_{us}V_{cs}^{*} + V_{ub}V_{cb}^{*} = 0$$
$$\sim \lambda \qquad \sim \lambda \qquad \sim \lambda^5$$

With b-quark contribution neglected: only 2 generations contribute
→ **real 2x2 Cabibbo matrix**

CP violation in charm not observed

New Physics can enhance CP-violating observables up to O(%)

CP asymmetries in $D \to h^+h^-$

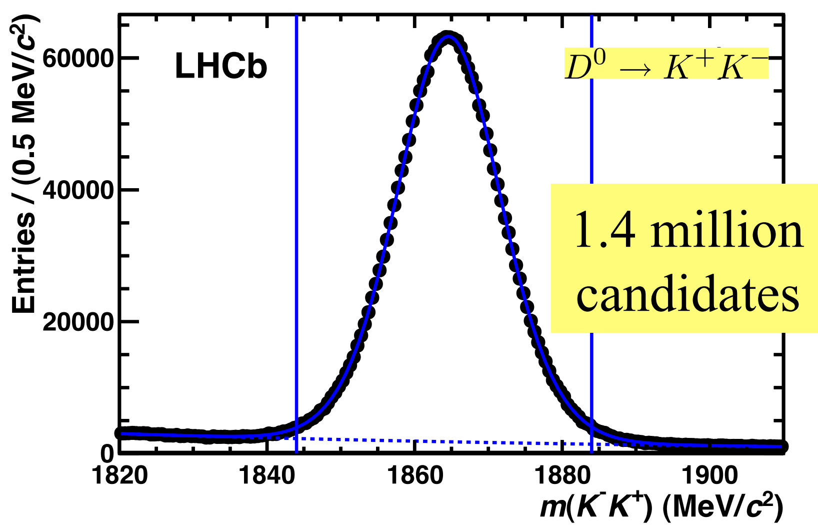
$$A_{\text{raw}}(f) \equiv \frac{N(D^{*+} \to D^0(f)\pi^+) - N(D^{*-} \to \overline{D}^0(\bar{f})\pi^-)}{N(D^{*+} \to D^0(f)\pi^+) + N(D^{*-} \to \overline{D}^0(\bar{f})\pi^-)}$$

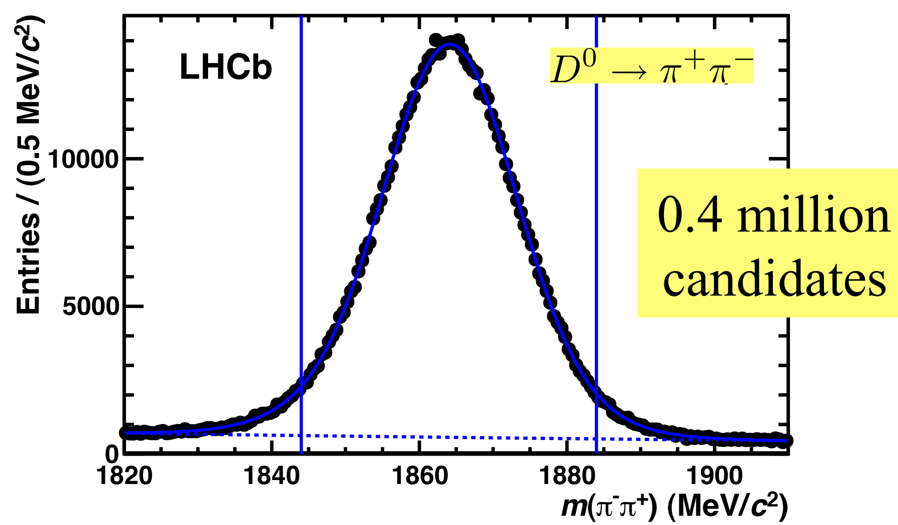
D flavour tagged with slow pion from D^*

$$\underset{}{A_{\text{RAW}}(f)^*} = \underbrace{A_{CP}(f)}_{\text{Physics}} + \underbrace{A_{\text{D}}(f) + A_{\text{D}}(\pi_{\text{s}})}_{\text{Detector}} + \underbrace{A_{\text{P}}(D^{*+})}_{\text{Production}}$$

$$\boxed{\Delta A_{CP} \equiv A_{raw}(KK) - A_{raw}(\pi\pi) = A_{CP}(KK) - A_{CP}(\pi\pi)}$$

Production and detection asymmetries cancel

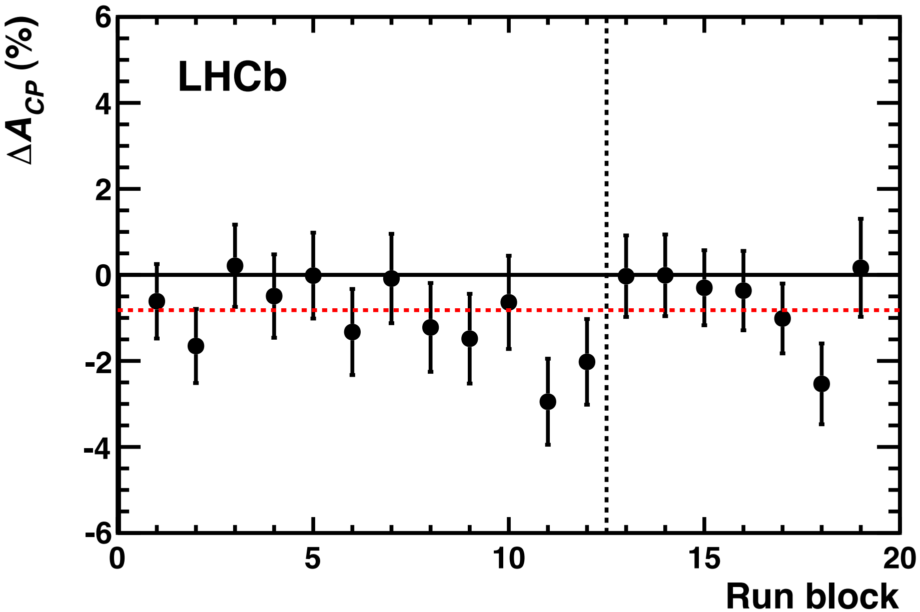




Results

arXiv:1112.0938, submitted to PRL

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



First 3.5σ evidence for CP violation in charm sector!

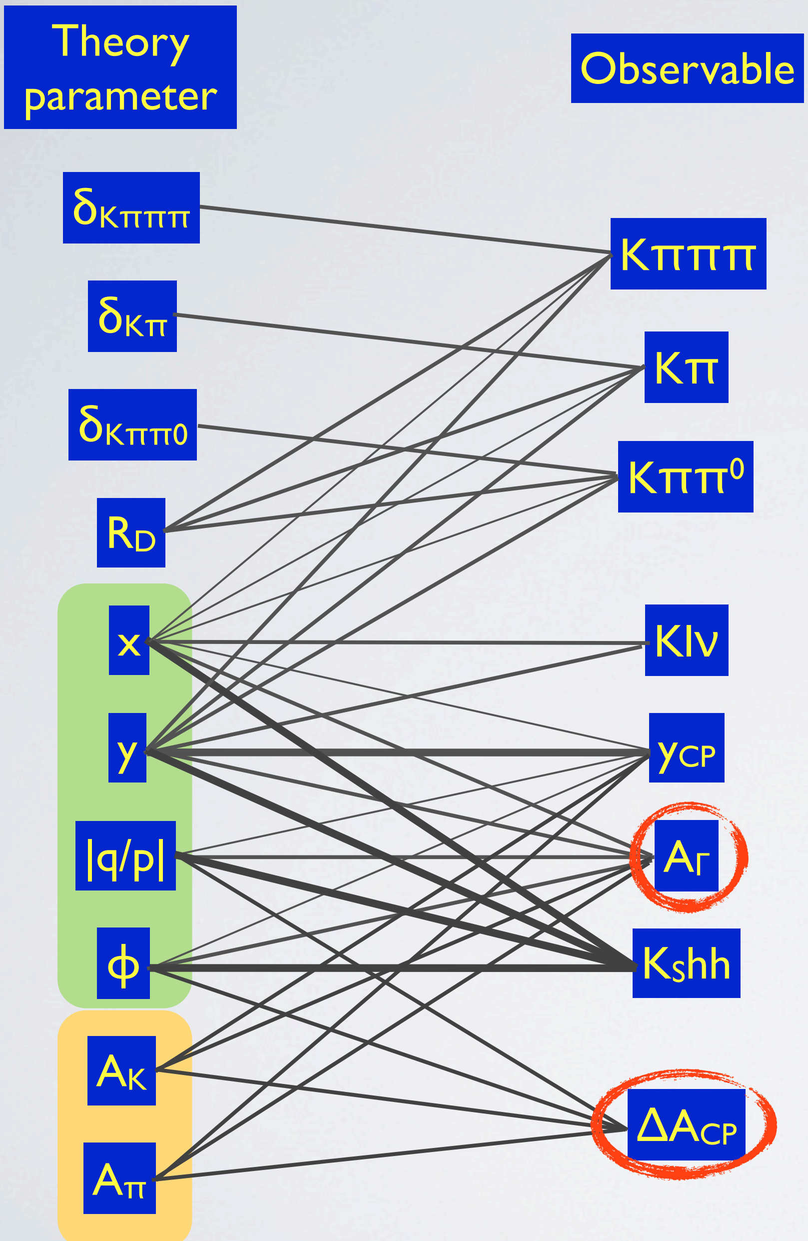
Analysis based on 60 % of collected data.

Update on full dataset for Winter Conferences

Is this sign of new physics? Need further information.

from theorists: better understanding of SM predictions

from experiments: measurements of more charm observables

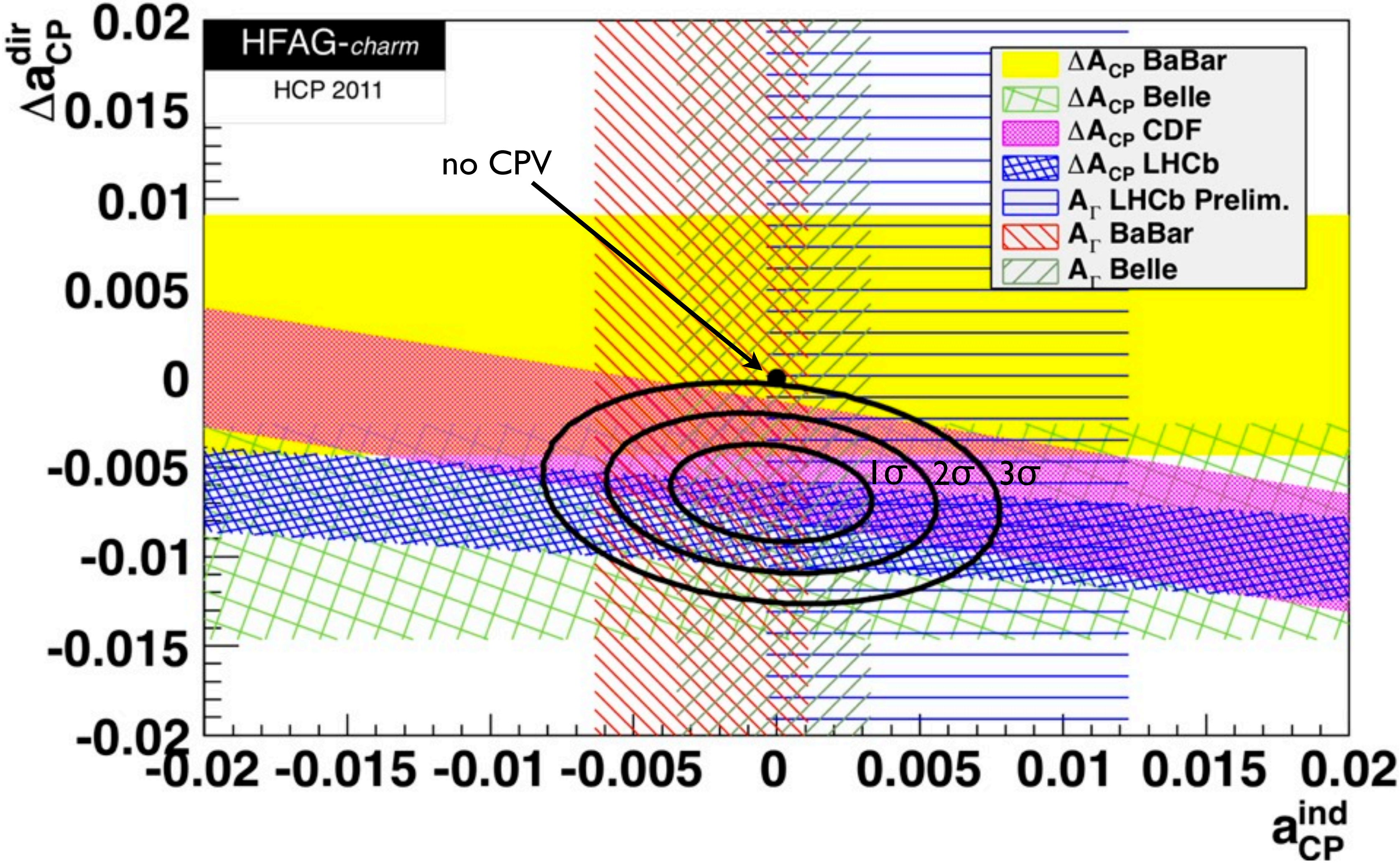


Bottom line:

A_Γ & ΔA_{CP} are discovery modes

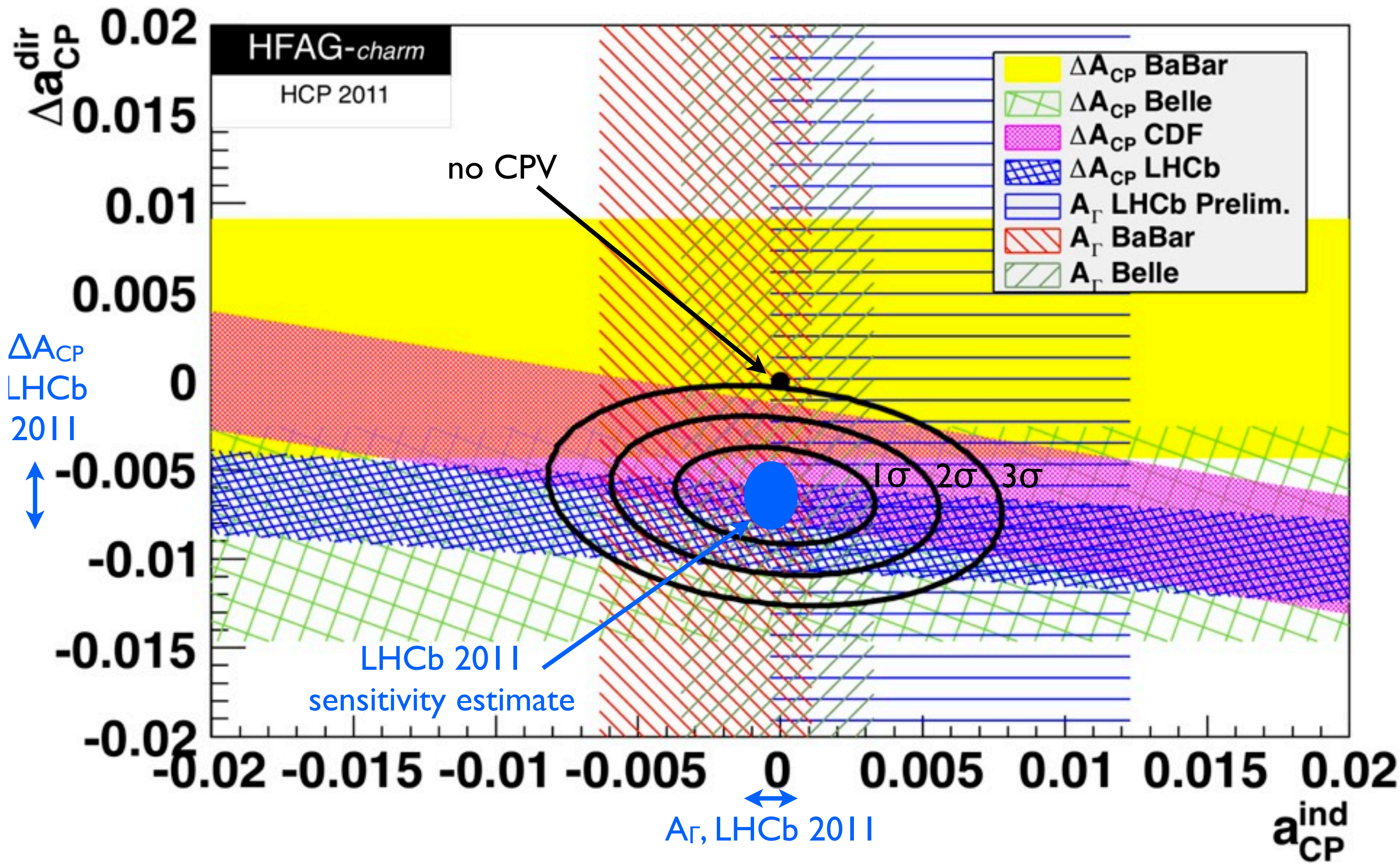
For theoretical interpretation need to measure all together

World average



Consistency with NO CP violation: 0.15%

Prospect with 2011 data



Search for new physics in $b \to s$ loop decay processes

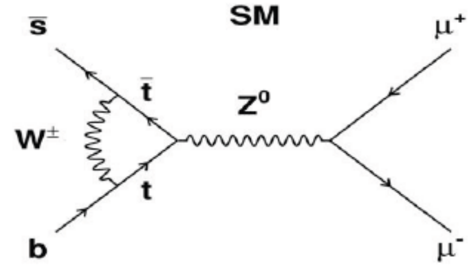
$B_s \to \mu^+\mu^-$	EW or Higgs penguin
$B^0 \to K^*\mu^+\mu^-$	EW penguin
$B_s \to \phi\phi$	hadronic penguin
$B_s \to \phi\gamma$	radiative penguin

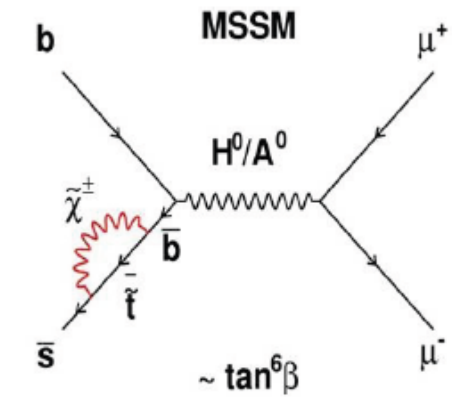
$B_s \to \mu^+\mu^-$

- $B_s \to \mu^+\mu^-$ is very rare but well predicted in the SM
  - FCNC loop suppression
  - Helicity suppression

  $BR_{SM}(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2)\times 10^{-9}$

  [E. Gamiz *et al.*, PRD 80:014503, 2009]





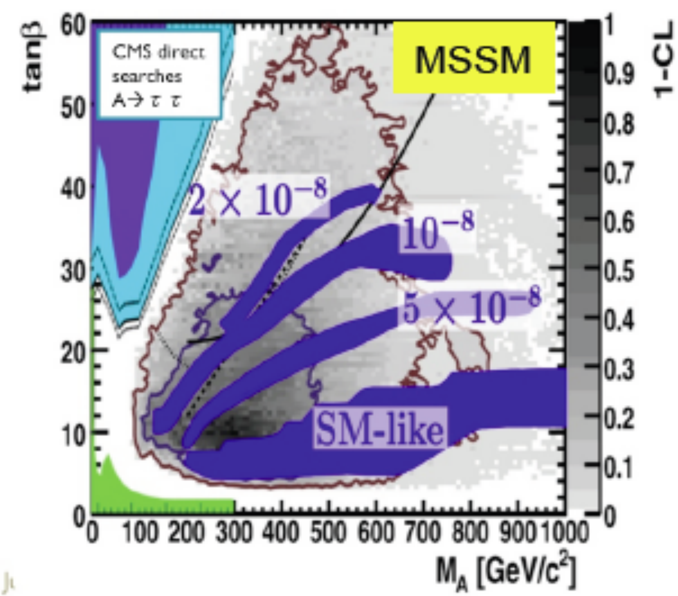
- Sensitive to new physics in scalar/pseudo-scalar sector

  e.g. MSSM with high $\tan\beta$

$$BR\left(B_s \to \mu^+\mu^-\right) \propto \frac{\tan^6\beta}{M_A^4}$$

- Measurement or limit will become strong constraint on NP, e.g. on $(\tan\beta, M_A)$ plane

  [O. Buchmueller *et al.*, Eur.Phys.J.C64:391, 2009]



$B_s \to \mu^+\mu^-$ status

$B_s \to \mu^+\mu^-$
Spring 2011

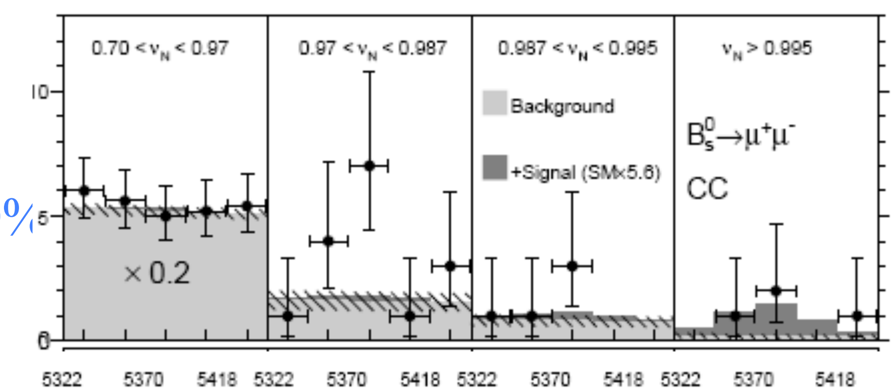
Experiment	Data	Upper Limit (95% C.L.)
CDF	3.7 fb^{-1}	$< 4.3 \times 10^{-8}$
D0	6.1 fb^{-1}	$< 5.1 \times 10^{-8}$
LHCb	36 pb^{-1}	$< 5.6 \times 10^{-8}$
CMS	1.14 fb^{-1}	$< 1.9 \times 10^{-8}$

(4.0×10^{-8})

- CDF recently reported a hint of signal with 7 fb^{-1}
  - p-value background only: 0.3%
  - p-value background + SM BR: 1.9%
  - p-value background + 5.6×SM BR: 50%

$$B\left(B_s \to \mu^+\mu^-\right) = 1.8^{+1.0}_{-0.9} \times 10^{-8}$$

[CDF, arXiv:1107.2304]



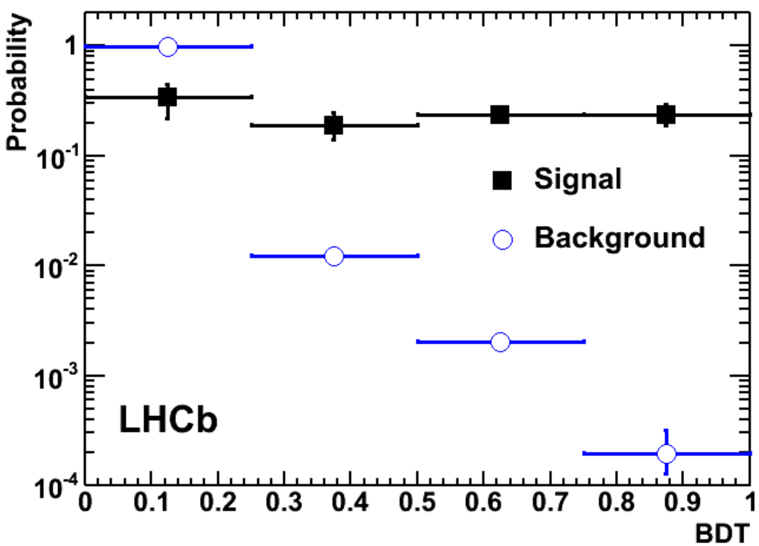
LHCb analysis strategy

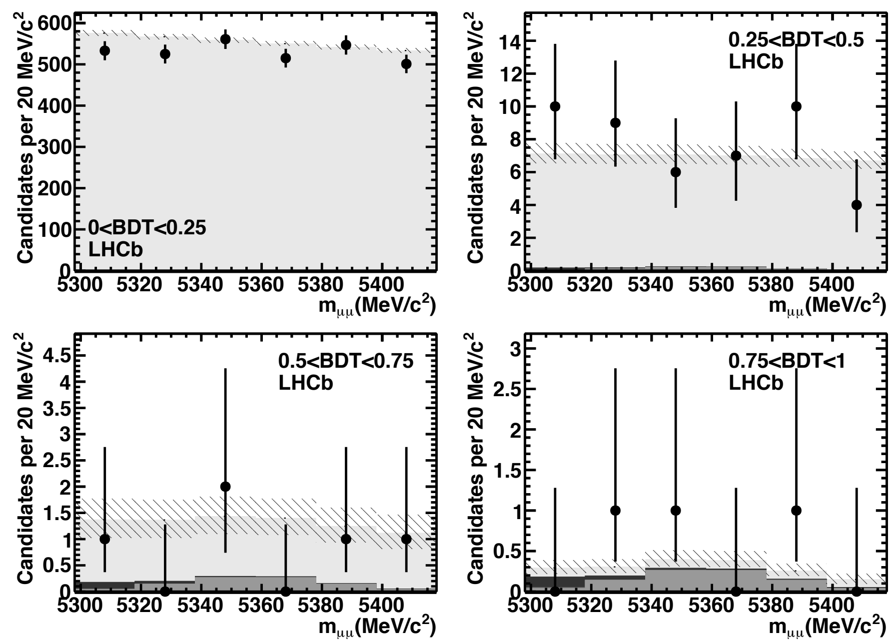
- Discriminating signal and background using 2 variables
  - invariant mass of $\mu^+\mu^-$: parameterization from data
  - output of a Boosted Decision Tree (BDT): built on 9 kinematical and topological variables, trained on MC, shape of BDT output obtained on $B \rightarrow hh$ (signal) and B mass sideband (background)
- Normalization
  - using $B^+ \rightarrow J/\psi K^+$, $B_s \rightarrow J/\psi\phi$ and $B_d \rightarrow K\pi$
  - LHCb $f_s/f_d = 0.267^{+0.021}{}_{-0.20}$ LHCb-CONF-2011-028, arXiv: 1106.4435
- Assessing BR and setting limit
  - For a given BR, compare observed and expected numbers of events in 6×4 bins of $m(\mu^+\mu^-)$ and BDT output for signal+bkg and bkg hypotheses
  - Calculate CLs [A. Read, J. Phys. G 28 (2002) 2693]
  - Exclude the BR at 1-α C.L. if CLs < α
  - The highest BR which is not excluded is the CLs limit at 1-α C.L.

BDT and mass distributions

4 bins in BDT output
120 MeV B mass search window divided into 6 bins

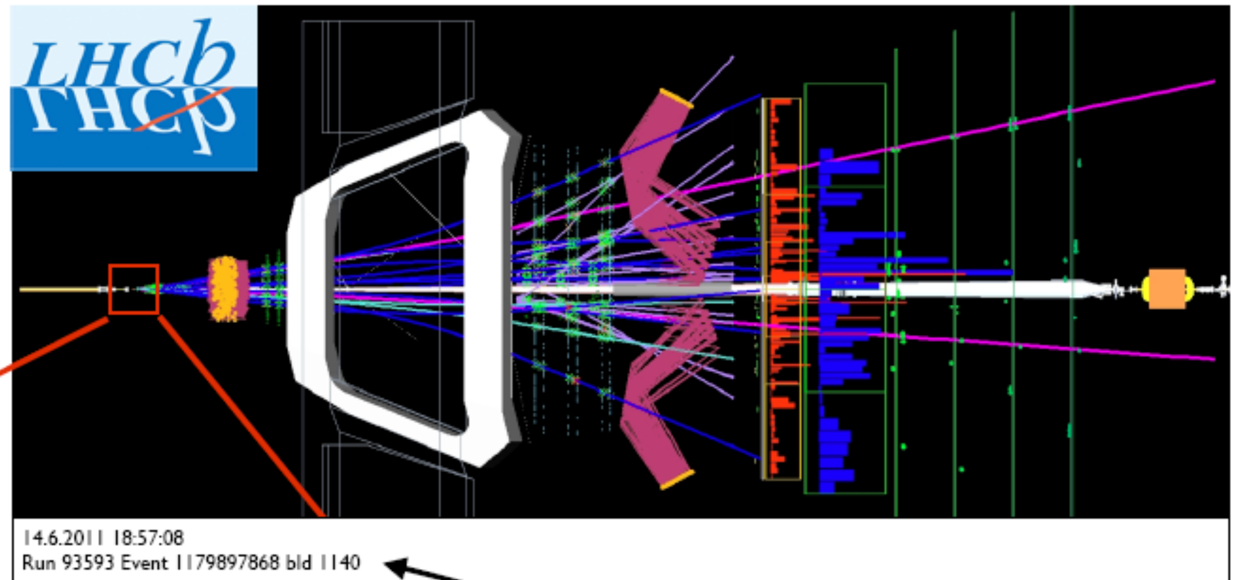
arXiv:1112.3056, submitted to PLB

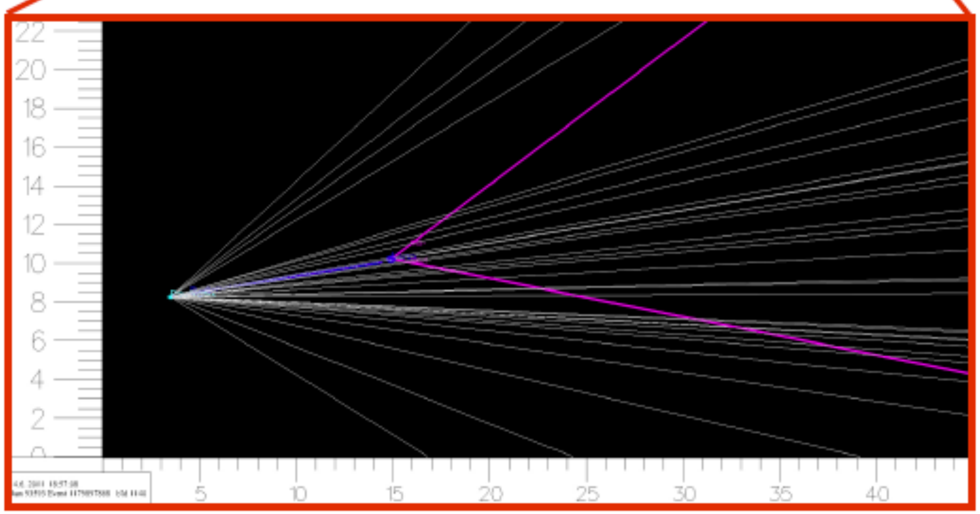


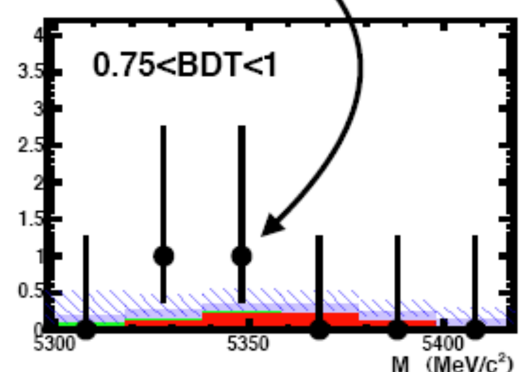


LHCb: $B_s \rightarrow \mu^+\mu^-$?

$m_{\mu\mu} = 5.357$ GeV
BDT = 0.90
Decay length = 11.5 mm
Tracks shown for $p_T > 0.5$ GeV

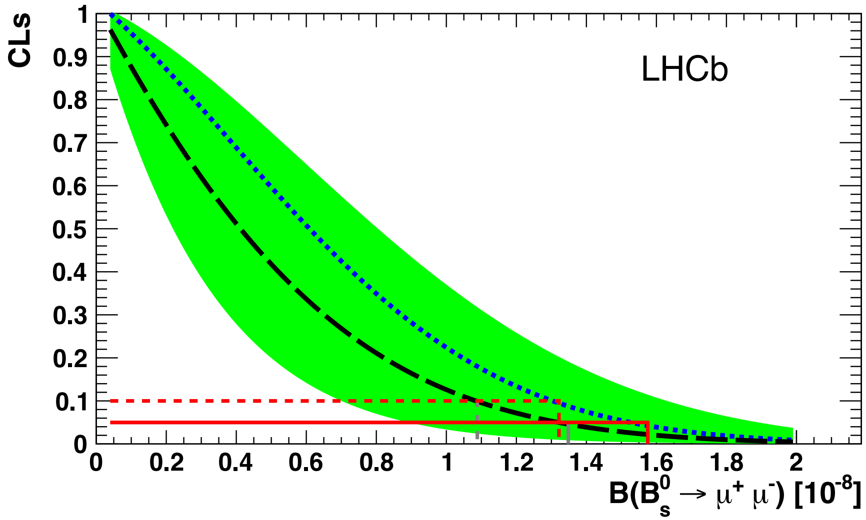






$B_s \to \mu^+\mu^-$: Results and future outlook

World's best limit: LHC*b* with $0.37\,\mathrm{fb}^{-1}$



$BR(B_s \to \mu^+\mu^-) < 1.6 \times 10^{-8}$ at 95% CL

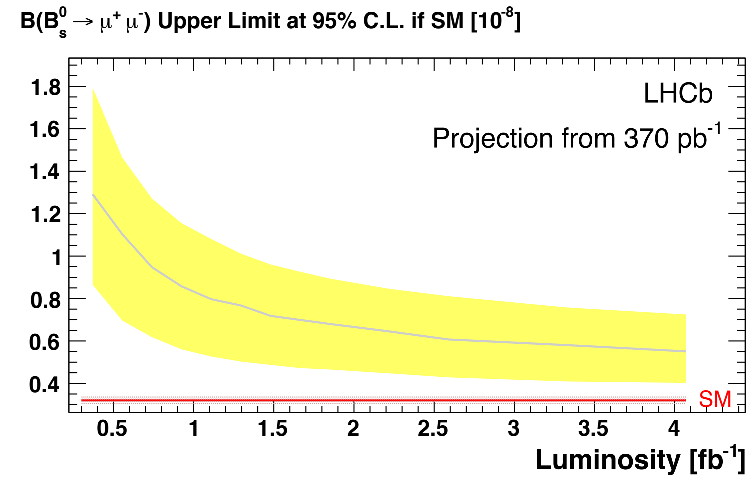
$BR(B_d \to \mu^+\mu^-) < 3.6 \times 10^{-9}$ at 95% CL

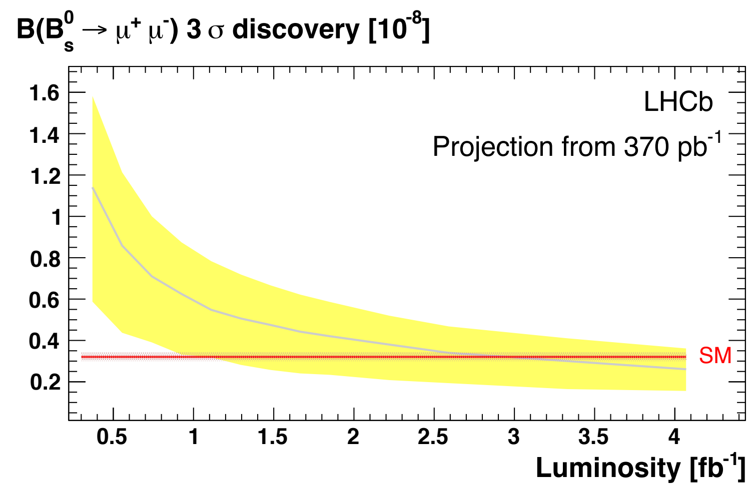
Submitted to PLB [arXiv:1112.1600]

Analysis being updated with the $1.02\,\mathrm{fb}^{-1}$ LHC*b* data on tape

$\Rightarrow$ Good chance of a 3σ discovery!

BR exclusion and discovery projections





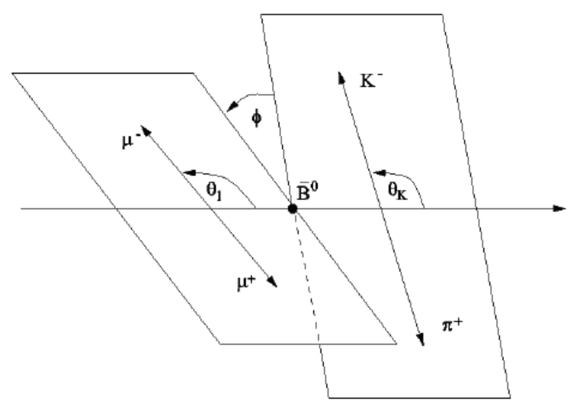
$B^0 \to K^*\mu^+\mu^-$

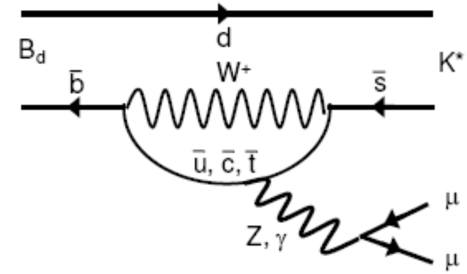
- FCNC b→s decays
- Sensitive to NP in loops: MSSM, LHT, …
- Described by three angles (θ_l, θ_K, ϕ) and $\mu^+\mu$ invariant mass q^2
- Many observables, particularly lepton forward-backward asymmetry A_{FB} vs q^2

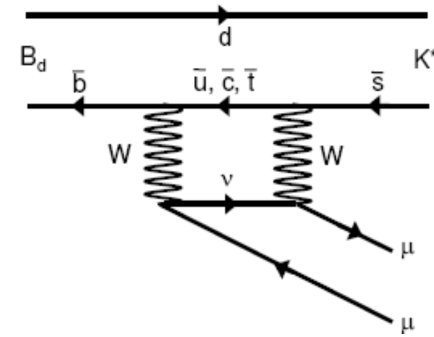
$$A_{\rm FB} = \left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_l \frac{d^2(\Gamma-\bar{\Gamma})}{dq^2\, d\cos\theta_l} \Bigg/ \frac{d(\Gamma+\bar{\Gamma})}{dq^2} = \frac{3}{8}(2\, S_6^s + S_6^c)$$

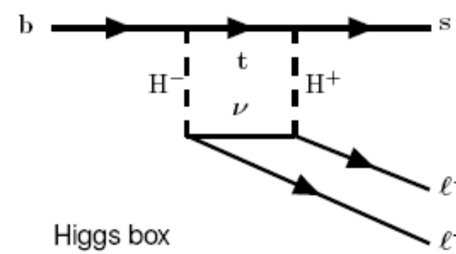
Observable	mostly affected by
S_1^s, S_1^c, S_2^s, S_2^c	C_7, C_7', C_9, C_9', C_{10}, C_{10}'
S_3	C_7', C_9', C_{10}'
S_4	C_7, C_7', C_{10}, C_{10}'
S_5	C_7, C_7', C_9, C_{10}'
S_6^s	C_7, C_9
A_7	C_7, C_7', C_{10}, C_{10}'
A_8	C_7, C_7', C_9, C_9', C_{10}'
A_9	C_7', C_9', C_{10}'
S_6^c	$C_S - C_S'$

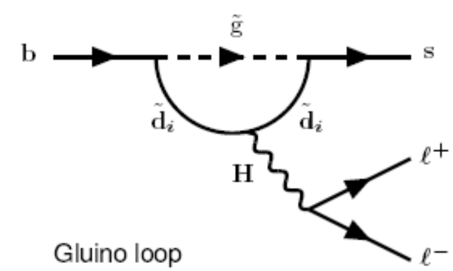
JHEP 0901:019,2009





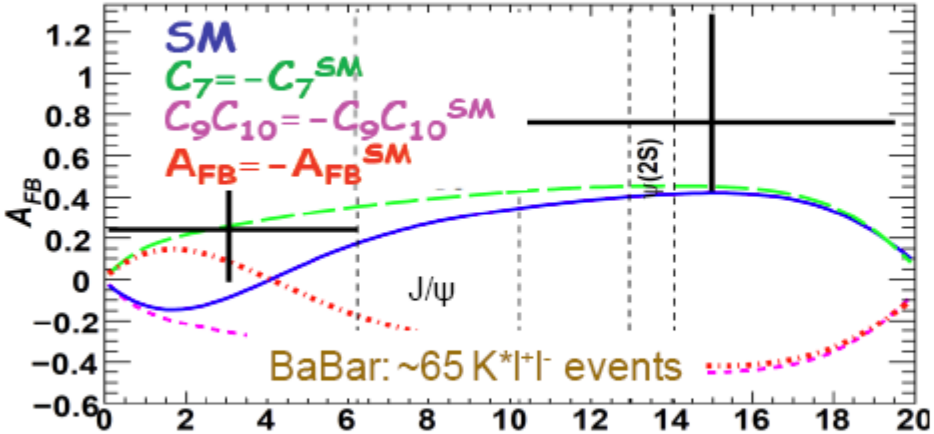




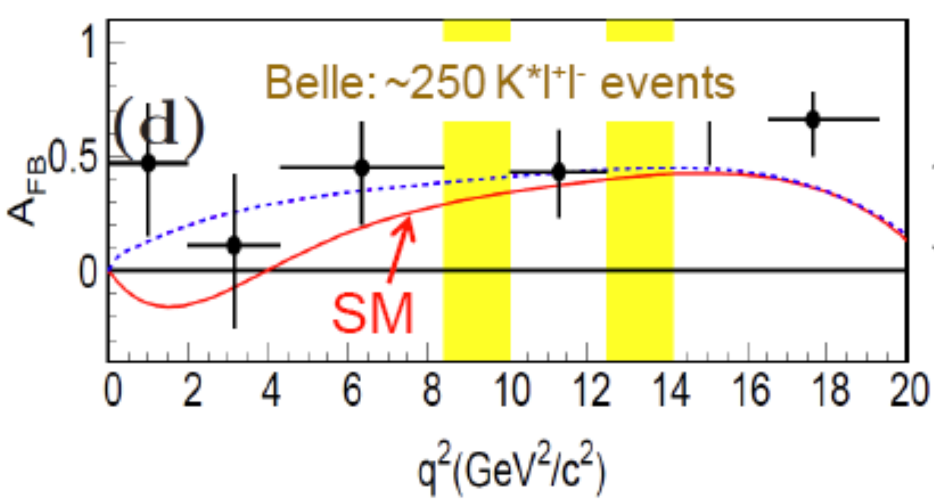


B factories and CDF results

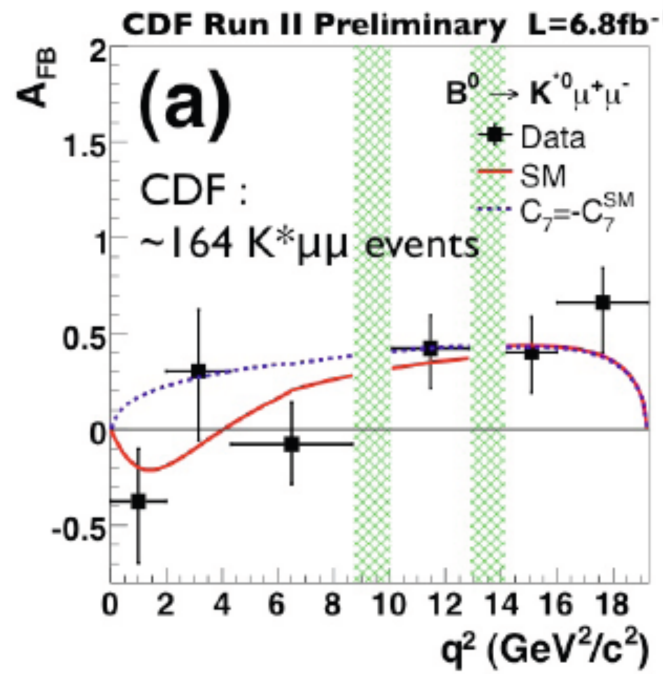
Intriguing behaviour with poor precision.



PRD 79 (2009) 031102



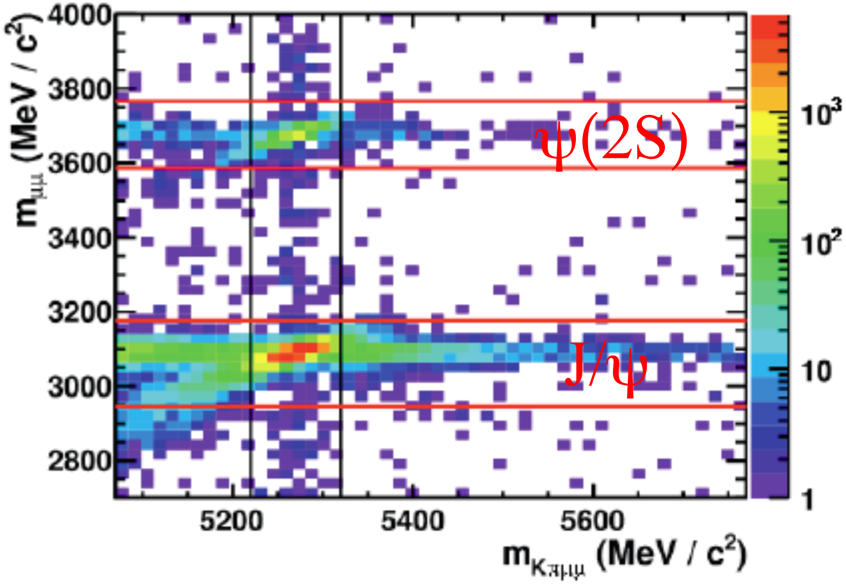
PRL 103 (2009) 171801

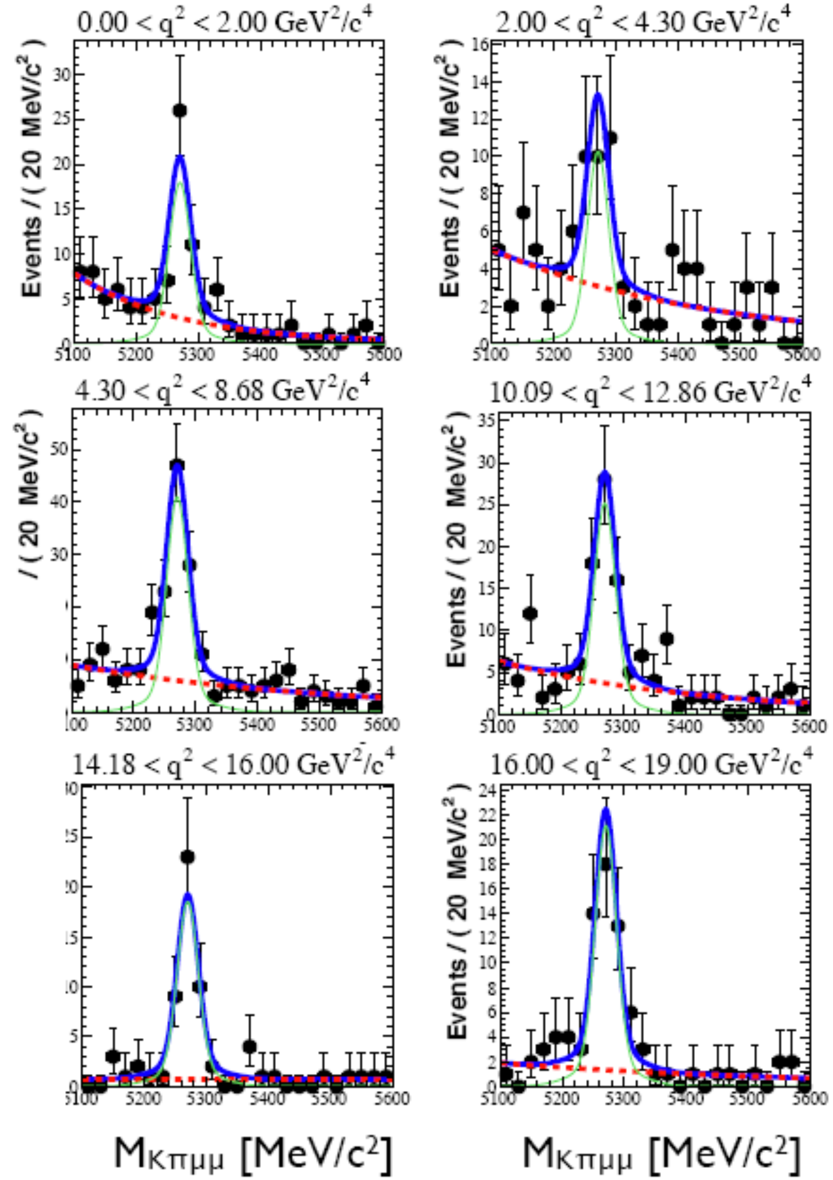


arxiv:1108.0695

LHCb analysis

LHCb-CONF-2011-038





- Select 302±20 signals in 309 pb^{-1} using a Boosted Decision Tree
- Veto J/ψ and psi(2S)
- Perform angular fit in six bins of q^2 to measure
  - A_{FB}, longitudinal fraction F_L

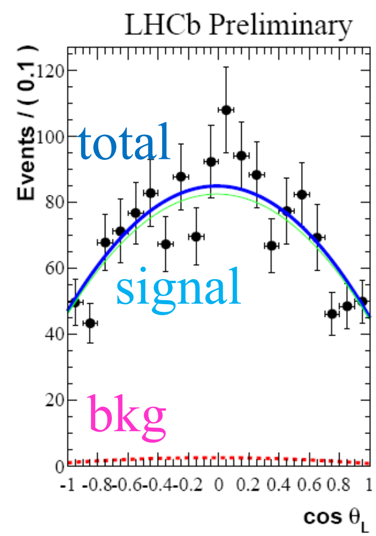
Angular fit

- Perform simultaneous fit of θ_l and θ_K

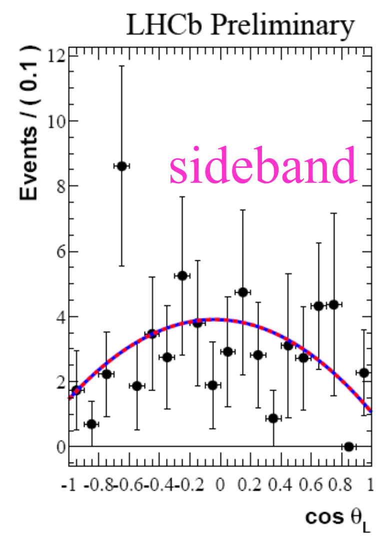
$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta_K\, dq^2} = \frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta_\ell\, dq^2} = \frac{3}{4}F_L(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$

- Angular efficiency from full MC simulation
- Fit procedure validated on $B^0 \to J/\psi K^*$ data and full MC
- Background angular parameterization obtained from B mass sidebands

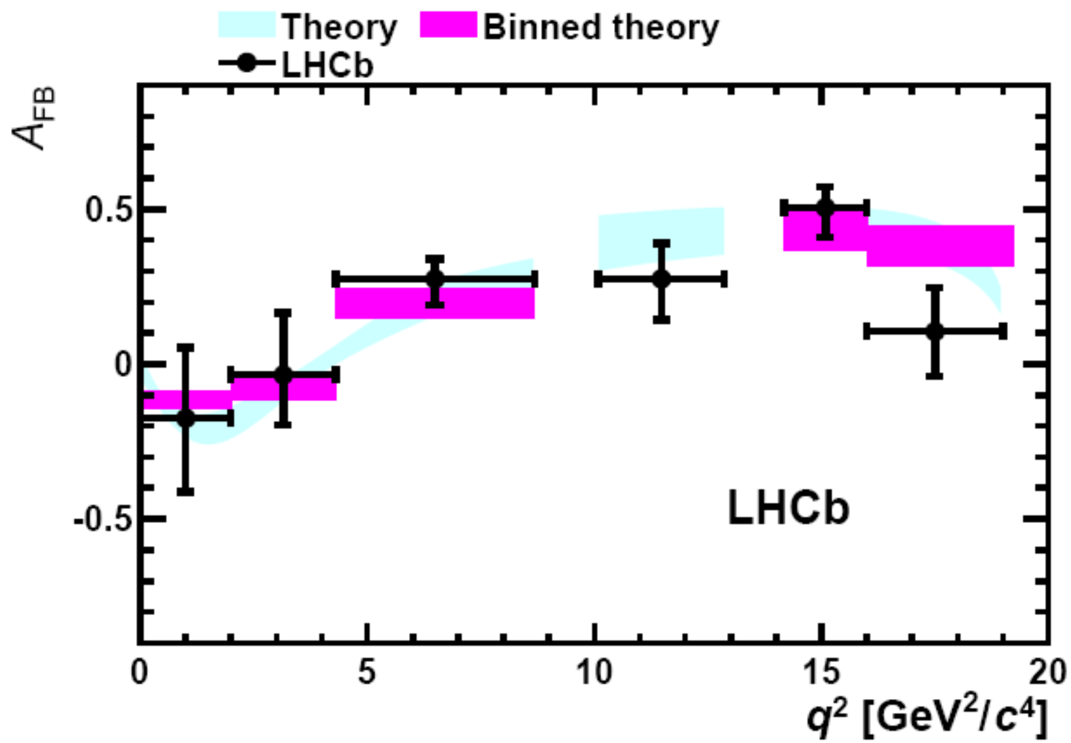


B mass signal window



B mass sideband

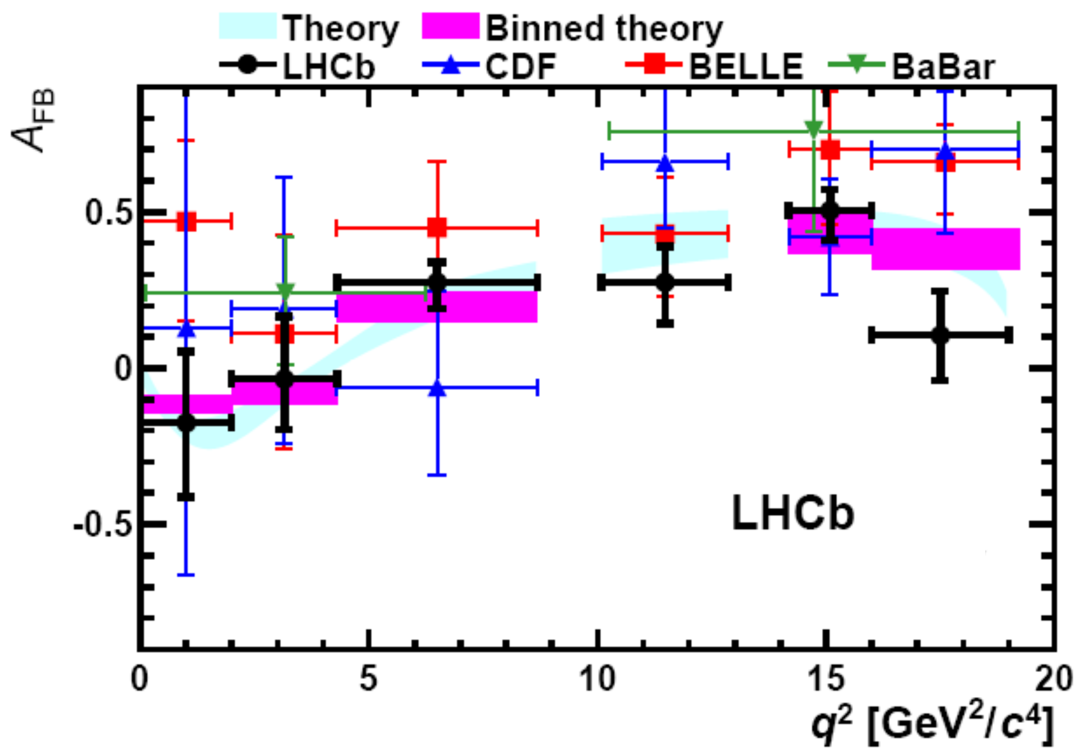
LHCb results: A_{FB}



arXiv:1112.3515, submitted to PRL

Good agreement with SM predictions

LHCb results: A_{FB}

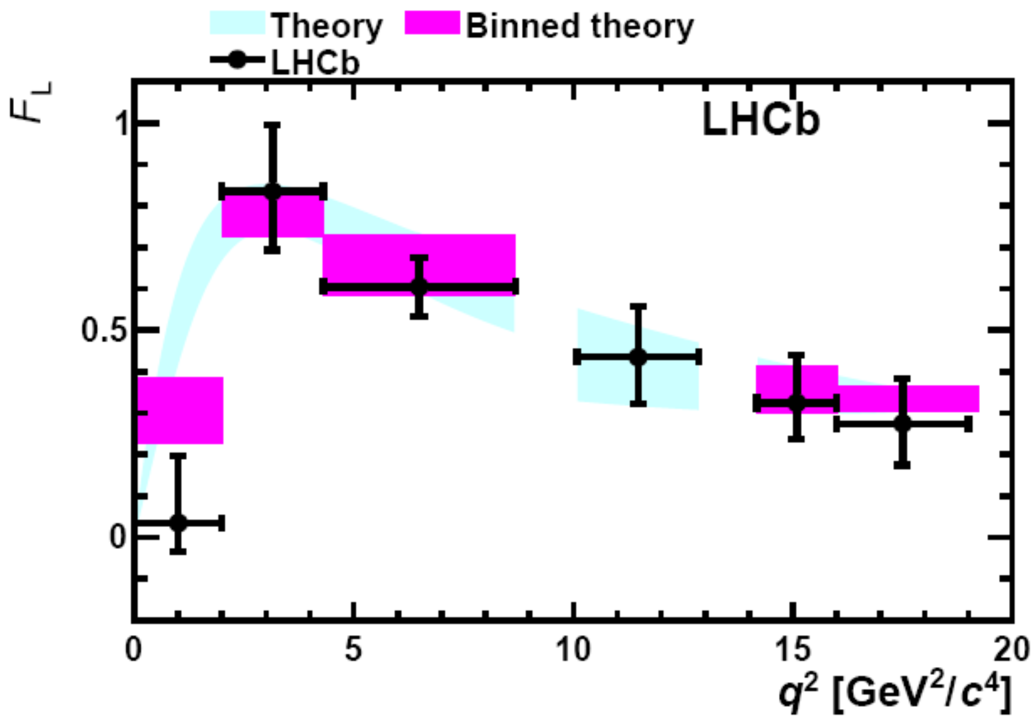


LHCb [arXiv:1112.3515, submitted to PRL]

BaBar [PRD **79** (2009)], Belle [PRL **103** (2009)], CDF [PRL **106** (2011)]

Positive A_{FB} in low q^2 region by previous experiments not confirmed

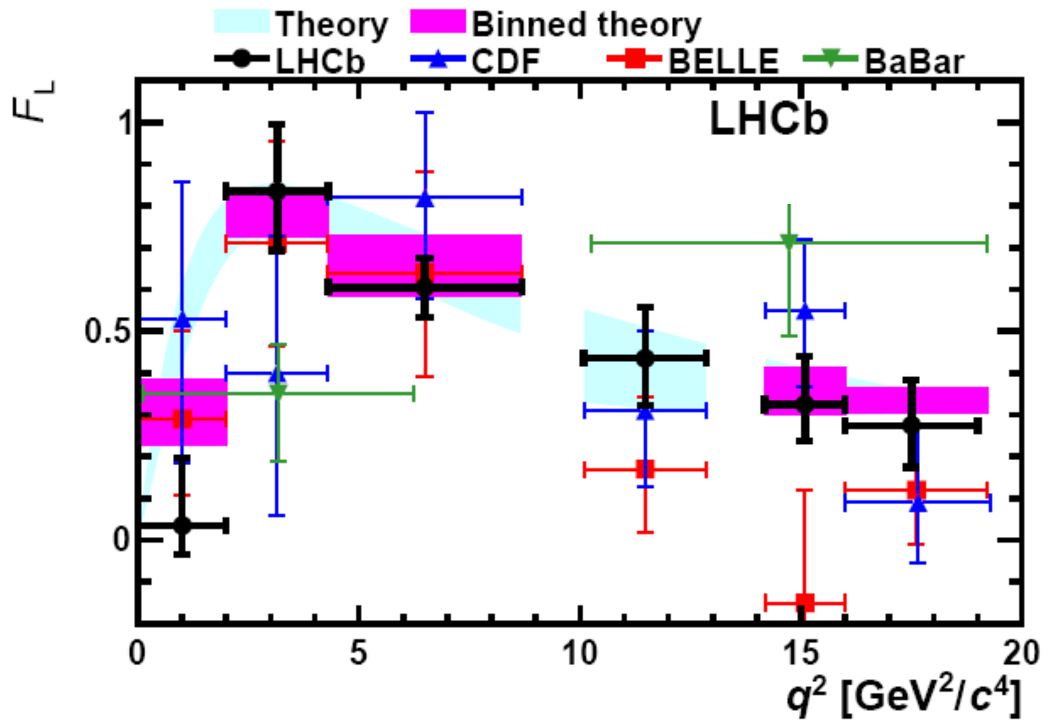
LHCb results: F_L



arXiv:1112.3515, submitted to PRL

Good agreement with SM predictions

LHCb results: F_L

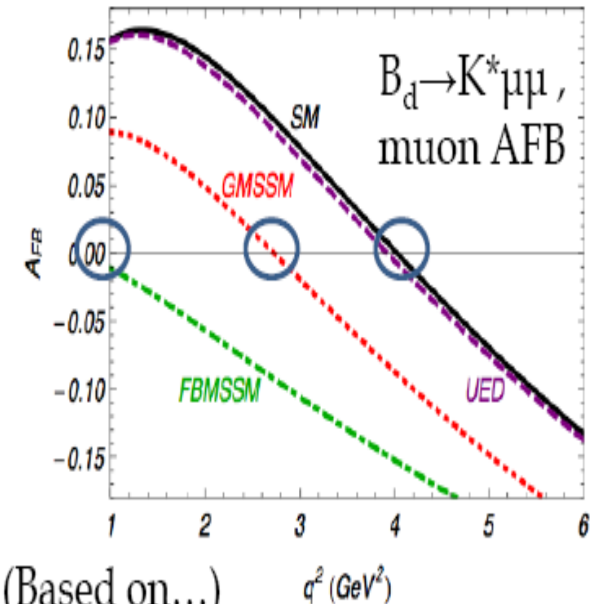


LHCb [arXiv:1112.3515, submitted to PRL]

BaBar [PRD **79** (2009)], Belle [PRL **103** (2009)], CDF [PRL **106** (2011)]

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

- Data in good agreement with SM predictions at current precision
- Constraints on Wilson Coefficients will be studied
- Measure zero-crossing point, well predicted in SM, sensitive to NP
- Interesting to study other observables in full angular analysis
  - CP asymmetries
  - $A_T^{(2)}$,and $A_T^{(im)}$, sensitive to right handed currents (C_7')

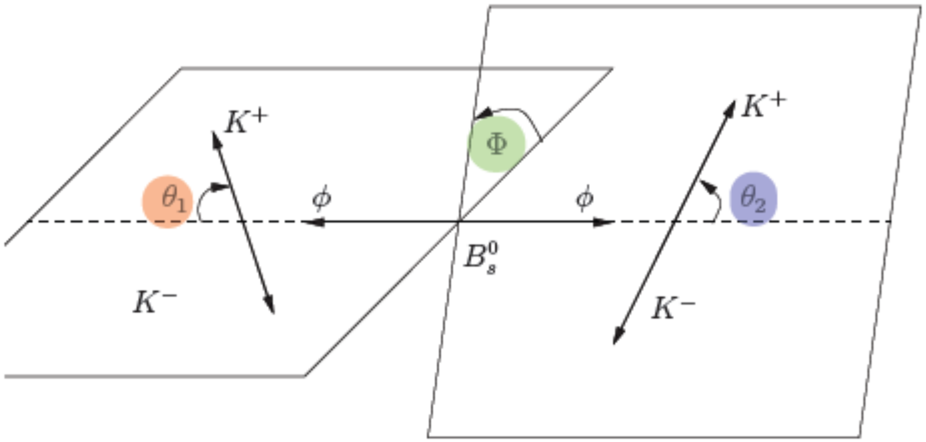


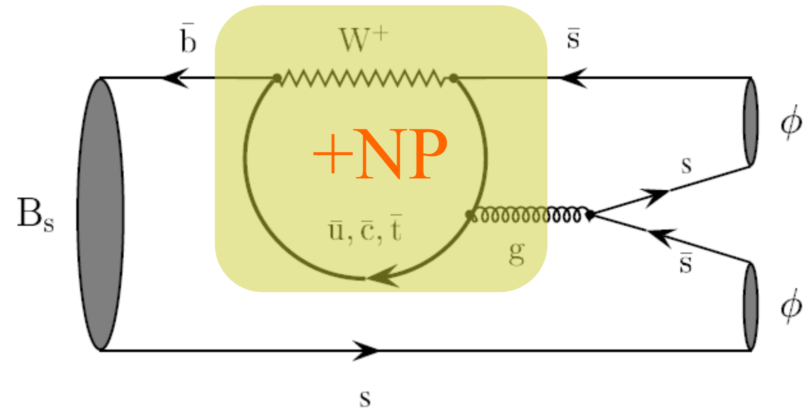
(Based on...)

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

$$\frac{d^2\Gamma(B \to K^*\ell^+\ell^-)}{dq^2 d\phi} = \frac{1}{2\pi}\frac{d\Gamma}{dq^2}\left[1 + \frac{1}{2}F_T(q^2)\left(A_T^{(2)}(q^2)\cos 2\phi + A_T^{(\mathrm{im})}(q^2)\sin 2\phi\right)\right]$$

NP in $B_s \to \phi\phi$





Time-integrated
Triple product asymmetry

$$A_U = \frac{N(U>0)-N(U<0)}{N(U>0)-N(U<0)}, A_V = \frac{N(V>0)-N(V<0)}{N(V>0)-N(V<0)}$$

$$\frac{d^4\Gamma}{dt d\Omega} \propto |A_0(t)|^2 \cdot f_1(\Omega) + |A_{\parallel}(t)|^2 \cdot f_2(\Omega) + |A_{\perp}(t)|^2 \cdot f_3(\Omega) + \boxed{\Im(A_{\parallel}^*(t) A_{\perp}(t))} \cdot f_4(\Omega) + \Re(A_0^*(t) A_{\parallel}(t)) \cdot f_5(\Omega) + \boxed{\Im(A_0^*(t) A_{\perp}(t))} \cdot f_6(\Omega),$$

$U = \sin 2\Phi$

$V = \sin(\pm\Phi)$ sign from $f_6(\Omega)$

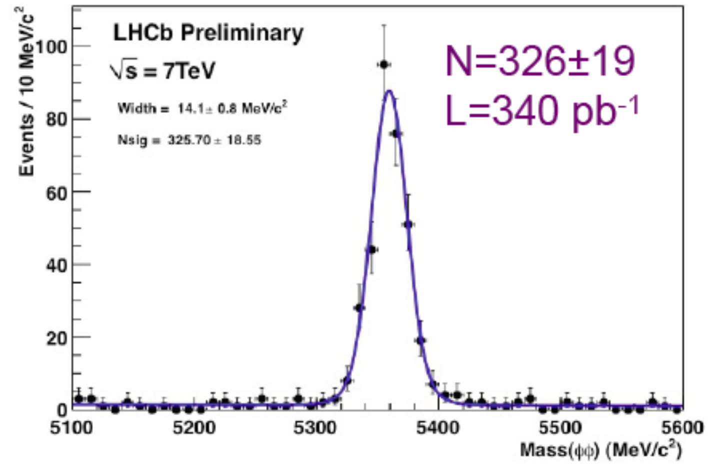
SM prediction $A_{U/V} = 0$. Non-zero measurement means weak phase difference between CP even and odd eigenstates, clear sign of NP

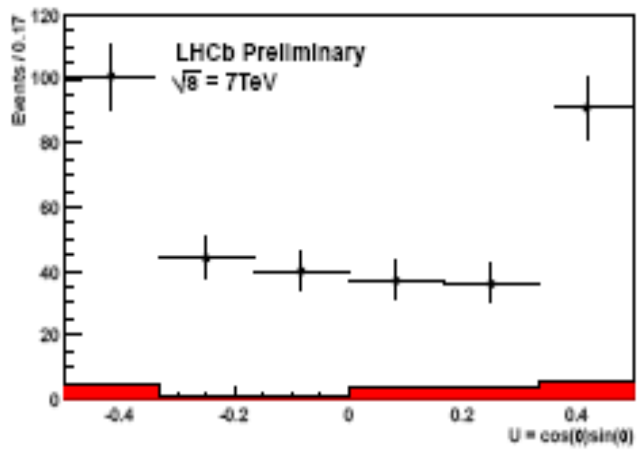
[M. Gronau and J. L. Rosner, arXiv:1107.1232]

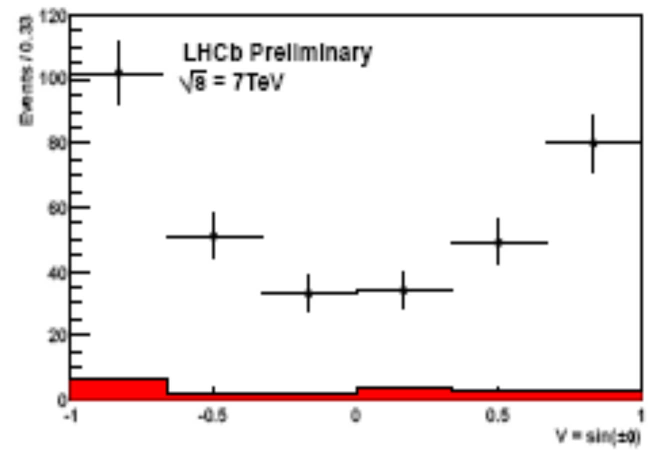
$B_s \rightarrow \phi\phi$

LHCb-CONF-2011-052

Very clean mass peak.
No flavour tagging needed for triple product asymmetry







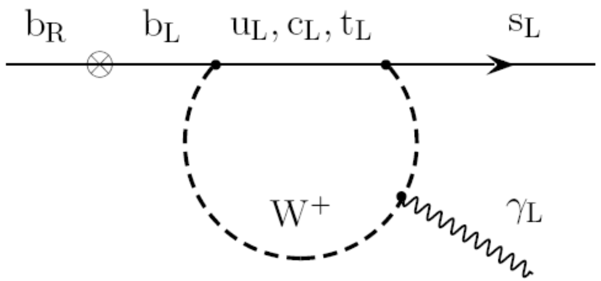
$$\boxed{A_U = -0.064 \pm 0.057 \pm 0.014}$$

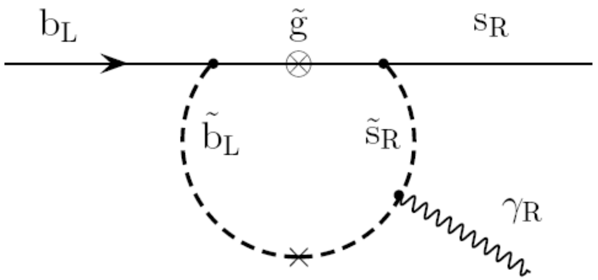
$$\boxed{A_V = -0.070 \pm 0.057 \pm 0.014}$$

CDF (arXiv: 1107.4999):
A_U = -0.007 ± 0.064 (stat) ± 0.018 (syst)
A_V = -0.120 ± 0.064 (stat) ± 0.016 (syst)

- Consistent with zero
- Next step : measure CP asymmetry

NP in $B_s \to \phi\gamma$





Dominating SM quark level diagram has left handed photons

An example MSSM diagram with right-handed photons

Experimental probe: A_Δ (or effective lifetime)

[F. Muheim, Y. Xie, R. Zwicky, PLB 664:174, 2008]

$$R(t) \propto e^{-\Gamma_s t}\left[\cosh\left(\Delta\Gamma_s t/2\right) + A_\Delta \sinh\left(\Delta\Gamma_s t/2\right)\right]$$

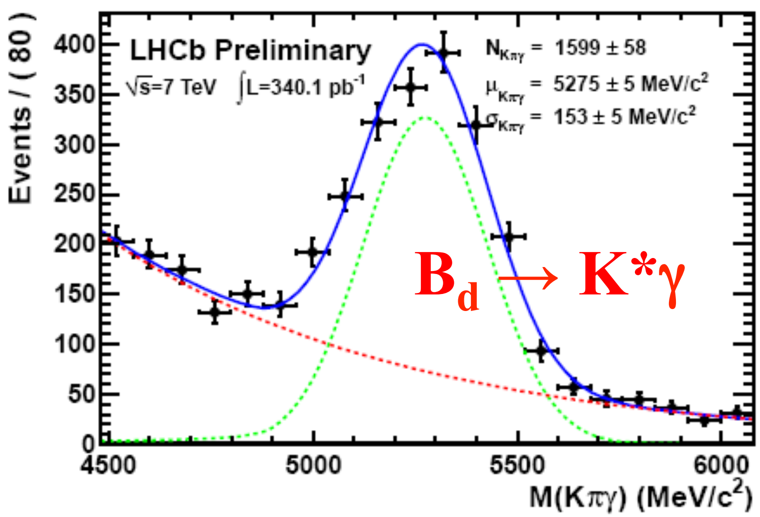
A_Δ sensitive to fraction of right-handed photons (even for small ϕ_s)

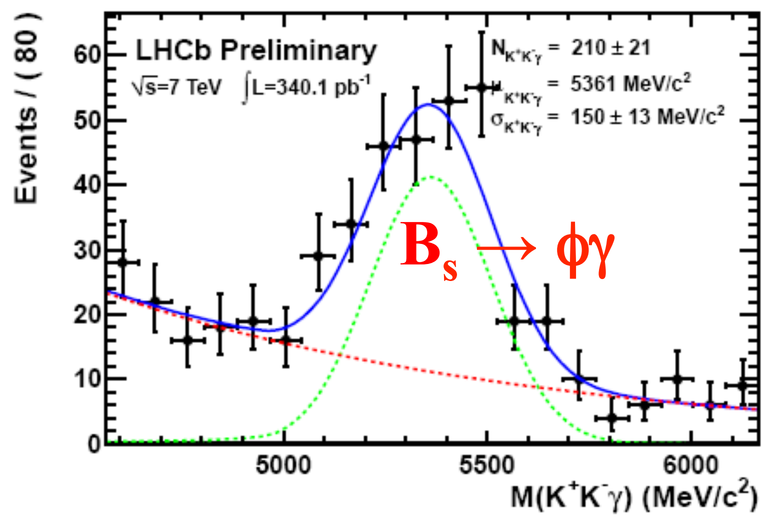
$A_\Delta \sim 0$ in SM, can be enhanced by NP with large RH currents.

$B_s \rightarrow \phi\gamma$

First step: measure BR. LHCb-CONF-2011-055

$$\frac{\mathcal{B}(B^0 \rightarrow K^{*0}\gamma)}{\mathcal{B}(B^0_s \rightarrow \phi\gamma)} = 1.52 \pm 0.14(\text{stat}) \pm 0.10(\text{syst}) \pm 0.12(f_s/f_d)$$





Next step: measure A_Δ

LHCb ugrade

- 2 fb-1 by end of 2012 and ~5 fb^{-1} up to 2017
  - Pursue severe test of SM
- Upgrade
  - 40 MHZ full software trigger @ 2 $\times 10^{33}$ cm^{-2} s^{-1}
  - 10 times more event yields
  - Major upgrade of the tracking and RICH systems
  - Ready by 2018

- Physics case in Letter of Intent
  - Discover and fully understand physics beyond the SM through precision measurements of key parameters in B and D physics
  - Search for lepton flavour violation: 1GeV Majorana neutrinos , LFV τ decays
  - Explore physics in the forward direction: long lived exotics, EW measurement, QCD study …

Conclusions

- LHCb has achieved excellent results in key measurements
- No significant deviation from SM seen yet
- Will continue new physics search
  - at higher precision
  - in boarder scope