CP violation and Rare Decays
(a selected list of topics)

Gaia Lanfranchi (INFN & CERN)

on behalf of the LHCb Collaboration
including ATLAS,Babar, Belle, CDF, CMS, D0 results

Les Rencontres de Blois -2012

Brief history of the Blois castle:

1) X^{th} century: birth of the Blois castle

- physics model: Aristotle's model with the Sun, the Moon, the planets and the sphere of fixed stars rotating around the Earth
- anomalies: Ptolemy's epicycles to describe the motions of planets

Brief history of the Blois castle:

1) X^{th} century: birth of the Blois castle

- physics model: Aristotle's model with the Sun, the Moon, the planets and the sphere of fixed stars rotating around the Earth
- anomalies: Ptolemy's epicycles to describe the motions of planets

2) 17^{th} century: end of the construction of the Blois castle

- solution: Galileo demonstrated that the observed motions of celestial objects can be explained without putting the Earth at rest in the center of the universe.

Gaston d'Orleans's wing

Brief history of the Blois castle:

1) Xth century: birth of the Blois castle

- physics model: Aristotle's model with the Sun, the Moon, the planets and the sphere of fixed stars rotating around the Earth
- anomalies: Ptolemy's epicycles to describe the motions of planets

2) 17th century: end of the construction of the Blois castle

- solution: Galileo demonstrated that the observed motions of celestial objects can be explained without putting the Earth at rest in the center of the universe.

3) End of 19th century: renovation of the Blois castle

- physics model: Newton's classical physics, Maxwell's electromagnetic theory, Clausius's thermodynamics
- anomalies: black body spectrum

Brief history of the Blois castle:

1) X^{th} century: birth of the Blois castle

- physics model: Aristotle's model with the Sun, the Moon, the planets and the sphere of fixed stars rotating around the Earth
- anomalies: Ptolemy's epicycles to describe the motions of planets

2) 17^{th} century: end of the construction of the Blois castle

- solution: Galileo demonstrated that the observed motions of celestial objects can be explained without putting the Earth at rest in the center of the universe.

3) End of 19^{th} century: renovation of the Blois castle

- physics model: Newton's classical physics, Maxwell's electromagnetic theory, Clausius's thermodynamics
- anomalies: black body spectrum
- solution: 1901: Planck describes the black body spectrum as a system of oscillators each of them with energy $\varepsilon = h\,\nu$ → *the birth of quantum mechanics*

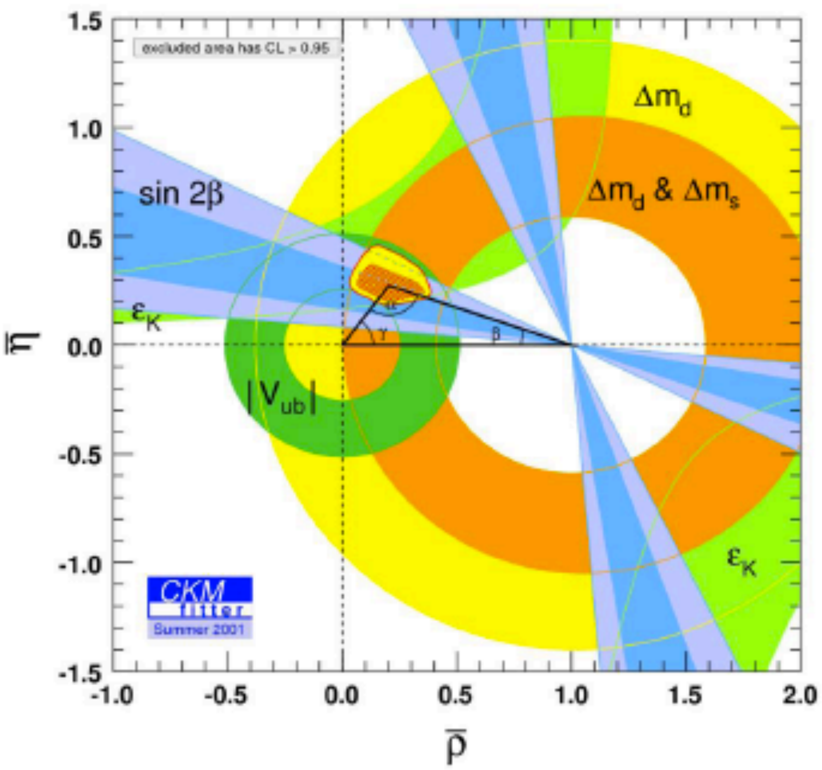
Brief history of the Blois castle:

4) XXIst century: Les rencontres de Blois 2012

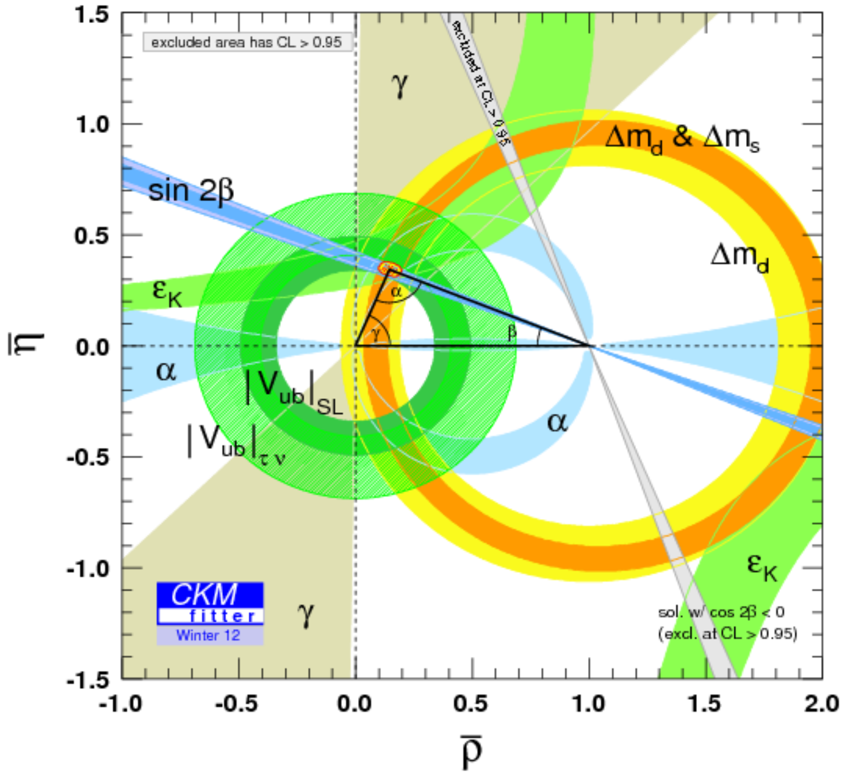
- physics model: the Standard Model with the CKM mechanism controlling the weak interactions between quarks
- anomalies: the content of this talk

Evolution of the CKM picture in the last 10 years

EPS 2001



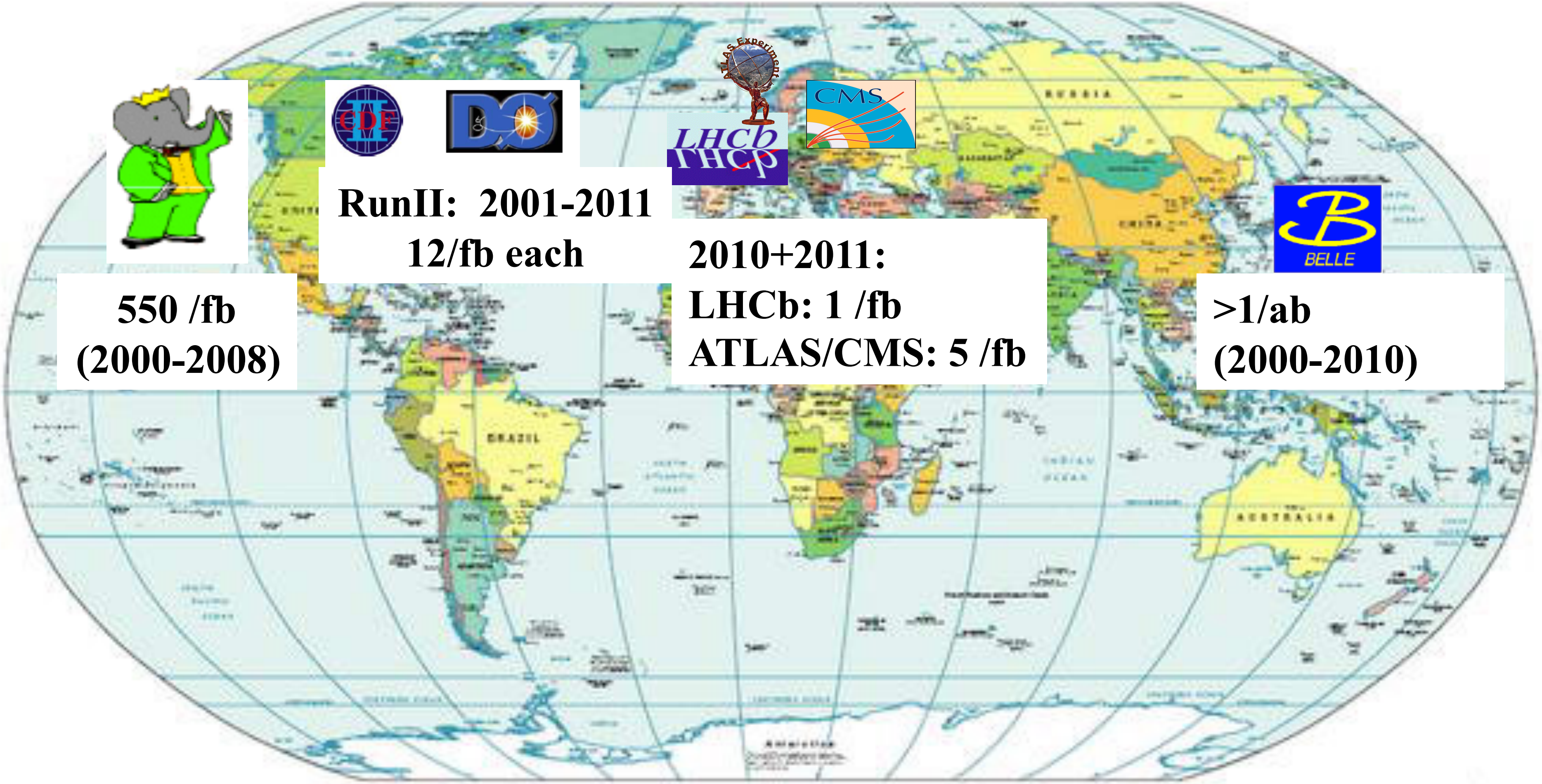
Winter 2012



The impressive success of CKM mechanism as the main source of flavor and CPV
(the legacy of Belle, Babar, CDF and D0)

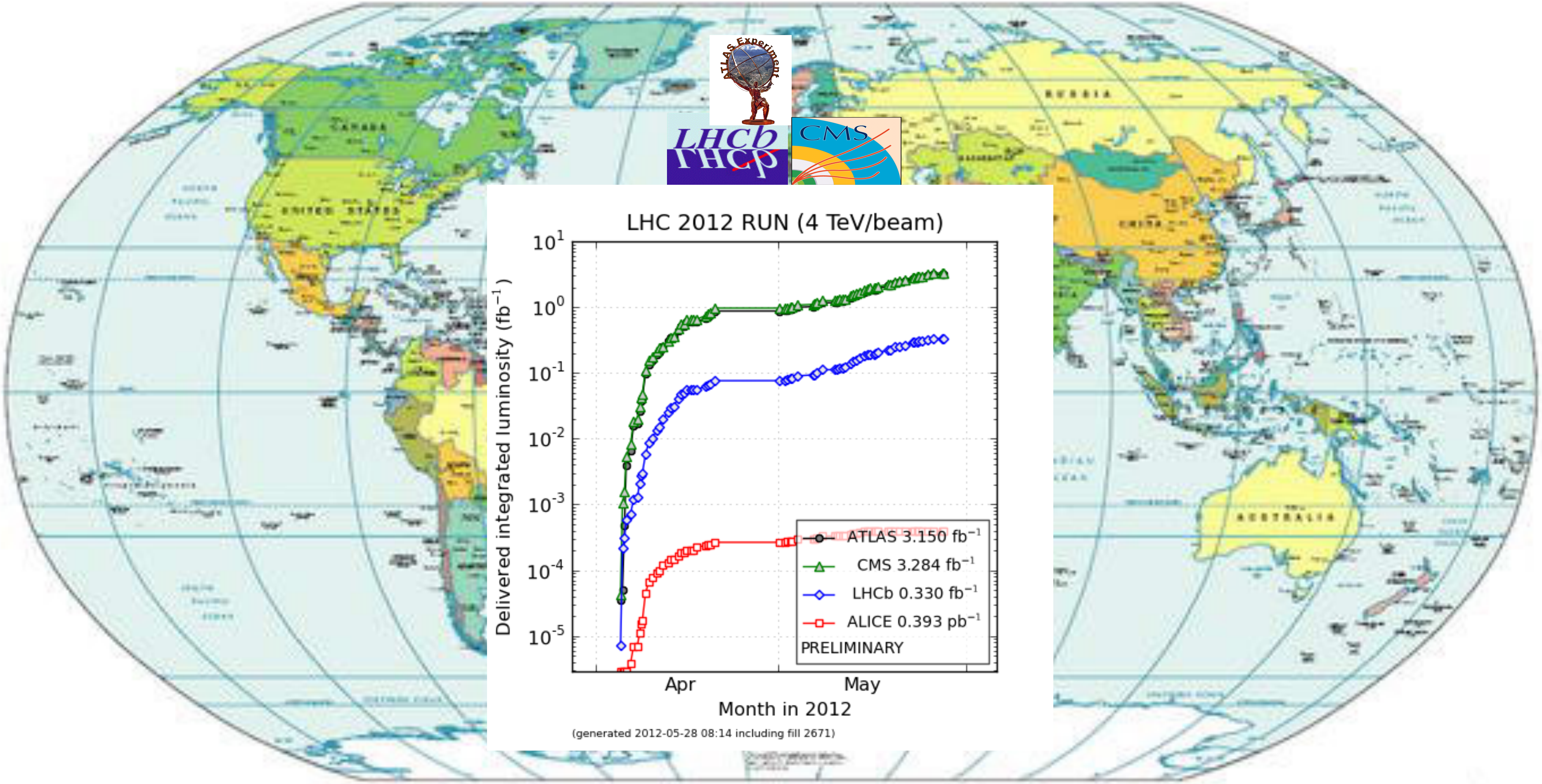
A world wide effort

(some of the main players in the heavy quark sector)



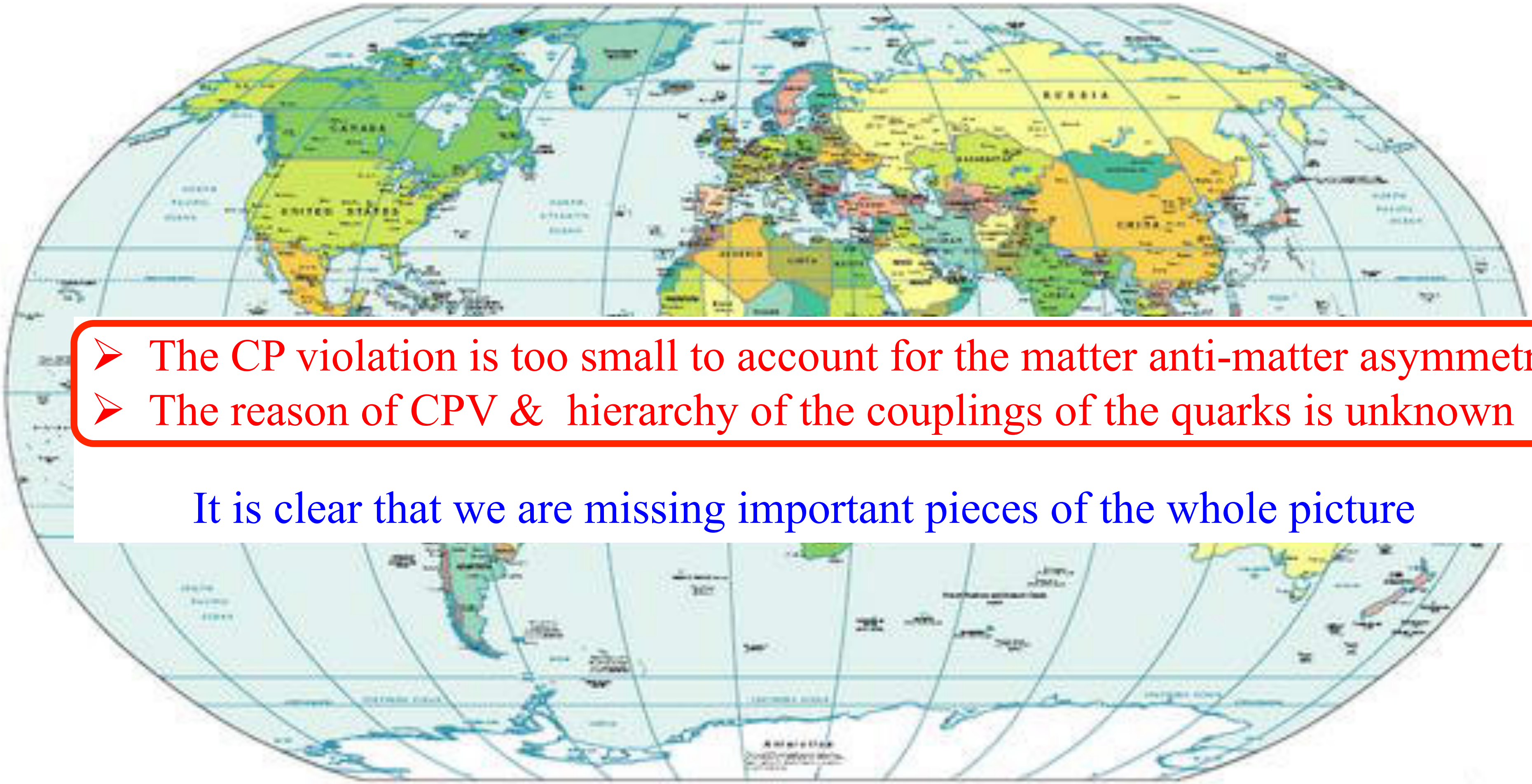
A world wide effort
(some of the main players in the heavy quark sector)

…That is keeping going….



A world wide effort
(some of the main players in the heavy quark sector)

But still a lot of open questions:



- The CP violation is too small to account for the matter anti-matter asymmetry
- The reason of CPV & hierarchy of the couplings of the quarks is unknown

It is clear that we are missing important pieces of the whole picture

Strategies for indirect NP search

- Improve measurement precision of CKM elements
  - Compare measurements of same quantity, which may or may not be sensitive to NP
  - Extract all CKM angles and sides in many different ways
    - any inconsistency will be a sign of New Physics

Precision CKM metrology, including NP-free determinations of CKM angle γ

- Measure FCNC transitions, where New Physics is more likely to emerge, and compare to predictions
  - e.g. OPE expansion for $b \to s$ transitions:

Single B decay measurements with NP discovery potential

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i [\ \underbrace{C_i(\mu) O_i(\mu)}_{\text{left-handed part}} + \underbrace{C_i'(\mu) O_i'(\mu)}_{\text{right-handed part suppressed in SM}}\ ]$$

$i = 1,2$	Tree
$i = 3-6,8$	Gluon penguin
$i = 7$	Photon penguin
$i = 9,10$	Electroweak penguin
$i = S$	Higgs (scalar) penguin
$i = P$	Pseudoscalar penguin

  - New Physics may
    - modify $C_i^{(')}$ short-distance Wilson coefficients
    - add new long-distance operators $O_i^{(')}$

Outline

1) BR($B \rightarrow \tau\nu$) or sin(2β)?
2) The “strange” brother: CPV in B_s
3) New physics in B_s &/or B_d mixing?
4) The angle γ
5) CPV in charm
6) EW penguins: latest results
7) BR($B_s \rightarrow \mu\mu$): status of the art

1) BR(B→τν) or sin2β ?

Chateau de Blois:
Louis XII roi de France

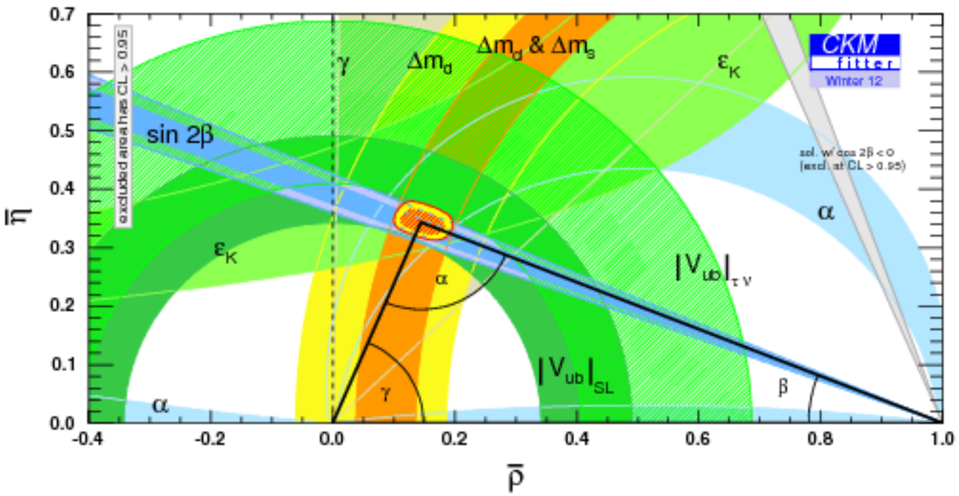
The CKM matrix: the first unitarity triangle

Multiplying the 1st and 3rd column of the CKM matrix we have the first triangle of unitarity with the well known angles (α,β,γ) (or ϕ1,ϕ2,ϕ3)

$$V_{\rm CKM} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} .$$

$$V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0$$

http://ckmfitter.in2p3.fr/



$$\beta = \phi_1 = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right),$$

$$\alpha = \phi_2 = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right),$$

$$\gamma = \phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right).$$

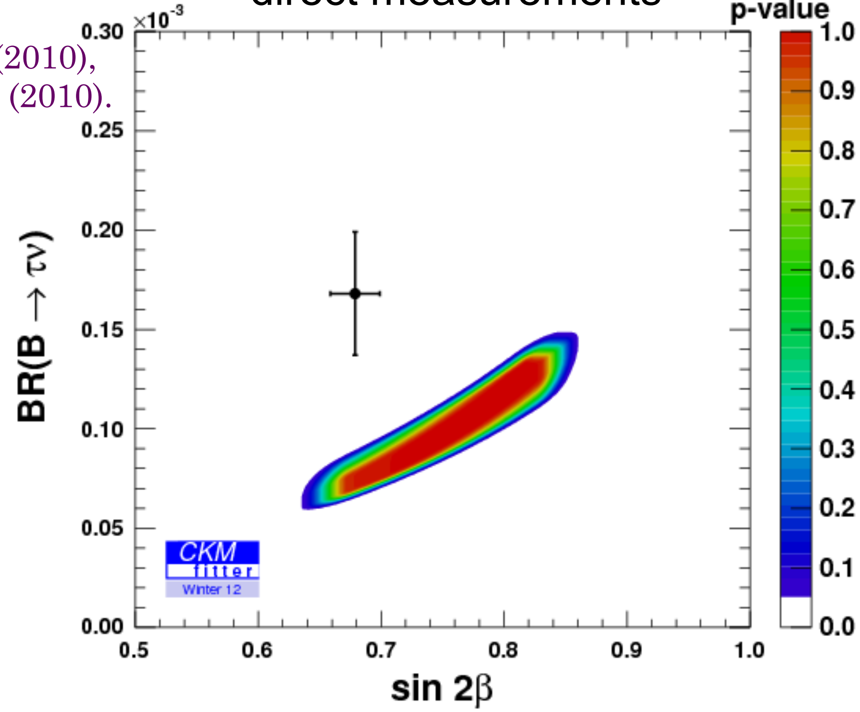
The first anomaly in CKM:sin(2β) vs BR(B→τν)

☐ The indirect determination of sin2β deviates by 2.7 σ from the current WA for direct determination.

☐ The BR(B→τν) and the resulting value of $|V_{ub}|$ (BR(B→τν)~$f_B^2|V_{ub}|^2$) differ by 2.8 σ from the predictions of global fit (which is dominated by sin(2β) value)

CKM fit w/o BR(B→τν)& sin(2β) vs direct measurements

Belle: Phys. Rev. D 82, 071101 (2010),
Babar: Phys. Rev. D 82, 073012 (2010).



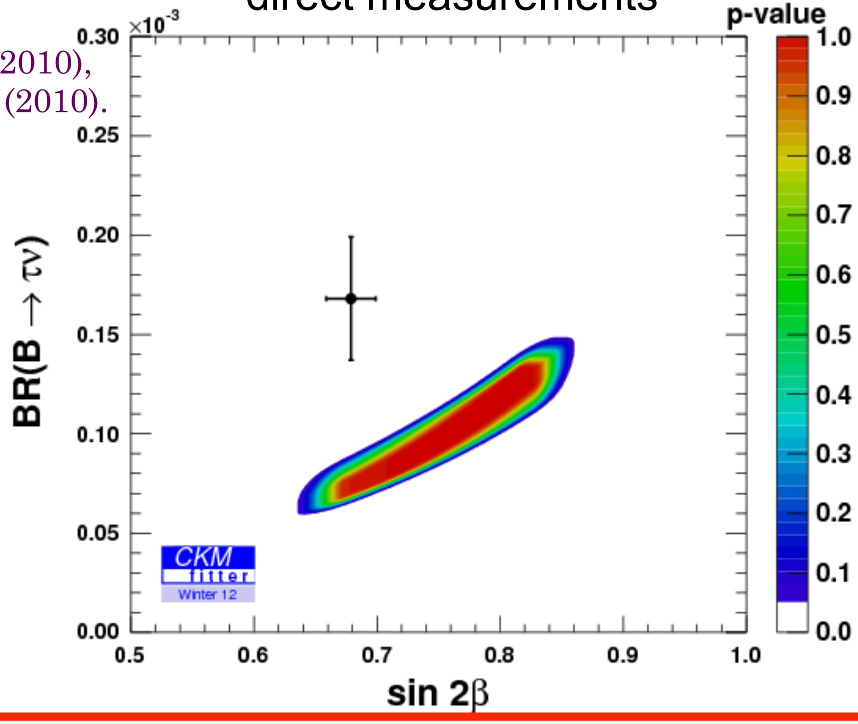
The first anomaly in CKM:sin(2β) vs BR(B→τν)

☐ The indirect determination of sin2β deviates by 2.7 σ from the current WA for direct determination.

☐ The BR(B→τν) and the resulting value of $|V_{ub}|$ (BR(B→τν)~$f_B^2|V_{ub}|^2$) differ by 2.8 σ from the predictions of global fit (which is dominated by sin(2β) value)

CKM fit w/o BR(B→τν)& sin(2β) vs direct measurements

Belle: Phys. Rev. D 82, 071101 (2010),
Babar: Phys. Rev. D 82, 073012 (2010).



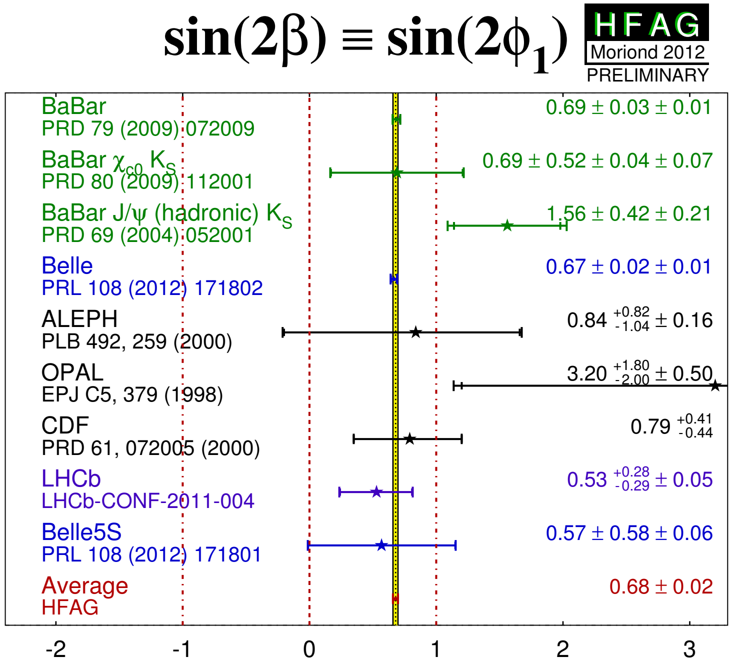
BR(B→τν) too high or sin(2β) too low

The BR(B→τν) enhancement cannot be explained by the decay constant (known at 10% level in LQCD)

The first anomaly in CKM: $\sin(2\beta)$ vs $BR(B \to \tau\nu)$

☐ The indirect determination of $\sin 2\beta$ deviates by 2.7 σ from the current WA for direct determination.

☐ The $BR(B \to \tau\nu)$ and the resulting value of $|V_{ub}|$ ($BR(B \to \tau\nu) \sim f_B^2 |V_{ub}|^2$) differ by 2.8 σ from the predictions of global fit (which is dominated by $\sin(2\beta)$ value)



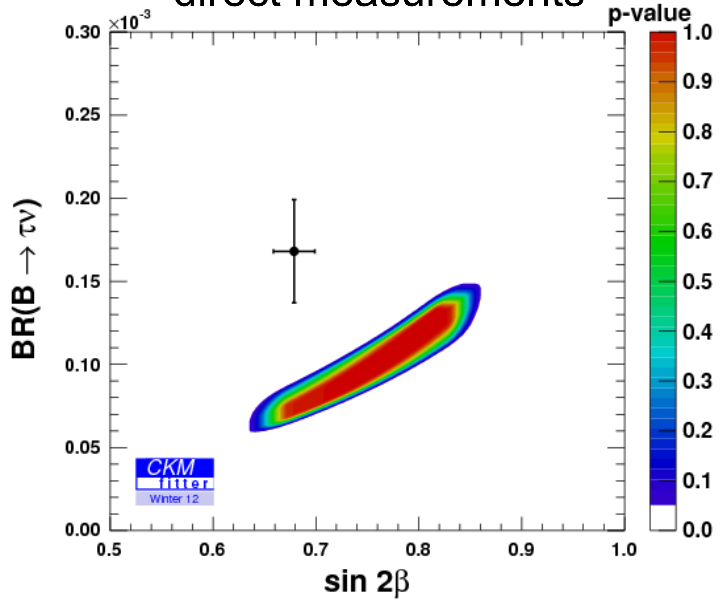
New $\sin(2\beta)$ result from Belle based on full dataset [arXiv 1201.0238]
$\sin 2\beta = 0.667 \pm 0.023(stat) \pm 0.012(syst)$ confirms with unprecedented accuracy previous measurements

The first anomaly in CKM:sin(2β) vs BR(B→τν)

☐ The indirect determination of sin2β deviates by 2.7 σ from the current WA for direct determination.

☐ The BR(B→τν) and the resulting value of $|V_{ub}|$ (BR(B→τν)~$f_B^2|V_{ub}|^2$) differ by 2.8 σ from the predictions of global fit (which is dominated by sin(2β) value)

CKM fit w/o BR(B→τν)& sin(2β) vs direct measurements



1) Charged Higgs contribution (sensitive to H-b-u) in BR(B→τν)?

2) New Physics is decays with a τ lepton in the final state?

also 3.4 σ excess seen in B→D(*) τ ν (H-b-c) over SM predictions [Babar: 1205.5442]

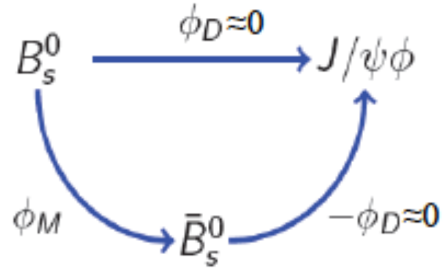
3) New phases in B_d mixing? Let's see the "strange" brother of sin(2β)

2) The "strange" brother:
the mixing-induced CPV phase in B_s system

chateau de Blois: gargouille

Mixing-induced CPV phase in B_s system

Golden channel for studying CPV in B_s system is $B_s \rightarrow J/\psi\ \phi$, the "strange" brother of $B^0 \rightarrow J/\psi K^0$

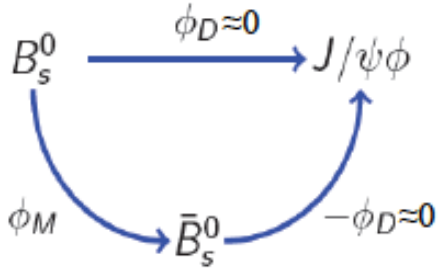


ϕ_s = phase difference between the $B_s \rightarrow J/\psi\varphi$ decay amplitudes without or with oscillation

ϕ_s is the equivalent of the phase 2β for $B^0 \rightarrow J/\psi K_S$

Mixing-induced CPV phase in B_s system

Golden channel for studying CPV in B_s system is $B_s \rightarrow J/\psi\ \phi$, the "strange" brother of $B^0 \rightarrow J/\psi K^0$



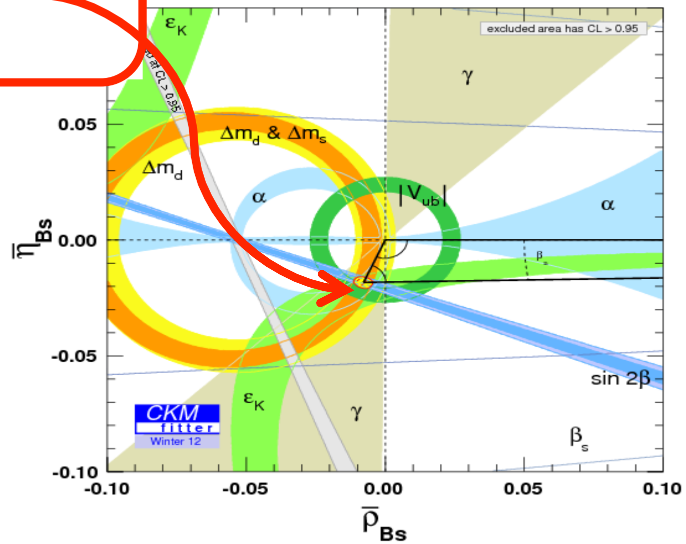
ϕ_s = phase difference between the $B_s \rightarrow J/\psi\phi$ decay amplitudes without or with oscillation

ϕ_s is the equivalent of the phase 2β for $B^0 \rightarrow J/\psi K_S$

The SM contribution to the mixing-induced phase is:

$$\phi_s^{\mathrm{SM}} = \phi_s^{\mathrm{M}} - 2\phi_s^{D} \simeq -2\beta_s = -2\arg\left(-\frac{\overbrace{V_{\mathrm{ts}}V_{\mathrm{tb}}^*}^{\text{mixing}}}{\underbrace{V_{\mathrm{cs}}V_{\mathrm{cb}}^*}_{\text{decay}}}\right) = -(2.1 \pm 0.1)^\circ$$

Lenz,Nierste,CKMFitter
arXiv:1203.0238

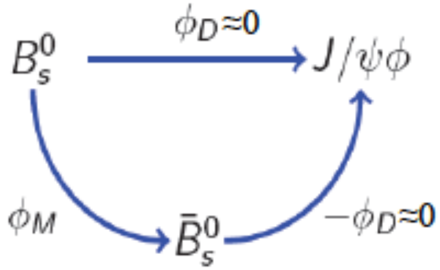


Which is phase of the "squashed" triangle obtained by multiplying the 2nd and 3rd columns of CKM matrix

$$V_{\mathrm{CKM}} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}.$$

Mixing-induced CPV phase in B_s system

Golden channel for studying CPV in B_s system is $B_s \to J/\psi\ \phi$, the "strange" brother of $B^0 \to J/\psi K^0$



ϕ_s = phase difference between the $B_s \to J/\psi\phi$ decay amplitudes without or with oscillation

ϕ_s is the equivalent of the phase 2β for $B^0 \to J/\psi K_S$

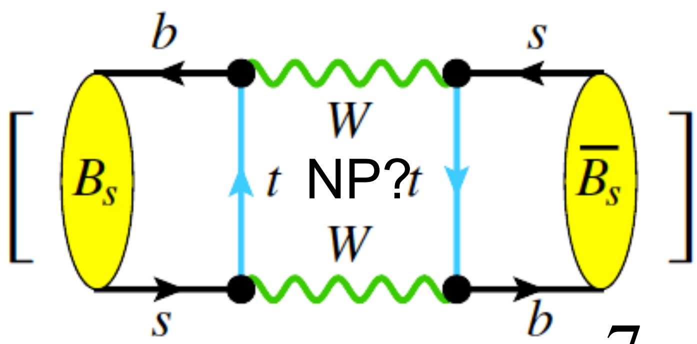
The SM contribution to the mixing-induced phase is:

$$\phi_s^{SM} = \phi_s^{M} - 2\phi_s^{D} \simeq -2\beta_s = -2\arg\left(-\frac{\overbrace{V_{ts}V_{tb}^*}^{\text{mixing}}}{\underbrace{V_{cs}V_{cb}^*}_{\text{decay}}}\right) = -(2.1 \pm 0.1)^\circ$$

Lenz,Nierste,CKMFitter
arXiv:1203.0238

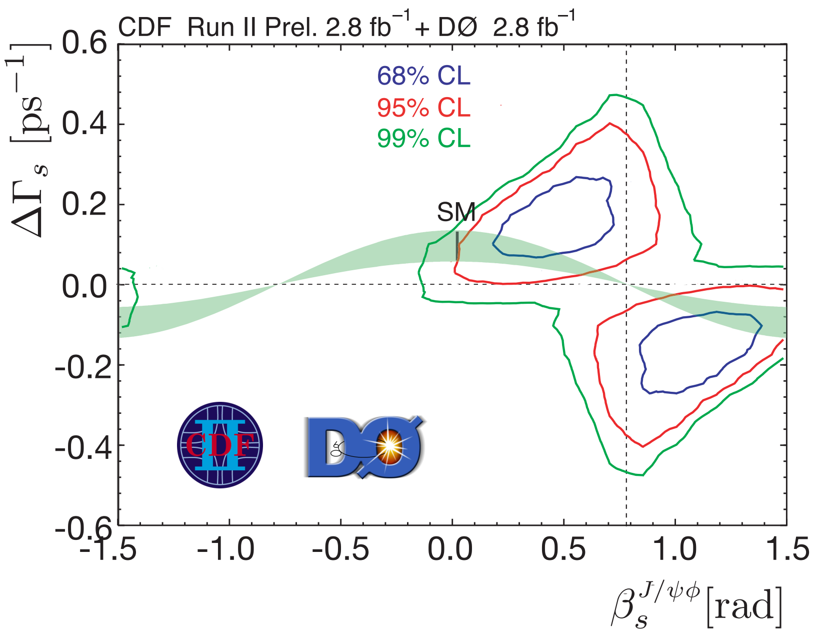
ϕs is very sensitive to New Physics contributions in B_s mixing and provides an excellent lab to look for new sources of CPV:

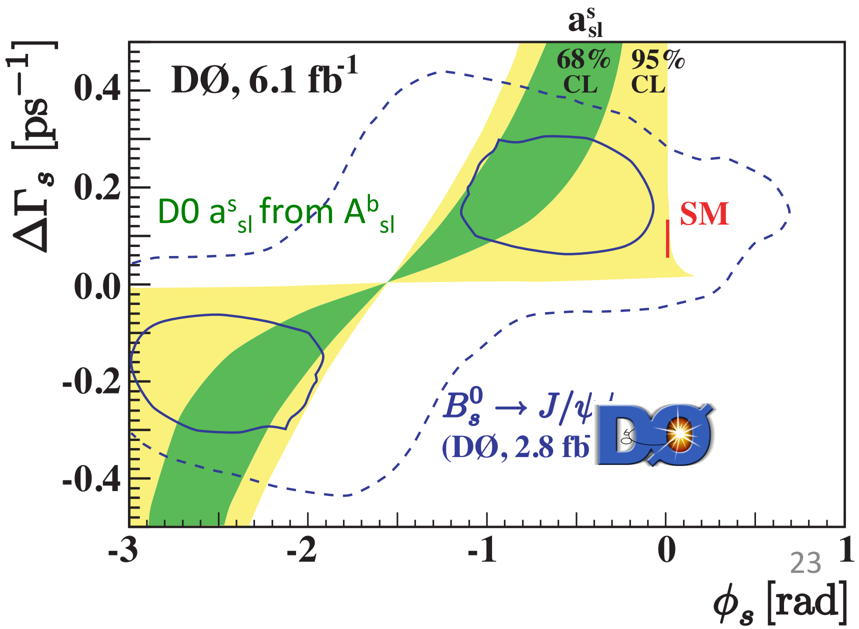
$$\phi_s = \phi_s^{SM} + \phi_s^{NP}$$



A bit of history

- **2007:** first tagged analysis by CDF, followed by D0
- **2009**: 2.1σ deviations from SM in CDF+D0 combination [DØ Note 5928-CONF]
- **2010**: D0 same-sign dimuon asymmetry A^b_{sl} in 6.1fb^{-1} showed 3.2σ from SM, implying large ϕ_s (assuming NP in B_s in M_{12} only) [PRD82 (2010) 032001]
- **2011:** D0 update of A^b_{sl} with 9 fb^{-1} showed 3.9σ deviation from SM [PRD84 (2011) 052007]
- ➔ a lot of excitement……





A bit of history

- **2007:** first tagged analysis by CDF, followed by D0
- **2009:** 2.1σ deviations from SM in CDF+D0 combination [DØ Note 5928-CONF]
- **2010**: D0 same-sign dimuon asymmetry A^b_{sl} in 6.1fb^{-1} showed 3.2σ from SM, implying large ϕ_s (assuming NP in B_s in M_{12} only) [PRD82 (2010) 032001]
- **2011**: D0 update of A^b_{sl} with 9 fb^{-1} showed 3.9σ deviation from SM [PRD84 (2011) 052007]

….but then larger dataset allowed to pin down the error on ϕs……

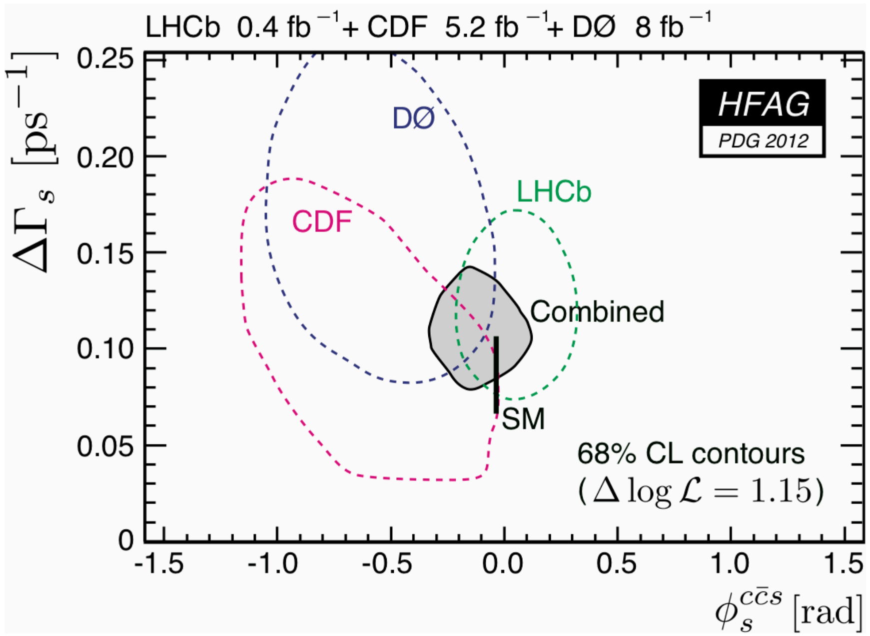
Summer 2011:

first LHCb tagged analysis result, 0.34 fb^{-1}

[PRL 108 (2012) 101803],

CDF update with 5.2 fb^{-1} [PRD85 (2012) 07002]

D0 update with 8 fb^{-1} [PRD85 (2012) 032006]



A bit of history

- **2007:** first tagged analysis by CDF, followed by D0
- **2009:** 2.1σ deviations from SM in CDF+D0 combination [DØ Note 5928-CONF]
- **2010**: D0 same-sign dimuon asymmetry A^b_{sl} in 6.1fb^{-1} showed 3.2σ from SM, implying large ϕ_s (assuming NP in B_s in M_{12} only) [PRD82 (2010) 032001]
- **2011**: D0 update of A^b_{sl} with 9 fb^{-1} showed 3.9σ deviation from SM [PRD84 (2011) 052007]

….but then larger dataset allowed to pin down the error on ϕs……

Summer 2011:

first LHCb tagged analysis result, 0.34 fb^{-1}

[PRL 108 (2012) 101803],

CDF update with 5.2 fb^{-1} [PRD85 (2012) 07002]

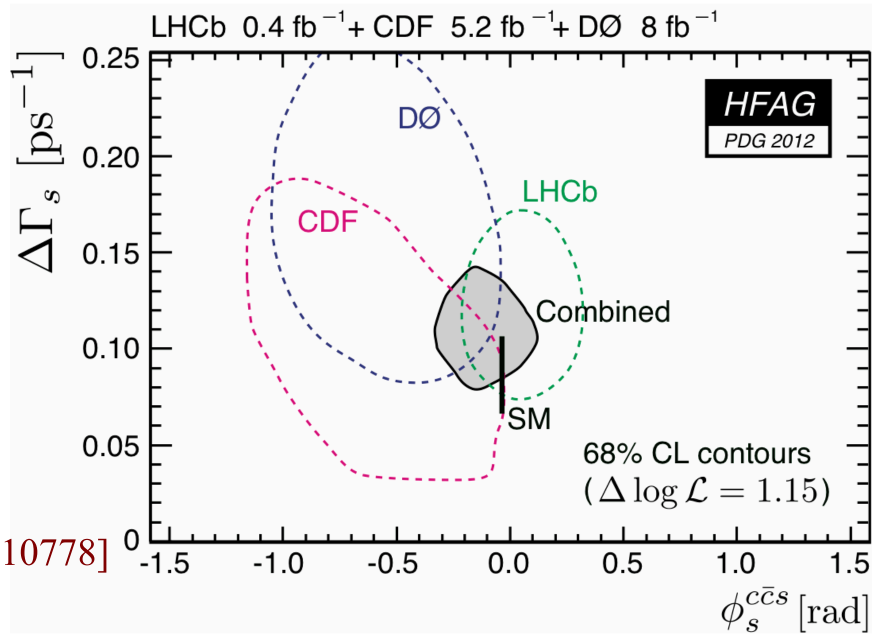
D0 update with 8 fb^{-1} [PRD85 (2012) 032006]

… more and more:

Moriond 2012:

CDF update with full Run II data (9/fb) [CDF Note 10778]

LHCb update with 1/fb [LHCb-CONF-2012-002]

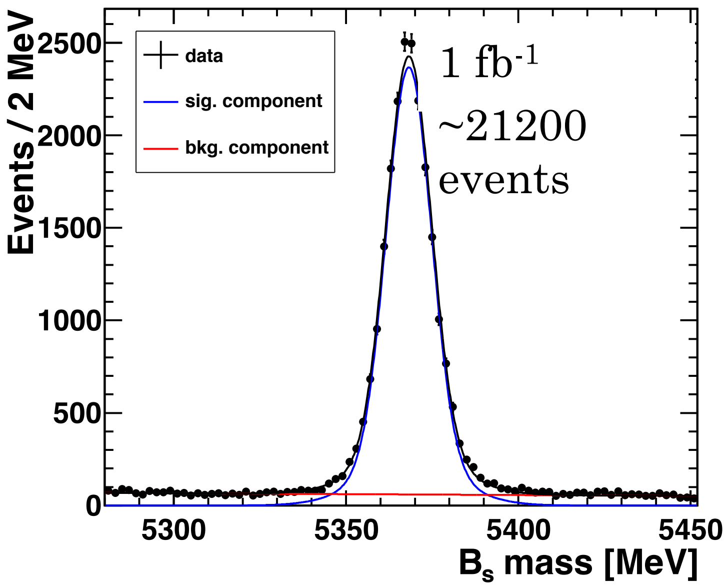


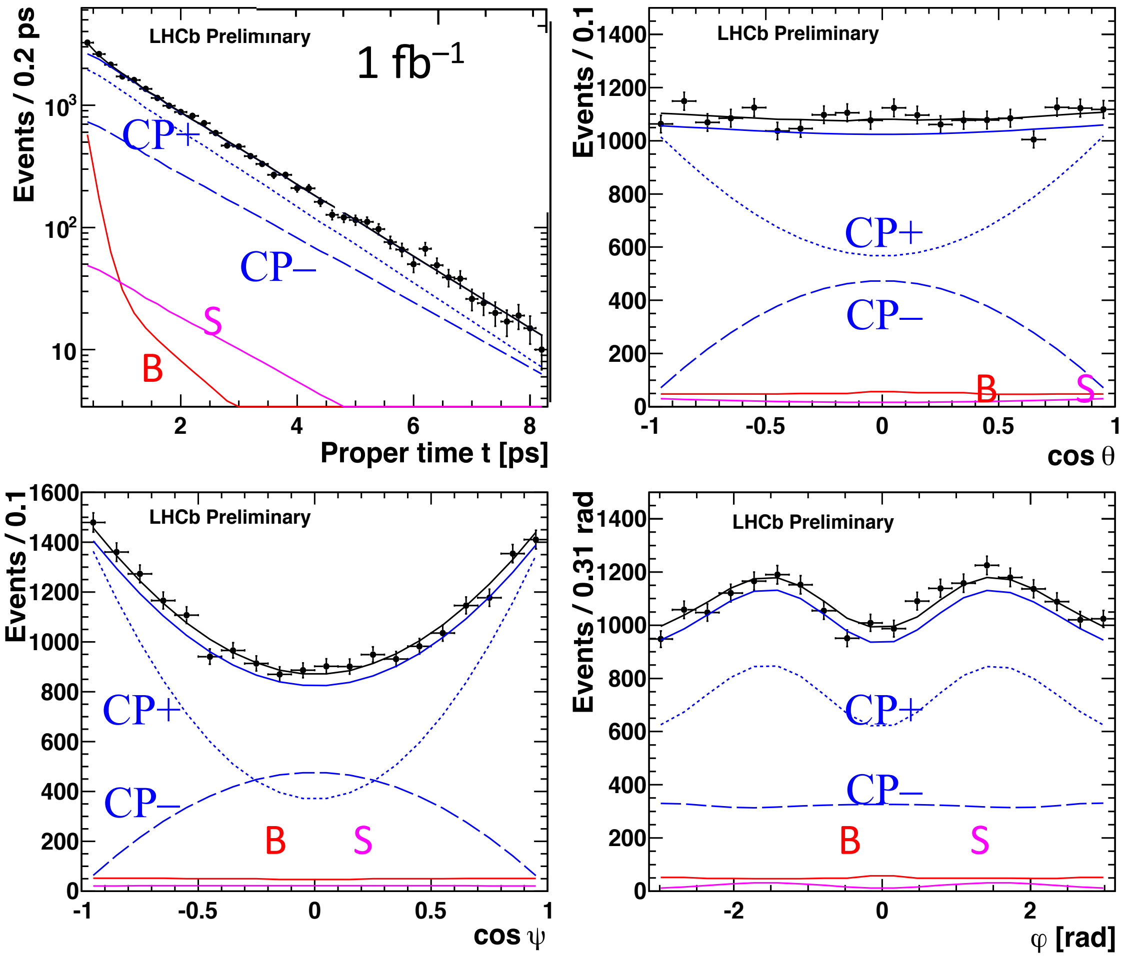
$B_s \to J/\psi\varphi$: LHCb latest result [1 fb^{-1}]

Full fit of tagged and untagged rates as a function of B_s mass, proper time and transversity angles:

LHCb-CONF-2012-002, 1/fb

$B_s \to J/\psi$ KK final state is a mixture of CP-even and CP-odd eigenstates so angular analysis needed





CP+ : $B_s \to J/\psi\varphi$ signal with CP-even final state

CP– : $B_s \to J/\psi\varphi$ signal with CP-odd final state

S : $B_s \to J/\psi KK$ signal with $J_{KK} = 0$ (S-wave, CP-odd)

B : combinatorial background

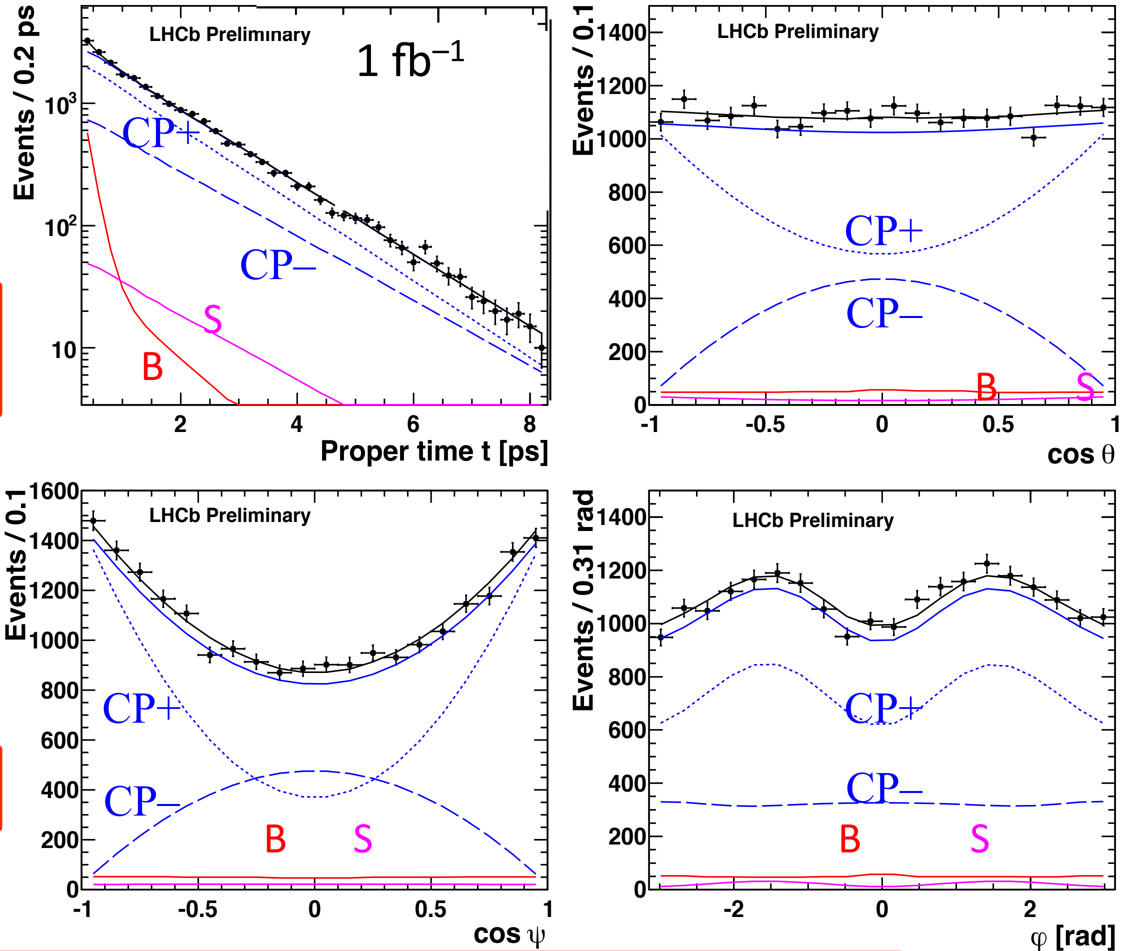
$B_s \to J/\psi\varphi$: LHCb latest result [$1 fb^{-1}$]

Full fit of tagged and untagged rates as a function of B_s mass, proper time and transversity angles:

LHCb-CONF-2012-002, 1/fb

Preliminary results:

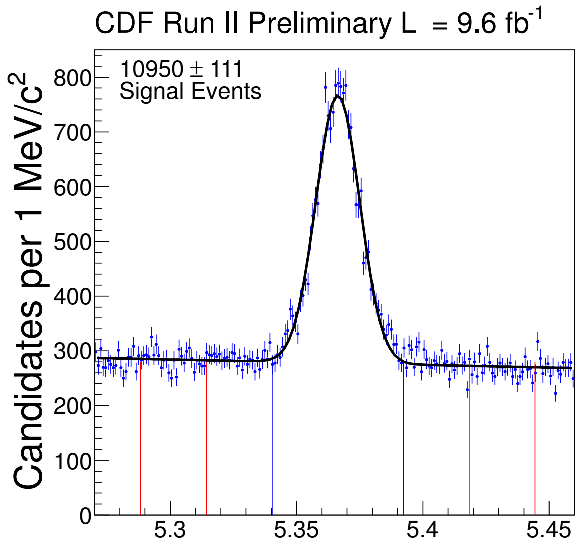
Parameter	Value	Stat.	Syst.
Γ_s [ps^{-1}]	0.6580	0.0054	0.0066
$\Delta\Gamma_s$ [ps^{-1}]	0.116	0.018	0.006
$\lvert A_\perp(0)\rvert^2$	0.246	0.010	0.013
$\lvert A_0(0)\rvert^2$	0.523	0.007	0.024
F_S	0.022	0.012	0.007
$\delta_\perp$ [rad]	2.90	0.36	0.07
$\delta_\parallel$ [rad]	[2.81, 3.47]		0.13
δ_s [rad]	2.90	0.36	0.08
ϕ_s [rad]	-0.001	0.101	0.027

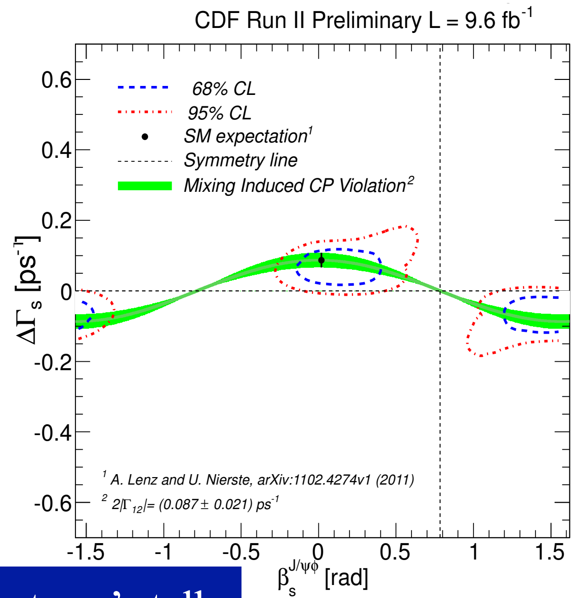


- ϕ_s measurement in agreement with SM predictions
- First(>5σ) observation of non-zero $\Delta\Gamma_s$

$B_s \rightarrow J/\psi\varphi$: CDF latest result [10 fb^{-1}]

CDF Note 10778





~11000 signal events

Opposite side tagging and
same side tagging (first half of Run II data)

Results:

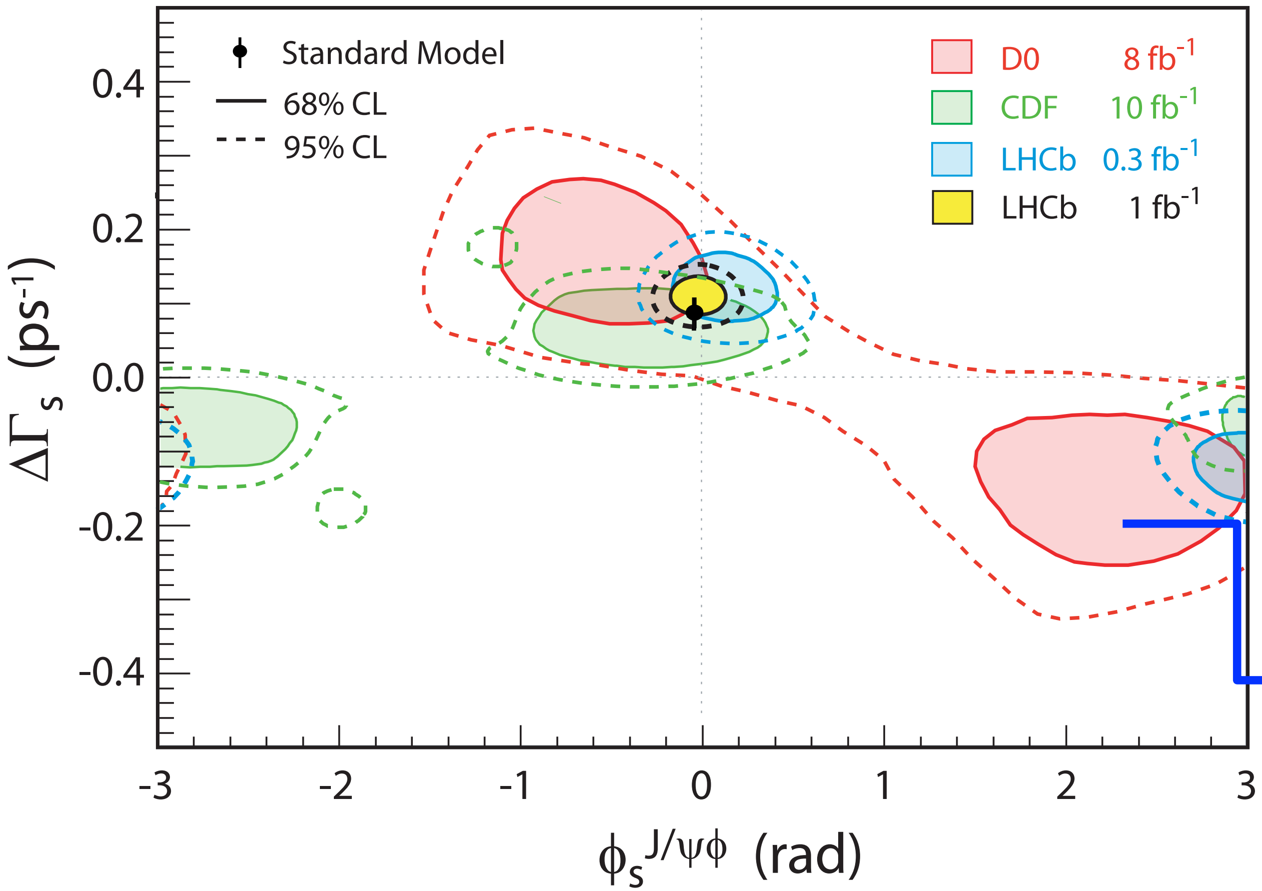
$$\tau(B_s^0) = 1.528 \pm 0.019\ (\text{stat}) \pm 0.009\ (\text{syst})\ \text{ps},$$
$$\Delta\Gamma_s = 0.068 \pm 0.026\ (\text{stat}) \pm 0.007\ (\text{syst})\ \text{ps}^{-1},$$
$$|A_0(0)|^2 = 0.512 \pm 0.012\ (\text{stat}) \pm 0.014\ (\text{syst}),$$
$$|A_{\|}(0)|^2 = 0.229 \pm 0.010\ (\text{stat}) \pm 0.017\ (\text{syst}),$$
$$\delta_\perp = 2.79 \pm 0.53\ (\text{stat}) \pm 0.15\ (\text{syst})\ \text{rad}.$$

$$\beta_s^{J/\psi\varphi} \in [-\pi/2, -1.51] \cup [-0.06, 0.30] \cup [1.26, \pi/2]\ \ (68\%\ \text{C.L.})$$

See I. Bertram's talk

CPV in $B_s \to J/\psi\varphi$: latest results

- Representation of latest results (pictorial view for illustration only):



PRD 85 (2012) 032006

CDF note 10778

arXiv:1112.3183

LHCb-CONF-2012-002

Ambiguity removed by LHCb

Good agreement with SM predictions

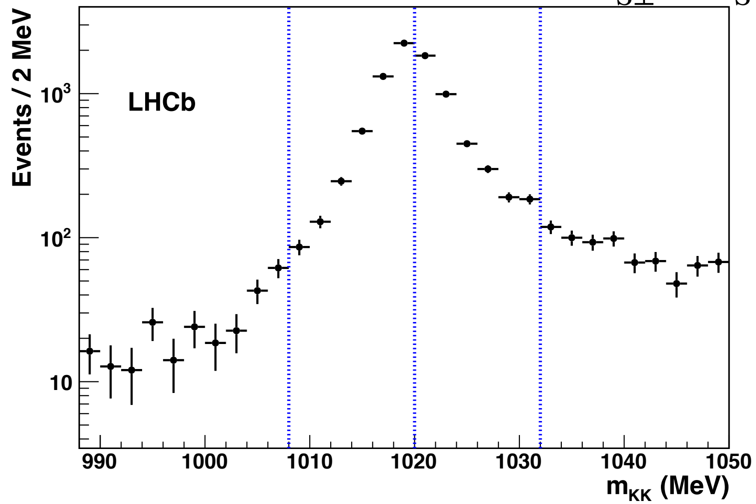
Sign of $\Delta\Gamma_s$

LHCb, arXiv:1202.4717
Accepted by PRL

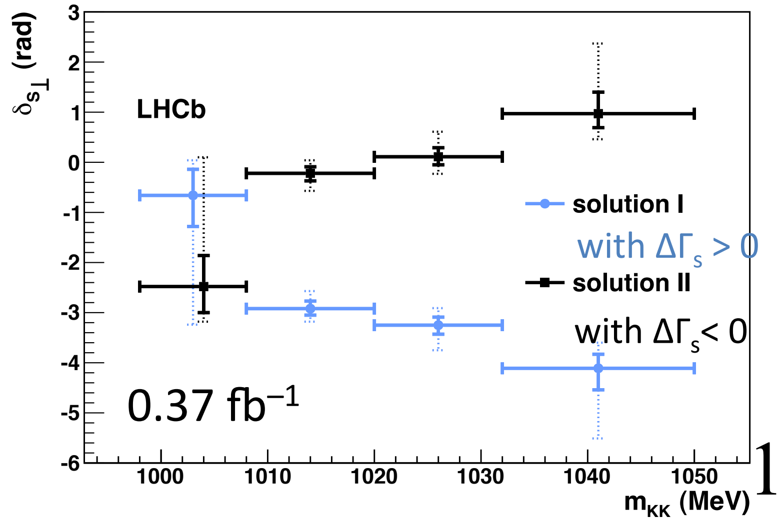
- Decay rates have an intrinsic 2-fold ambiguity

$$\left(\phi_s,\Delta\Gamma_{s,}\delta_{//},\delta_{\perp},\delta_S\right) \Leftrightarrow \left(\pi-\phi_s,-\Delta\Gamma_{s,}-\delta_{//},\pi-\delta_{\perp},-\delta_S\right) \quad \delta_{S\perp} \Leftrightarrow -\pi-\delta_{S\perp}$$

where $\delta_{S\perp} = \delta_S - \delta_{\perp}$



- Repeat the analysis in larger m(KK) range, not just around mass of $\phi(1020)$
  - expect
    - P-wave phases to increase rapidly with m(KK)
    - S-wave phase to vary slowly
    - hence $\delta_{S\perp} = \delta_S - \delta_{\perp}$ to decrease
  - observe:
    - solution with $\Delta\Gamma_s > 0$ behaves as expected



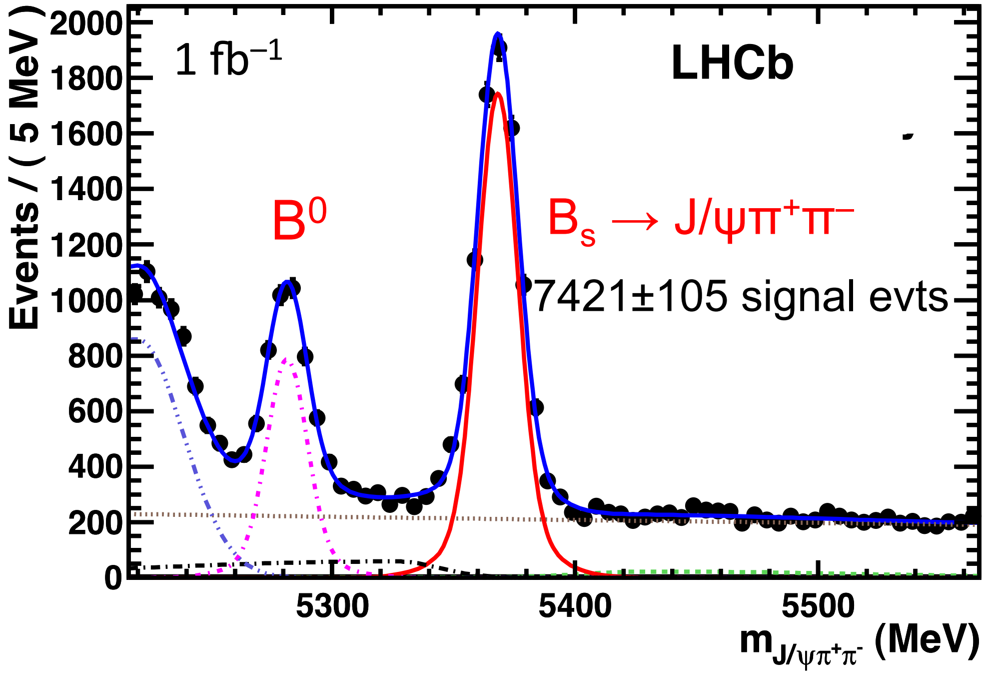
Solution $\Delta\Gamma_s = \Gamma_L - \Gamma_H > 0$ selected with a significance of 4.7σ
Heavy state lives longer than light state !

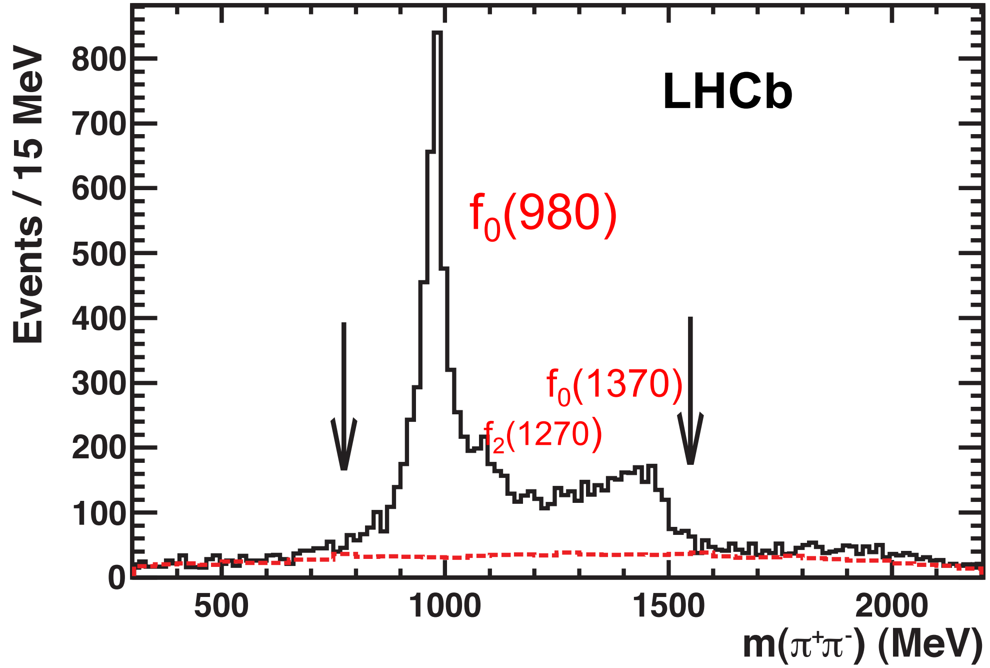
CPV in $B_s \to J/\psi\pi^+\pi^-$ + combined

- LHCb has measured ϕs also in $B_s \to J/\psi\pi^+\pi^-$
  - consider $775 < m(\pi\pi) < 1550$ MeV/c^2
  - angular analysis shows CP^- fraction is > 97.7% at 95% CL
  - measure $\phi_s = -0.02 \pm 0.17 \pm 0.02$

LHCb-PAPER-2012-006
arXiv 1204.5675
submitted to PLB

See T. Latham's talk





Combined preliminary LHCb $J/\psi\phi + J/\psi\pi\pi$ result (1 fb⁻¹):
$\phi_s = -0.002 \pm 0.083 \pm 0.027$

B_s system: status-of-the-art

Everything in good agreement with SM preditions..

	SM predictions [Lenz & Nierste, 1106.6308]	Status before 2011	status after 2011
ΔM_s [ps^{-1}]	17.3±2.6	17.70±0.08 [CDF]	17.73±0.05 [CDF+ LHCb]
$\Delta\Gamma_s$ [ps^{-1}]	0.087±0.021	$0.154^{+0.054}_{-0.070}$ (0.9σ) [CDF & D0]	0.116±0.019 (1σ) [LHCb, 1fb^{-1}]
$\phi_{J/\psi\,\phi}$ [°]	-2.1 ± 0.1	-44^{+17}_{-21} (2.3σ) [CDF & D0]	-0.06±6 [LHCb]

B_s system: status-of-the-art

….. But A_{sl} that (still) shows 3.9 σ deviations from SM predictions:

	SM predictions [Lenz & Nierste, 1106.6308]	**Status before 2011**	**Status after 2011**
ΔM_s [ps^{-1}]	17.3±2.6	17.70±0.08 [CDF]	17.73±0.05 [CDF+ LHCb]
$\Delta\Gamma_s$ [ps^{-1}]	0.087±0.021	$0.154^{+0.054}_{-0.070}$ (0.9σ) [CDF & D0]	0.116±0.019 (1σ) [LHCb, 1fb^{-1}]
$\phi_{J/\psi}$ [°]	-2.1 ± 0.1	-44^{+17}_{-21} (2.3σ) [CDF & D0]	-0.06±6 [LHCb]
A_{sl} [10^{-4}]	-2.8 ± 0.5	-85±28 (3.0 σ) [D0]	-79 ± 20 (3.9 σ) [D0,PRD84 (2011) 052007]
$a_{fs}^{(s)}$ [10^{-5}]	-1.9 ± 0.3	-1200 ± 700 (1.7 σ)	-1300 ± 800 (1.5σ)

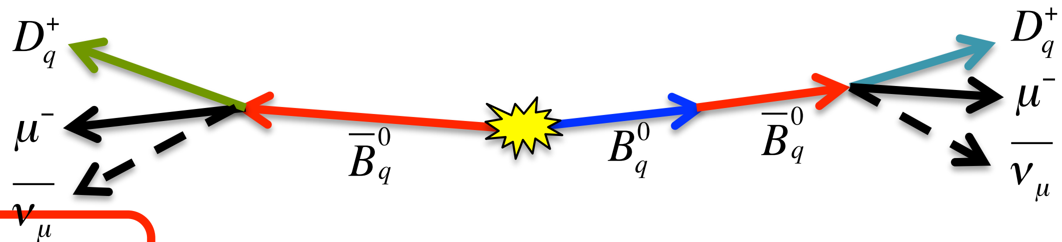
$a_{fs}^{(s)}$ calculated from measured A_{sl} & $a_{fs}^{(d)} = (-4.7 \pm 4.6) \times 10^{-3}$ from Babar&Belle

[HFAG,arXiv:1010.1589]

The semi-leptonic asymmetry

See I. Bertram's talk

The D0 semileptonic asymmetry:



$$A^b_{sl} = \frac{N^{++}_{b\bar{b}} - N^{--}_{b\bar{b}}}{N^{++}_{b\bar{b}} + N^{--}_{b\bar{b}}} = C_d a^d_{sl} + C_s a^s_{sl}$$

- C_d~0.6 and C_s~ 0.4 depend on the production rate of $B_{d,,s}$
- a_{sl} is the CP_asymmetry in flavor-specific modes:

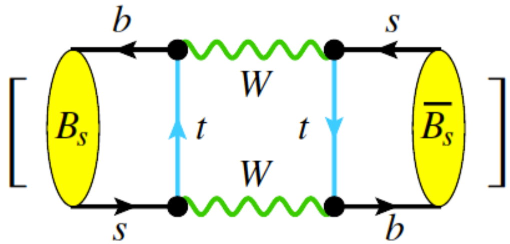
[HFAG, 1010.1589 and updates at http://www.slac.stanford.edu/xorg/hfag

$$a^{s,d}_{sl} = \frac{\Gamma(\overline{B^0}_{s,d} \to \mu^+ X) - \Gamma(B^0_{s,d} \to \mu^- X)}{\Gamma(\overline{B^0}_{s,d} \to \mu^+ X) + \Gamma(B^0_{s,d} \to \mu^- X)} = \frac{\Delta\Gamma_{s,d}}{\Delta M_{s,d}} \tan\varphi_{s,d}$$

with

$$\varphi_s = arg(M^s_{12}/\Gamma^s_{12}) \sim (0.22 \pm 0.06)^\circ$$

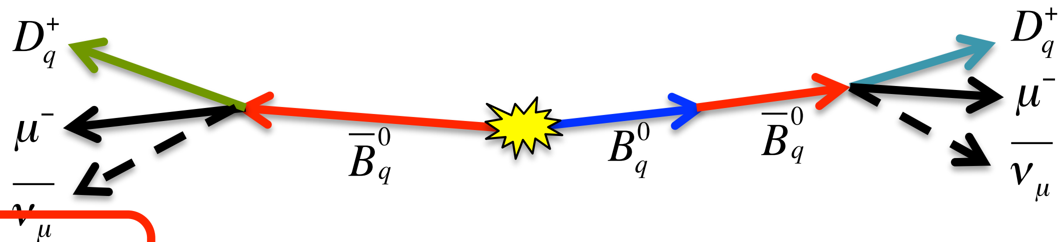
Lenz, Nierste '11



This phase contains is still related to the box diagram as βs but it is a different quantity (10 times smaller in fact). However, if NP modifies M_{12}, it modifies also βs.

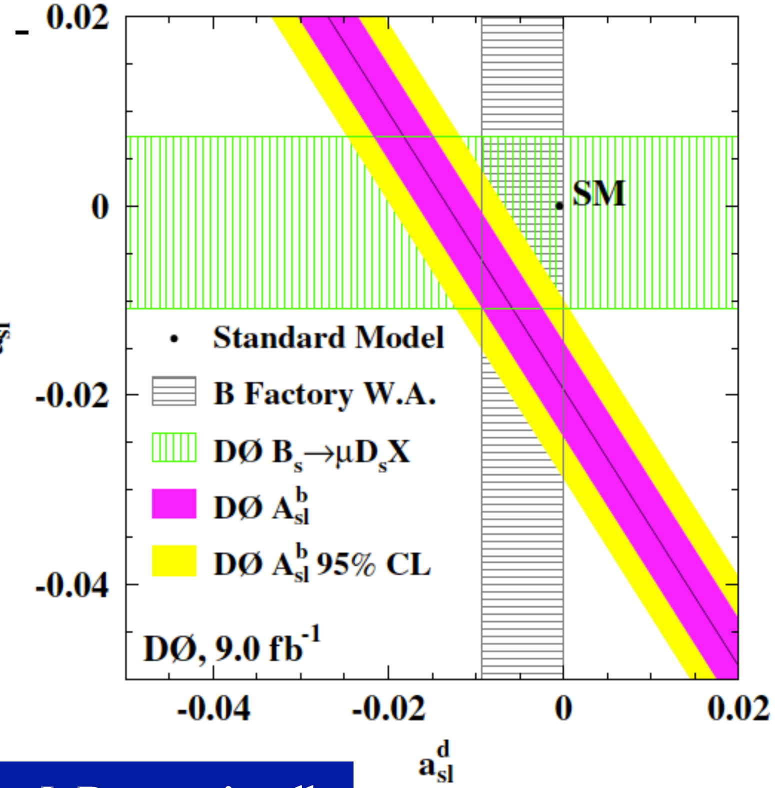
The semi-leptonic asymmetry

The D0 semileptonic asymmetry:



$$A_{sl}^b = \frac{N_{b\bar{b}}^{++} - N_{b\bar{b}}^{--}}{N_{b\bar{b}}^{++} + N_{b\bar{b}}^{--}} = C_d a_{sl}^d + C_s a_{sl}^s$$

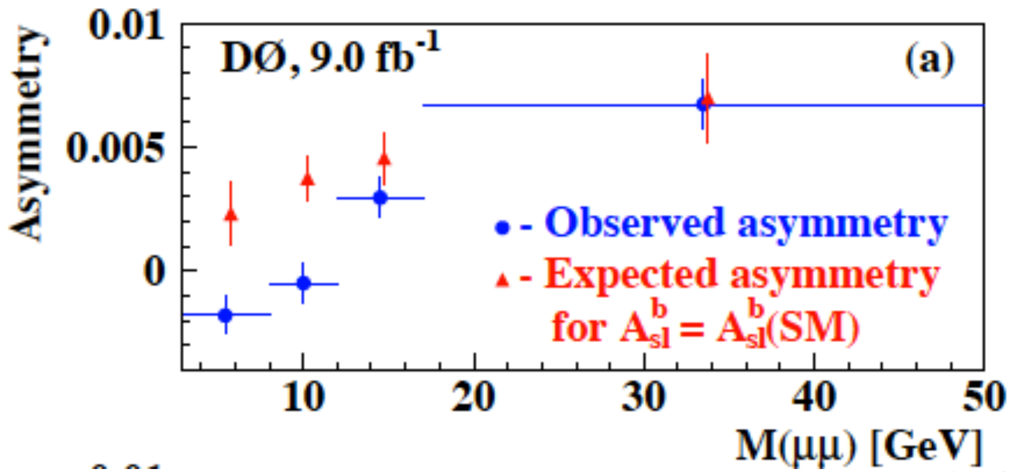
PRD 84 (2011) 052007



D0, 9 fb^{-1}, finds 3.9 σ discrepancy with SM:

$$A_{SL}^b = (-0.787 \pm 0.172(stat) \pm 0.093(syst))\%$$

$$A_{SL}^b(SM) = (-0.028^{+0.005}_{-0.006})\%$$



See I. Bertram's talk

3) New physics in B_d &/or B_s mixing?

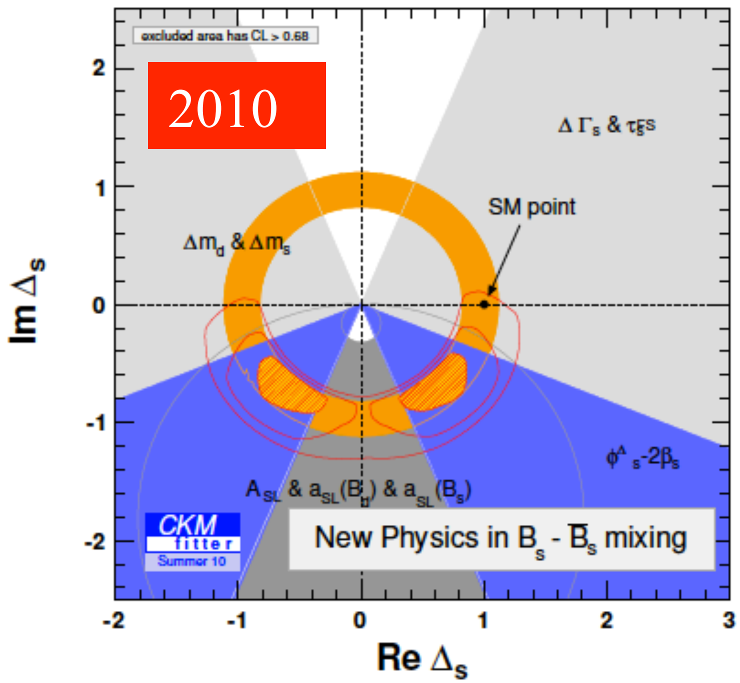
B_d

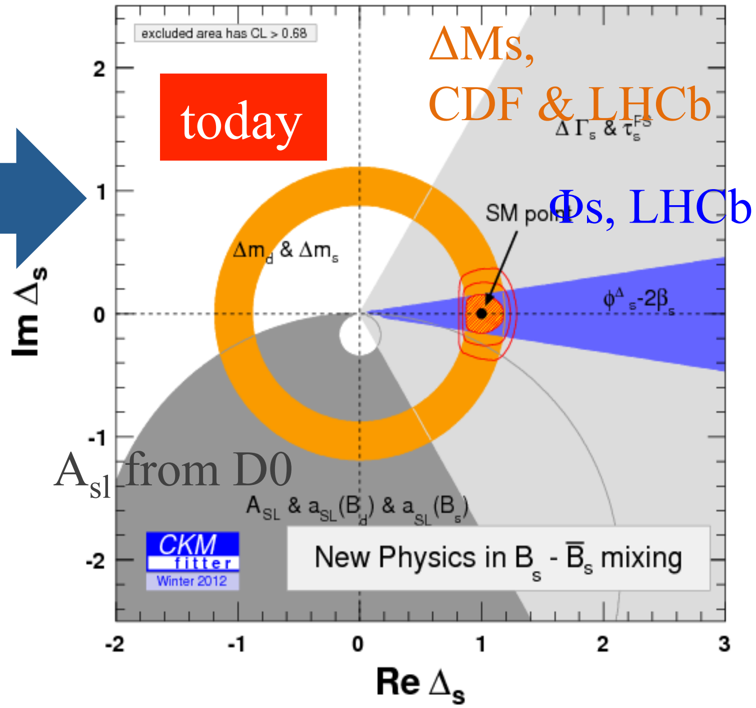
B_s

Blois castle, Louis XII fireplace

New Physics in M_{12}^s? 2010 vs 2012

Use parameterization of NP in: $M_{12}^s = M_{12}^{(SM,s)} \times \Delta_s$ with $\Delta_s = |\Delta_s|\, e^{i\varphi(NP)}$
[Lenz, Nierste and CKMFitter, arXiv 1203.0238]



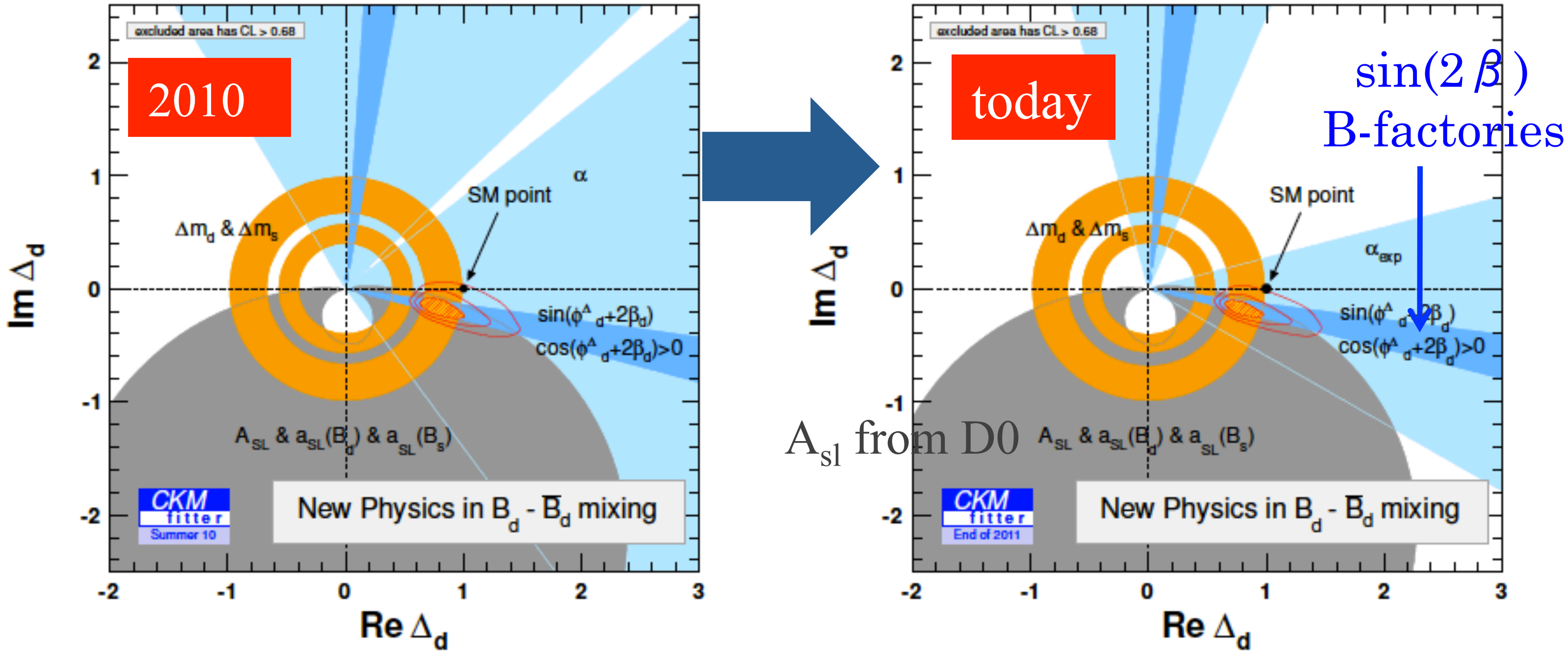


Tension in the B_s system (~2.7 σ in 2010) is gone thanks to the latest ϕ_s results but the discrepancy with A_{sl} is larger

New Physics in M_{12}^{d}? 2010 vs 2012

Use parameterization of NP in: $M_{12}^{d} = M_{12}^{(SM,d)} \times \Delta_d$ with $\Delta_d = |\Delta_d|\, e^{i\varphi(NP)}$

[Lenz, Nierste and CKMFitter, arXiv 1203.0238]



Tension in the B_d system augmented (2.7σ → 3.6 σ) but overall tension with SM decreased

Allowing for a new phase in B_d mixing could solve also the sin2β vs BR(B→τν) tension

[Lenz, Nierste et CKMFitter, arXiv 1203.0238]

4) The angle γ

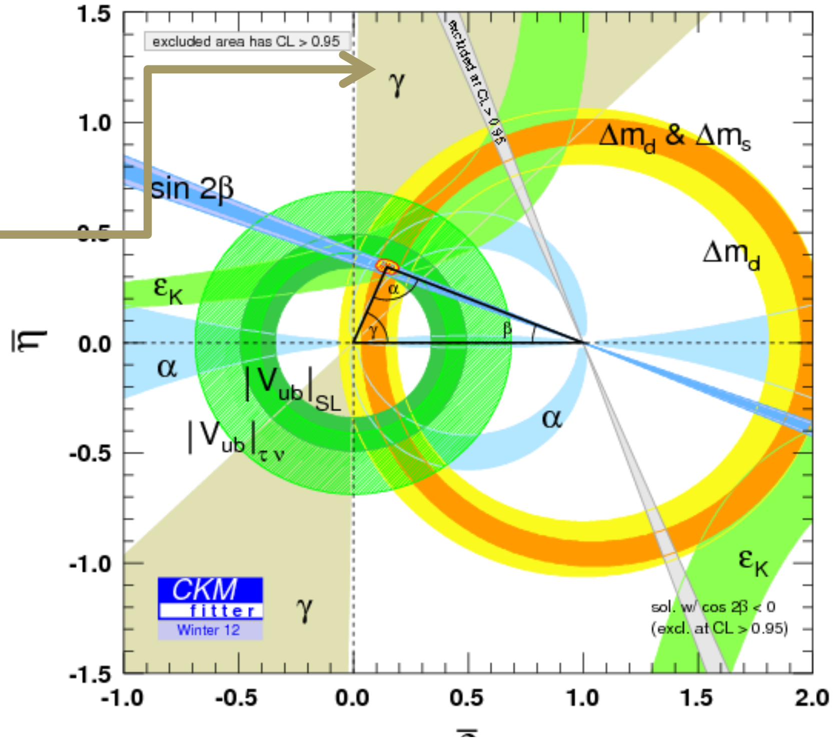
Blois castle, detail

The CKM matrix: γ angle

The tension in the ρ-η plane can profit by an accurate measurement of the angle γ

$$V = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$$\gamma = \phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right).$$



Despite the heroic efforts at the B-factories and CDF , γ error is still dominated by experimental uncertainties:

(direct) = $(66 \pm 12)^\circ$
(indirect) = $(67.2^{+4.4}_{-4.6})^\circ$

CKMFitter 2012, preliminary

Measuring γ via tree-level dominated processes

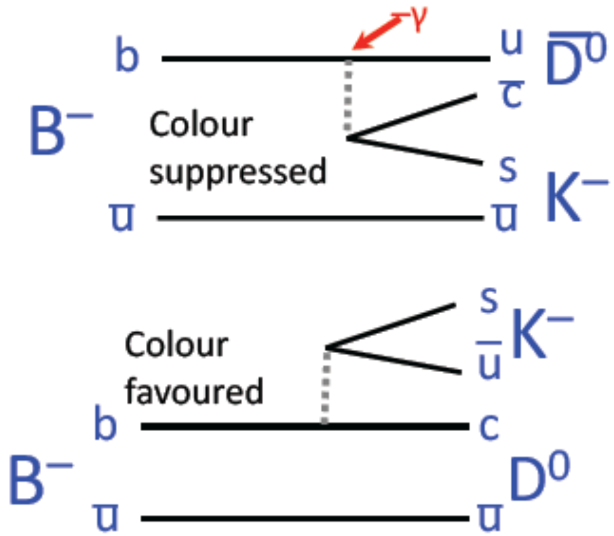
Tree level dominated processes allow clean extraction of gamma:

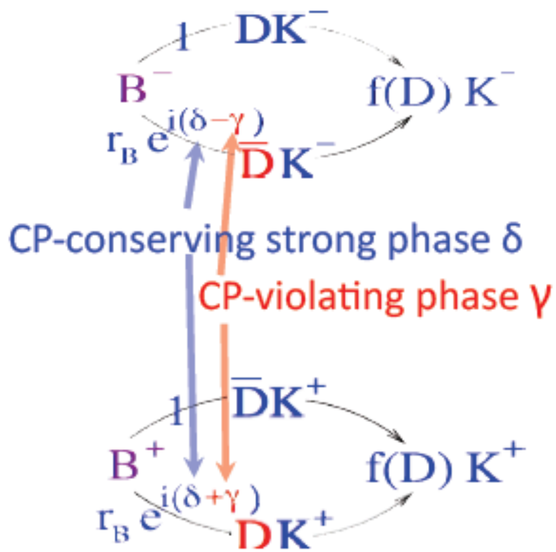
→access interference effects involving the phase between V_{ub} and V_{cb}

Time-integrated analysis uses $B^{\pm} \to D^{(*)} K^{\pm}$ with:

- D→ CP eigenstates (GLW)
- $D^{(*)}$ → flavour specific states (ADS)
- D → multi-body states (GGSZ):

Gronau, Wyler Phys.Lett.B265:172-176,1991, (GLW),
Gronau, London Phys.Lett.B253:483-488,1991 (GLW)
Atwood, Dunietz and Soni Phys.Rev.Lett. 78 (1997) 3257-3260 (ADS)
Giri,Grossman, Solfer,Zupan, Phys.Rev.D 68,0504018 (2003) (GGSZ/





The interference between color-suppressed and color-favored diagrams allows to extract the CP-violating phase gamma.

Measuring γ via tree-level dominated processes

Tree level dominated processes allow clean extraction of gamma:
→access interference effects involving the phase between V_{ub} and V_{cb}

Time-integrated analysis uses $B^{\pm} \to D^{(*)} K^{\pm}$ with:

- $D \to$ CP eigenstates (GLW)
- $D^{(*)} \to$ flavour specific states (ADS)
- $D \to$ multi-body states (GGSZ):

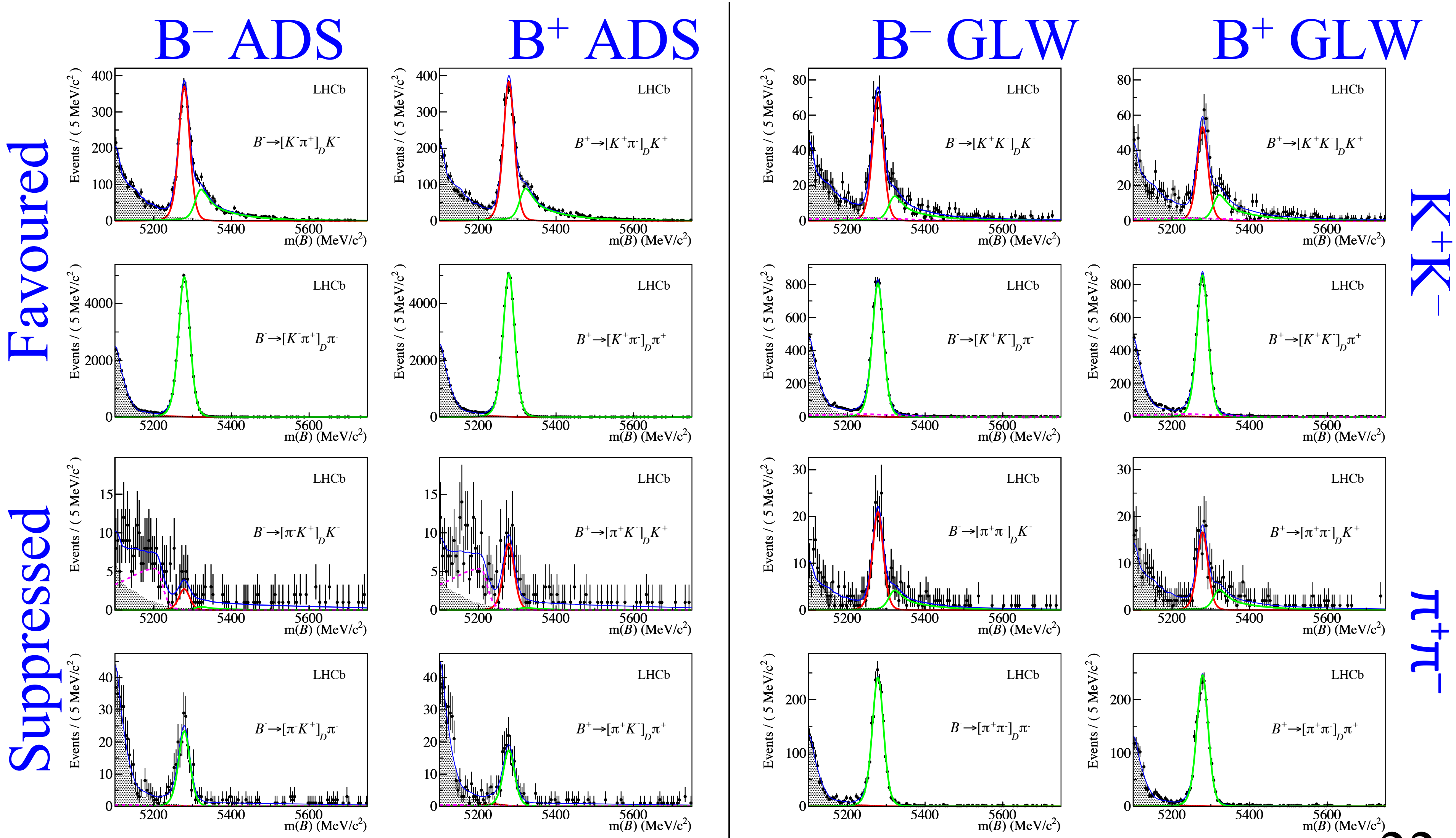
> Combined "ADS+GLW" strategy:

— Measure 16 rates: $B^- \to DK^-(\pi^-)$ and $B^+ \to DK^+(\pi^+)$ with $D \to K^-\pi^+$, $K^+\pi^-$, $\pi^+\pi^-$, K^+K^- and build up 6 CPV asymmetries and 3 ratios of partial widths and 4 charged separated partial widths of ADS suppressed-to-favoured mode

> Counting experiment. All parameters (r_B ,δ_B=ratio and phase between suppressed & allowed amplitudes, r_D, δ_D= ratio and phase between doubly Cabibbo suppressed and Cabibbo-favoured amplitudes) can be extracted simultaneously analyzing several decay channels (although CLEO-c input for δ_D helps).

$B^{\pm} \to DK^{\pm}$ and $B^{\pm} \to D\pi^{\pm}$

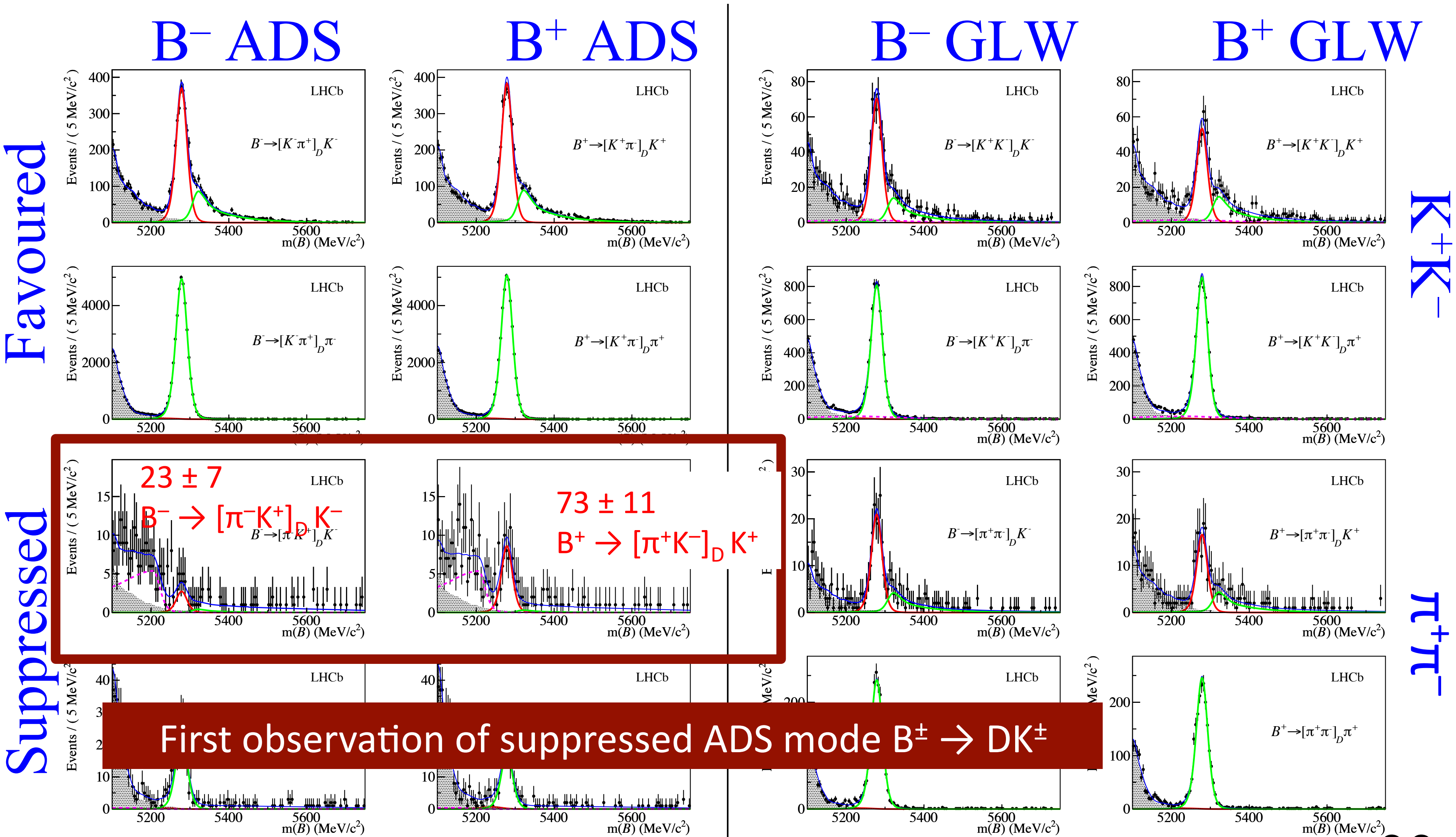
LHCb, 1 fb^{-1}, Phys. Lett. B 712 (2012), 203



22

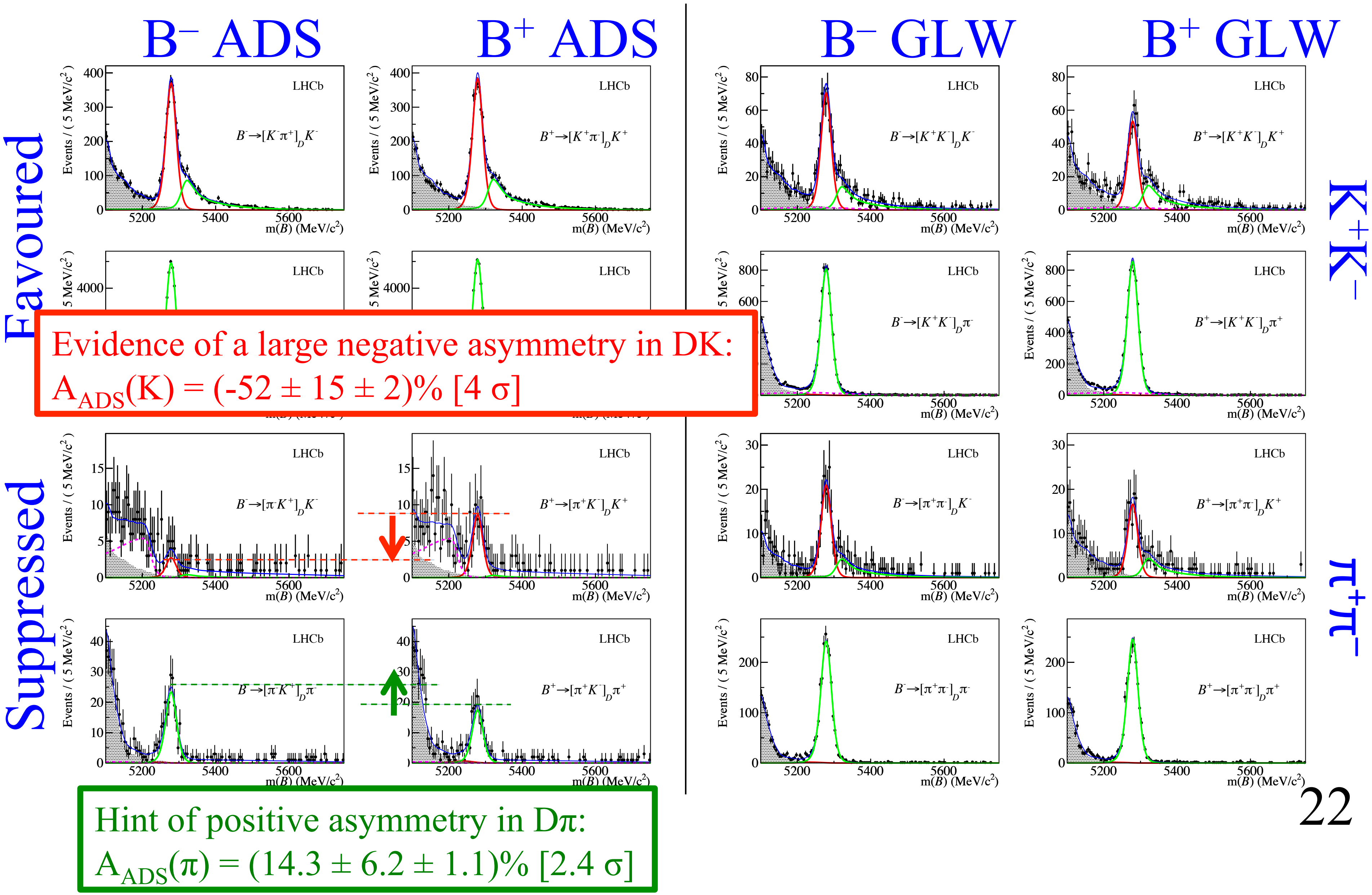
$B^{\pm} \rightarrow DK^{\pm}$ and $B^{\pm} \rightarrow D\pi^{\pm}$

LHCb, 1 fb^{-1}, Phys. Lett. B 712 (2012), 203



$B^{\pm} \to DK^{\pm}$ and $B^{\pm} \to D\pi^{\pm}$

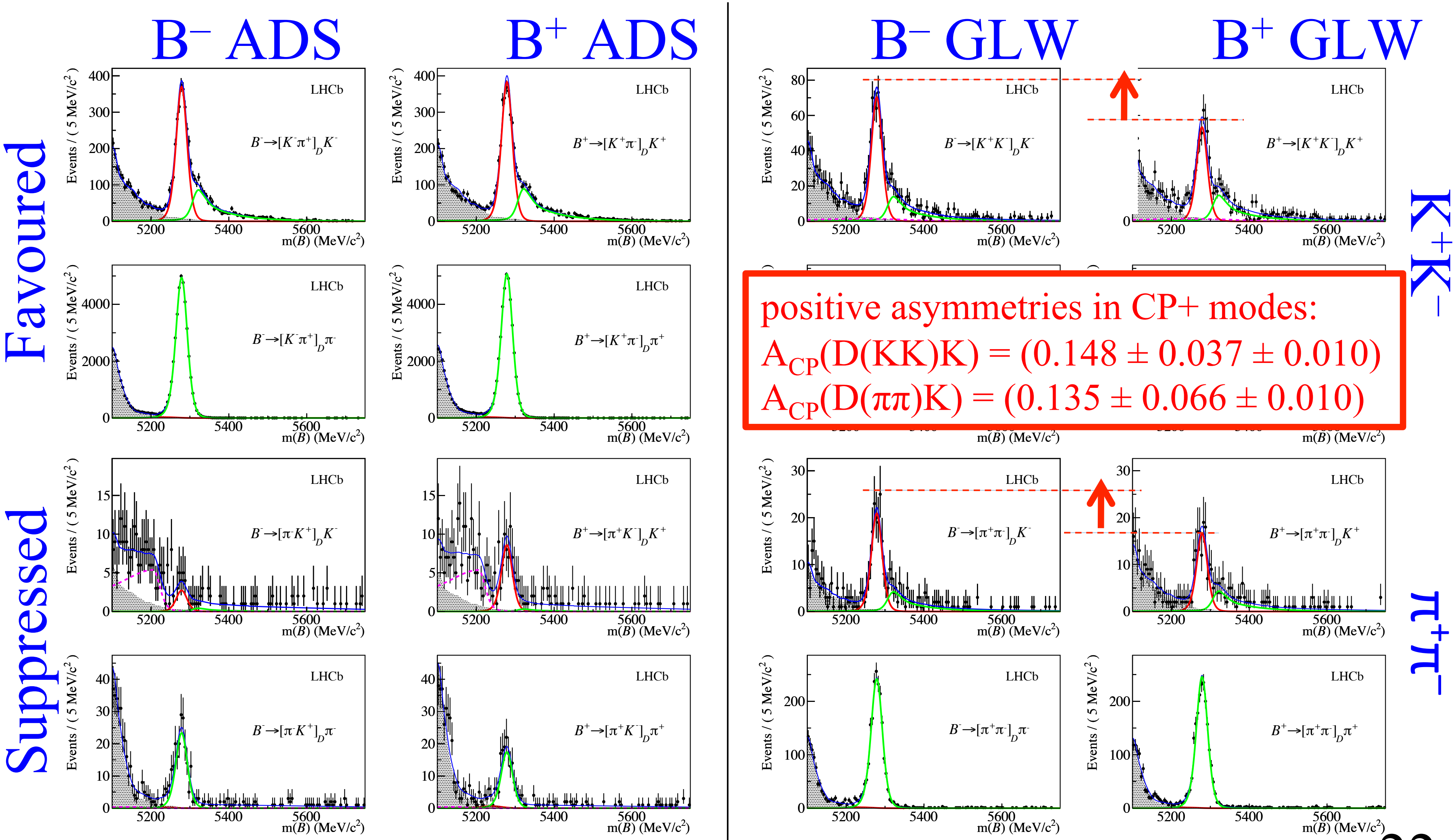
LHCb, 1 fb^{-1}, Phys. Lett. B 712 (2012), 203



22

$B^\pm \to DK^\pm$ and $B^\pm \to D\pi^\pm$

LHCb, 1 fb^{-1}, Phys. Lett. B 712 (2012), 203

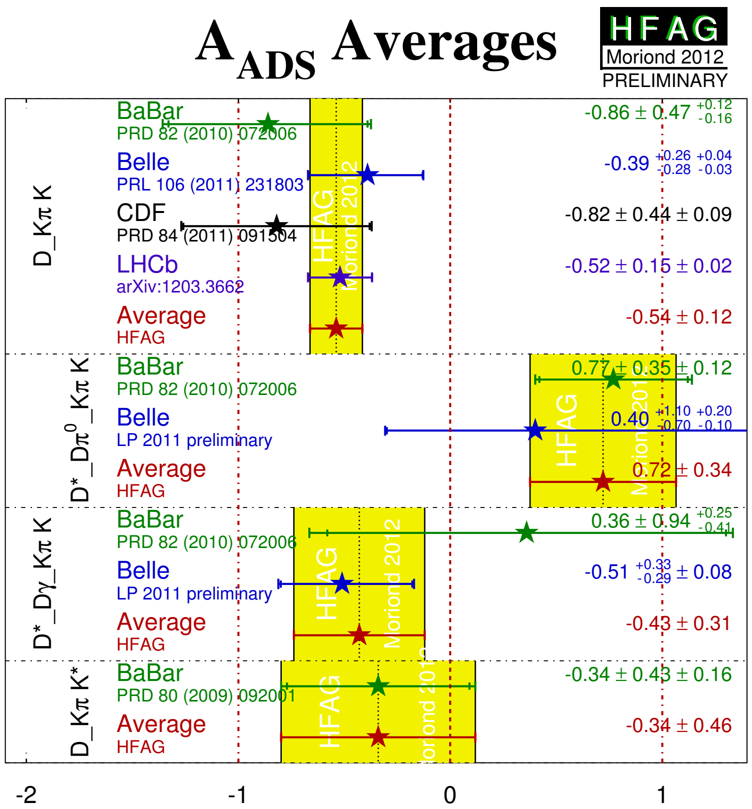


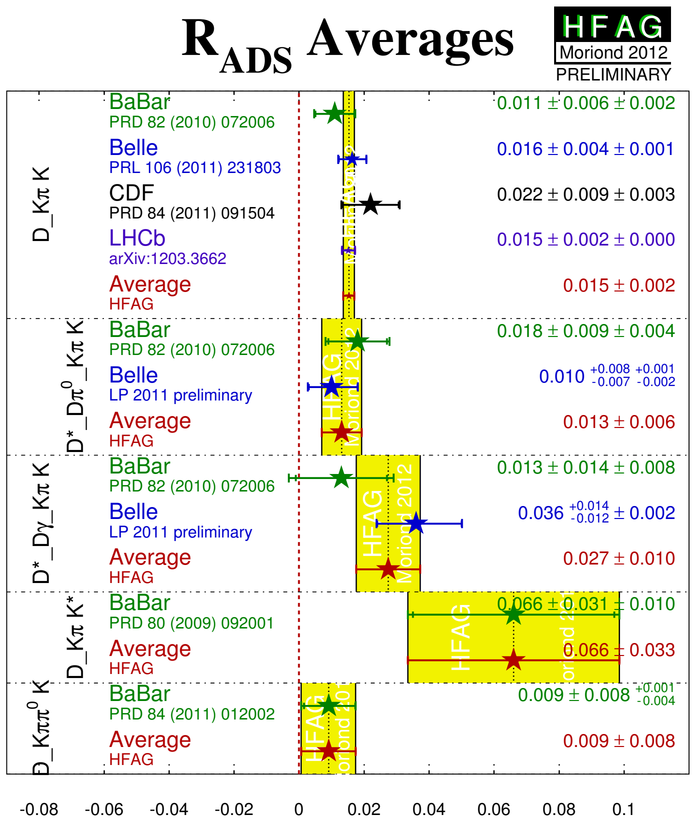
positive asymmetries in CP+ modes:

$A_{CP}(D(KK)K) = (0.148 \pm 0.037 \pm 0.010)$

$A_{CP}(D(\pi\pi)K) = (0.135 \pm 0.066 \pm 0.010)$

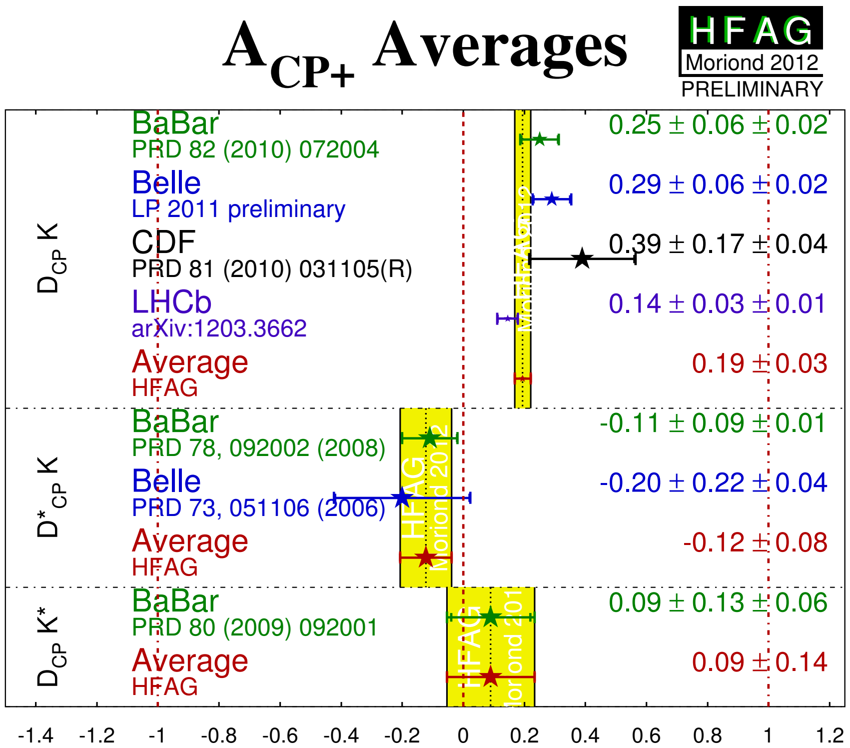
A_{ADS} and R_{ADS}: HFAG averages

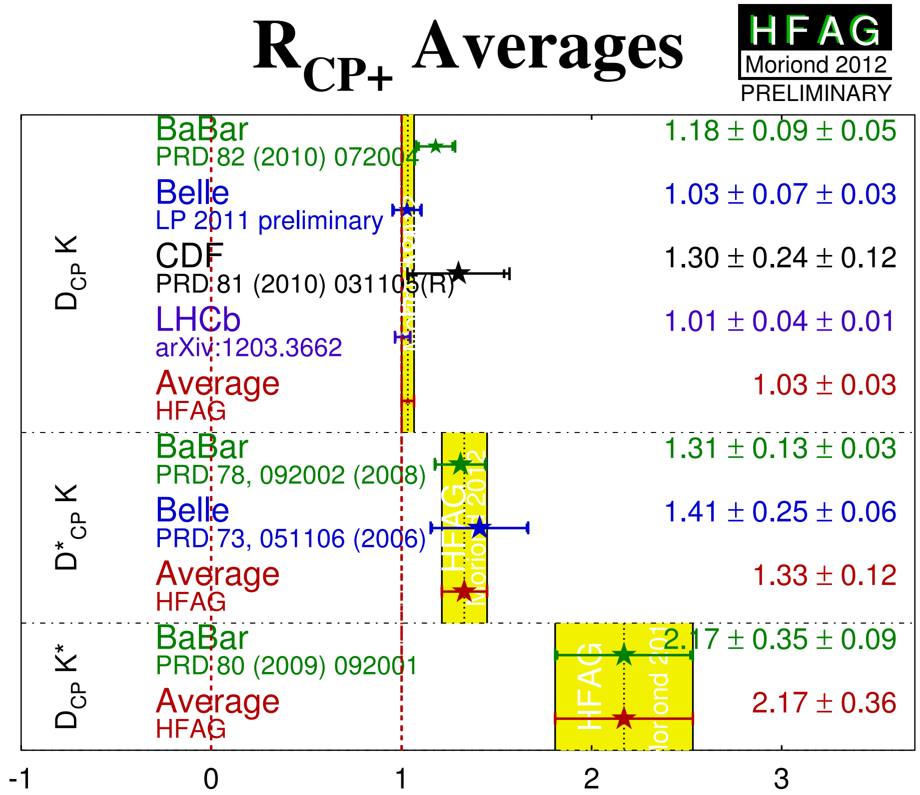




Where available, LHCb results are the most precise measurements.
B-factories dominate the other modes

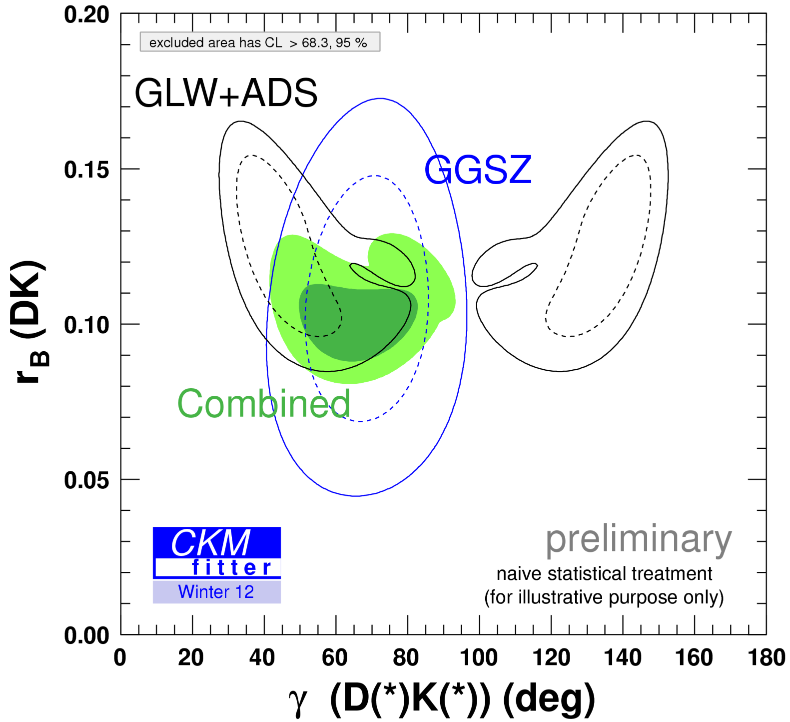
A_{CP} and R_{CP}: HFAG averages





Where available, LHCb results are the most precise measurements.
B-factories dominate the other modes

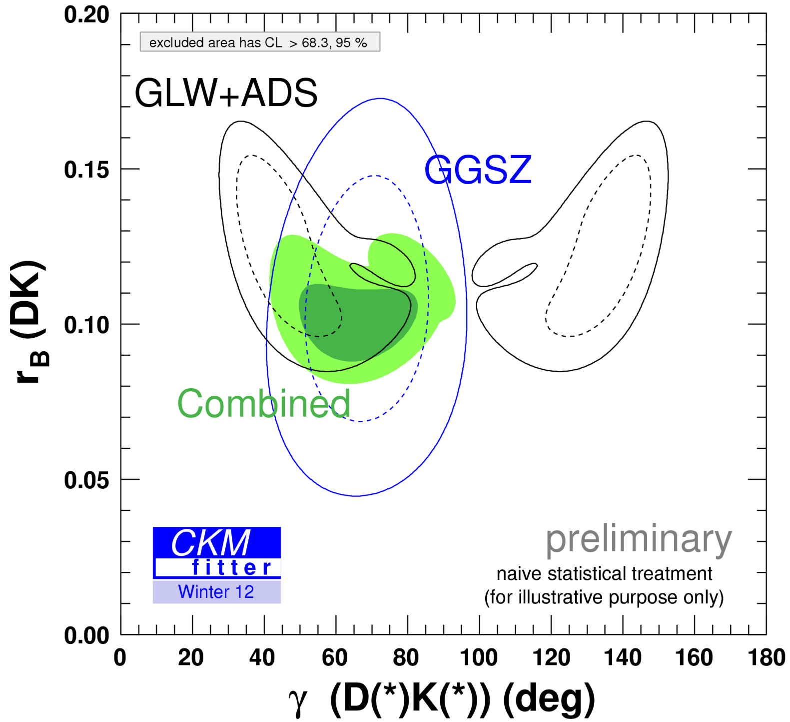
γ via tree-level dominated processes: combination



Most precise determination of ADS/GLW observables does not translate directly into most precise γ measurement.
→need input from many methods to pin down γ.

See A. Gomez's talk for a review of other methods to extract γ (time-dependent methods with Bs →Ds K and with B→ hh' decays)

γ via tree-level dominated processes: combination



Most precise determination of ADS/GLW observables does not translate directly into most precise γ measurement.
→need input from many methods to pin down γ.

See A. Gomez's talk for a review of other methods to extract γ (time-dependent methods with Bs →Ds K and with B→ hh' decays)

For example the GGSZ method (Dalitz plot analysis of B→ D K with D→$K^0_s h^+ h^-$ decay) provides the best constraint to γ with B-factories data:

Brand new result from Belle based on a model-independent analysis [Belle,arXiv:1204.6561]

$$\gamma = (77.3\ ^{+15.1}_{-14.9} \pm 4.1 \pm 4.3_{\delta D\ \text{from Cleo}})^\circ$$

LHCb expects to pin down the error on gamma to 5° by 2018: it will be interesting…

5) The charm sector

Chateau de Blois: Colombina by Francesco Melzi

CPV in charm

Large $D^0 - \overline{D}^0$ mixing discovered in 2007 by Babar and Belle and the new LHCb and CDF results on direct CP violation in charm system are giving new impetus to this field.

$$V = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

To first order:

1) No mixing if GIM is fully at work ($m_d == m_s$)
2) No CPV phase if CKM is fully at work (no phase with two generations)
So "in principle" large mixing and large CPV should be sign of New Physics……

CPV in charm

Large $D^0 - \overline{D}^0$ mixing discovered in 2007 by Babar and Belle and the new LHCb and CDF results on direct CP violation in charm system are giving new impetus to this field.

$$V = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

To first order:

1) No mixing if GIM is fully at work ($m_d == m_s$)
2) No CPV phase if CKM is fully at work (no phase with two generations)
So "in principle" large mixing and large CPV should be sign of New Physics……

Three types of CP violation:

→ In decay: amplitudes for a process and its conjugate differ (direct)
→In mixing: rates of $D^0 \to \overline{D}^0$ and $\overline{D}^0 \to D^0$ differ
→ in interference between mixing and decay diagrams

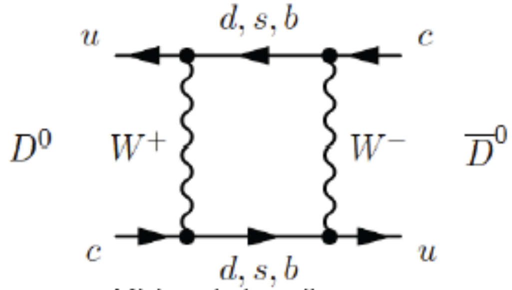
See M. Coombes & D. Epifanov's talks

Charm: indirect CPV

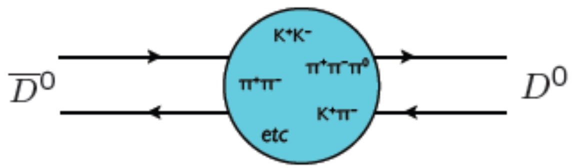
In SM indirect CPV expected very small and universal between CP eigenstates (10^{-3} for CPV parameters, 10^{-5} for observables like A_Γ)

→ but it can be enhanced by NP to o(%). [Bibliography too long, see spare slides]

Intermediate b : CKM suppressed
Intermediate d,s: GIM suppressed



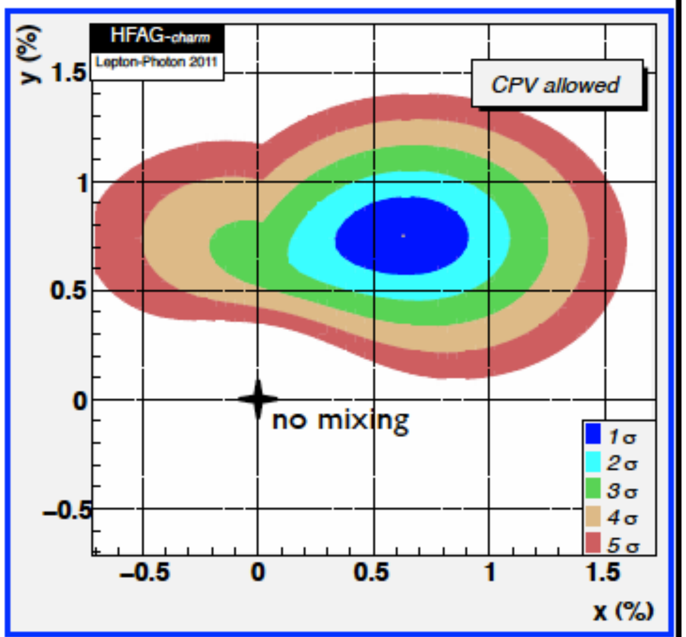
Mixing via box-diagram
Short range



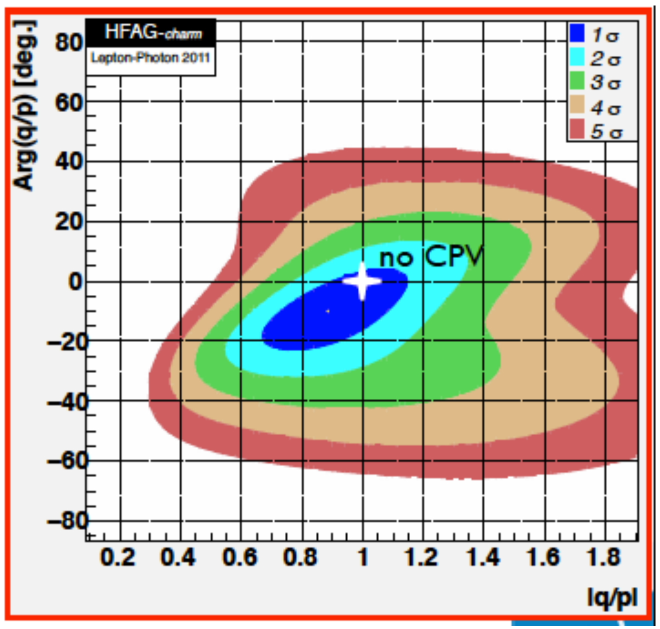
Mixes via hadronic intermediate states
Long range

Non perturbative: hard to predict in SM
Currently: |x|<0.01, |y|<0.01 (PRD69,114021)

"No-mixing" excluded at 10.2 σ:



CPV in mixing compatible with zero



Present constraints on CPV weak because CPV ~ $x_D \sin(2\varphi_D)$ and x_D~1%
→required sub-0.1% precision for CPV sensitivity!

See M. Coombes's talk

Charm: indirect CPV

Example mixing analysis is measurement of **"y_{CP}"**, which is D^0 width splitting parameter modified by CP-violating effects. Comparison to pure "y" measurements probes for CP-violation, as does measurement of pure CP-violating observable **A_Γ**

A_Γ: compare D^0 and $\overline{D}^0$ lifetimes in KK final state [tagged samples]

y_{CP}: compare lifetime of $D^0 \rightarrow$CP-eigenstate, eg. KK or ππ, to $D^0 \rightarrow$non-eigenstate eg. Kπ [untagged samples]

$$A_\Gamma = \frac{\tau(\overline{D}^0 \to K^-K^+) - \tau(D^0 \to K^+K^-)}{\tau(\overline{D}^0 \to K^-K^+) + \tau(D^0 \to K^+K^-)}$$

$$y_{CP} = \frac{\tau(K^-\pi^+)}{\tau(K^+K^-)} - 1$$

LHCb results based on 2010 data (~29 pb^{-1}) [LHCb,arXiv:1112.4698, subm. To JHEP]
not yet competitive with the world average

$$A_\Gamma = (-0.59 \pm 0.59 \pm 0.21)\%$$

c.f. WA of $(0.12 \pm 0.25)\%$

$$y_{CP} = (0.55 \pm 0.63 \pm 0.41)\%$$

c.f. WA of $(1.11 \pm 0.22)\%$

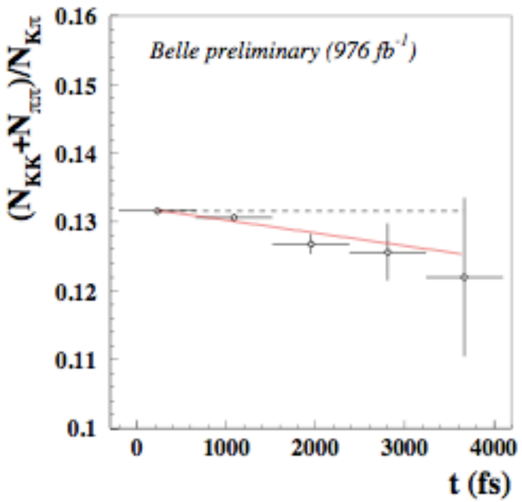
Charm: indirect CPV

Brand new results from B-factories presented two weeks ago at CHARM 2012.

Belle (Staric): measurements of D^0-D^0 mixing in $D^0 \rightarrow K^+ K^-$, $\pi+ \pi-$ decays updated with full dataset (976 fb^{-1}):

y_{CP} = (+1.11 ± 0.22 ± 0.11) % (4.5 σ)
→Most sensitive and most significant measurement of any mixing parameter up to now.

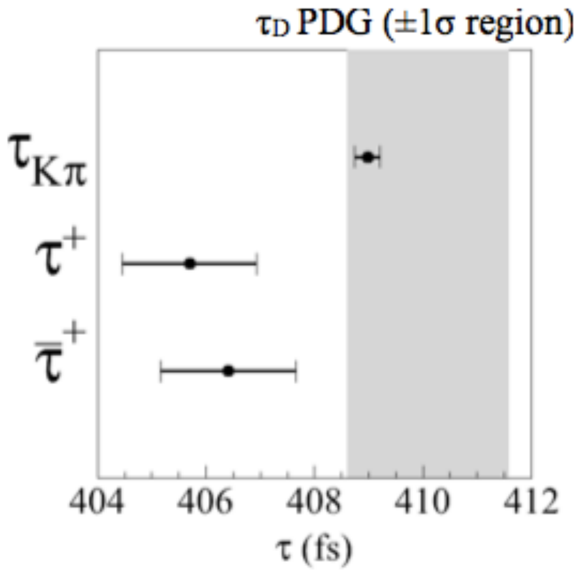
ΔΓ = (-0.03 ± 0.20 ± 0.08) %
→ Consistent with no indirect CPV



Babar (Neri): final value for y_{CP} and $\Delta Y == (1+y_{CP})A_\Gamma$ using 468 fb^{-1} of data:

y_{CP} = [0.720 ±0.180 (stat) ± 0.124 (syst)]%
ΔY = [0.088±0.255(stat) ± 0.058 (syst)] %

No mixing excluded at 3.3 σ level
No CPV observed



See M. Coombes's & I. Bertram's talks

Direct CPV in $D^0 \to \pi^+\pi^-$, K^+K^-:

CPV in mixing (indirect) can be related to direct CPV via the relation:

$$A_{CP}(h^+h^-) = a_{CP}^{dir}(h^+h^-) + \frac{\langle t \rangle}{\tau} a_{CP}^{ind}(h^+h^-)$$

$$A_{CP}(f) = \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\overline{D}^0 \to f)}$$

Considering ππ or KK final states we can build the difference:

$$A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = \Delta a_{CP}\,(\text{direct}) + \Delta\langle t\rangle/\tau \; a_{CP}^{\,ind}$$

HCP 2011: LHCb, 620 pb^{-1} : first evidence (3.5 σ) of CPV in charm:

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

LHCb, PRL 108 (2012) 11602

Moriond 2012: CDF, 9.6 fb^{-1}, confirms this result

$$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-0.62 \pm 0.21 \pm 0.10)\%$$

CDF, PRD 85 (2012) 012009

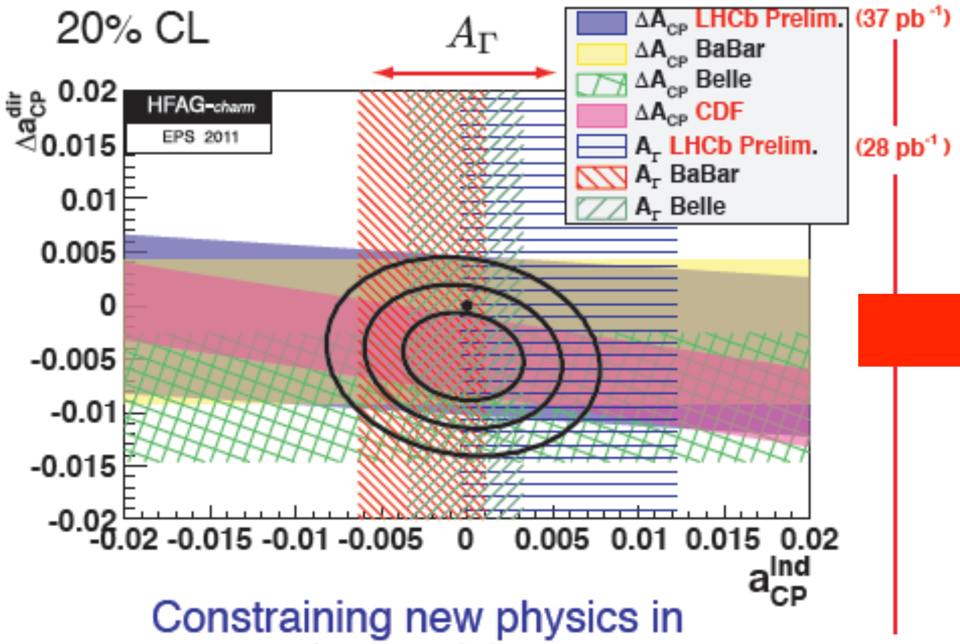
Combination of LHCb and CDF results in a 3.8 σ deviations from zero.

See M. Coombes's & I. Bertram's talks

Direct CPV in $D^0 \to \pi^+\pi^-, K^+K^-$:

EPS 2011 – July 2011

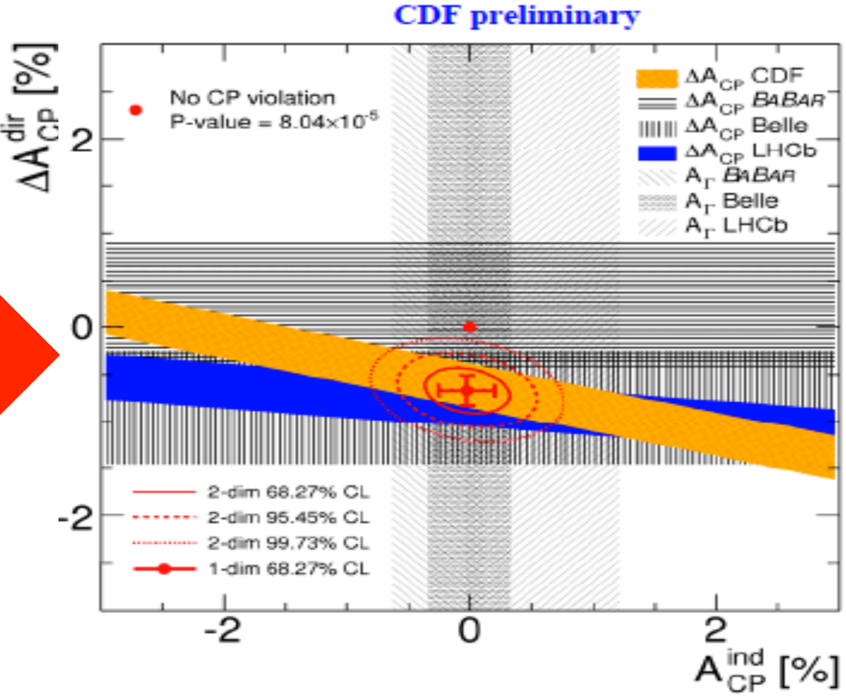
Data consistent with no CP violation at 20% CL



Constraining new physics in charm mixing

Moriond 2012 (6 months later)

CPV established at 3.8 σ level



What can we conclude from this result?
Is it SM or New Physics?

6) EW penguins
7) $B_s \rightarrow \mu\mu$: status of the art

(single decay measurements with NP discovery potential)

Chateau de Blois: royal emblems

Strategies for indirect NP search

- Improve measurement precision of CKM elements
  - Compare measurements of same quantity, which may or may not be sensitive to NP
  - Extract all CKM angles and sides in many different ways
    - any inconsistency will be a sign of New Physics

Precision CKM metrology, including NP-free determinations of CKM angle γ

- Measure FCNC transitions, where New Physics is more likely to emerge, and compare to predictions
  - e.g. OPE expansion for $b \rightarrow s$ transitions:

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \sum_i \Big[\underbrace{C_i(\mu) O_i(\mu)}_{\text{left-handed part}} + \underbrace{C_i'(\mu) O_i'(\mu)}_{\substack{\text{right-handed part} \\ \text{suppressed in SM}}} \Big]$$

Single B decay measurements with NP discovery potential

$i = 1,2$	Tree
$i = 3-6,8$	Gluon penguin
$i = 7$	Photon penguin
$i = 9,10$	Electroweak penguin
$i = S$	Higgs (scalar) penguin
$i = P$	Pseudoscalar penguin

  - New Physics may
    - modify $C_i^{(')}$ short-distance Wilson coefficients
    - add new long-distance operators $O_i^{(')}$

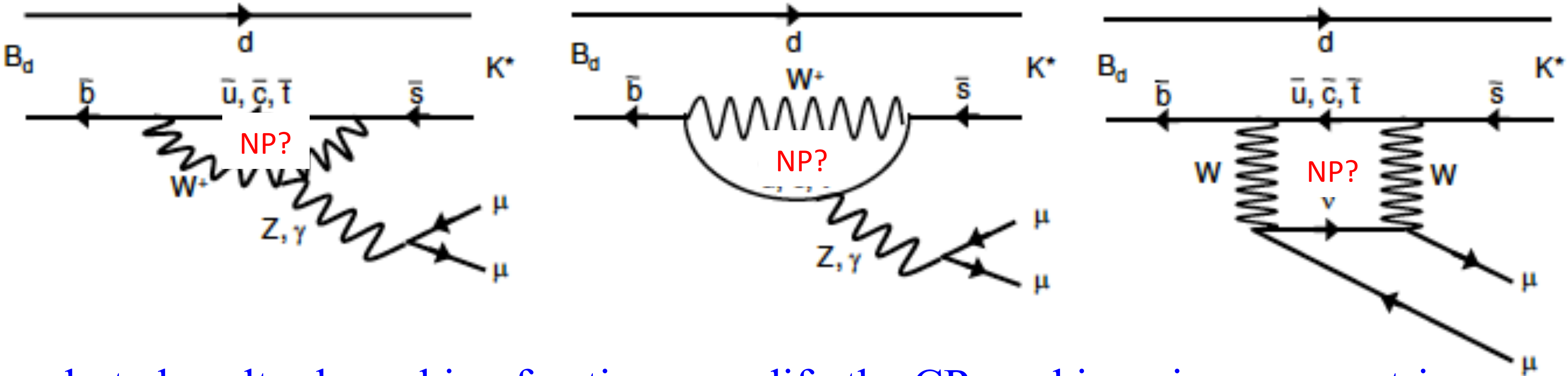
Search for NP in B→K$^{(*)}$l$^+$l$^-$

B→K$^{(*)}$l$^+$ l$^-$ are FCNC decays, forbidden at tree level.
Three effective Wilson coefficients can contribute:

- $C_7^{(')}$ from γ penguin (also in b→sγ process)
- $C_9^{(')}$($C_{10}^{(')}$) from vector (axial vector) part of W/Z box

New Physics can modify the helicity structure (angular distributions):

Interference of axial & vector currents give direct access to relative phases of diagrams involved [for example, W. Altmannshofer et al. JHEP 0901:019, 2009]



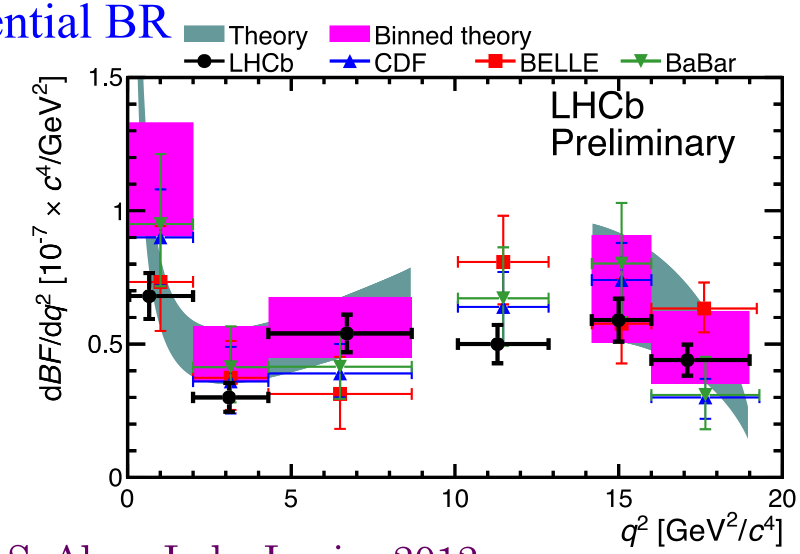
but also alter branching fractions, modify the CP- and isospin- asymmetries, produce lepton number violating decays (ex: B$^+$ → h$^-$ l$^+$ l$^+$)
[see R. Vazquez and S. Emery's talks]

see R. Vazquez & S. Emery's talks

Search for NP in $B \rightarrow K^{(*)} l^+ l^-$

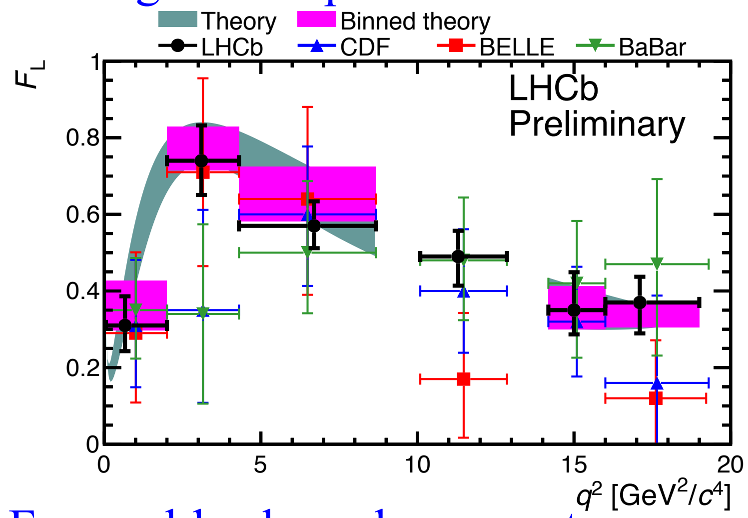
Partial BF and angular observables have been measured by Babar, Belle, CDF and LHCb: all show good agreement with SM predictions (within the uncertainties)

Differential BR



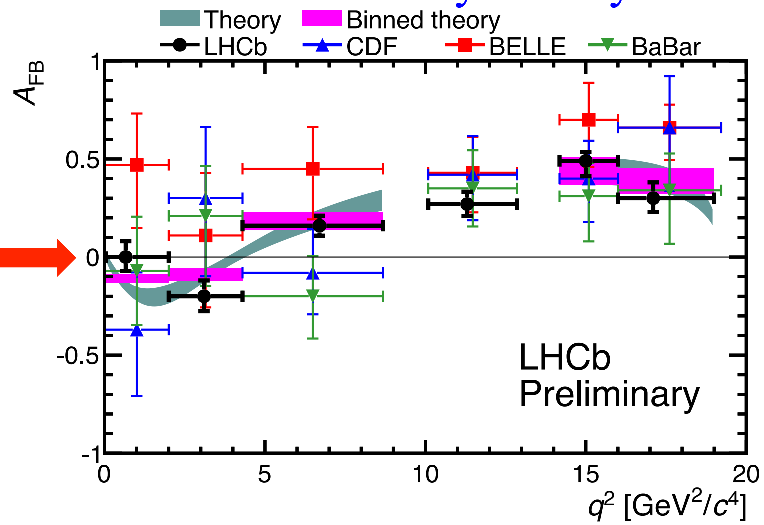
K* longitudinal polarization

q²= invariant di-leptons mass



Babar: S. Akar, Lake Louise 2012
Belle: Phys. Rev. Lett. 103, 171801 (2009)
CDF: Phys. Rev. Lett. 108, 081807 (2012)
LHCb: LHCb-CONF-2012-008
Theory predictions:
C. Bobeth, G. Hiller, D. van Dyk, JHEP 07 067 (2011)

Forward-backward asymmetry



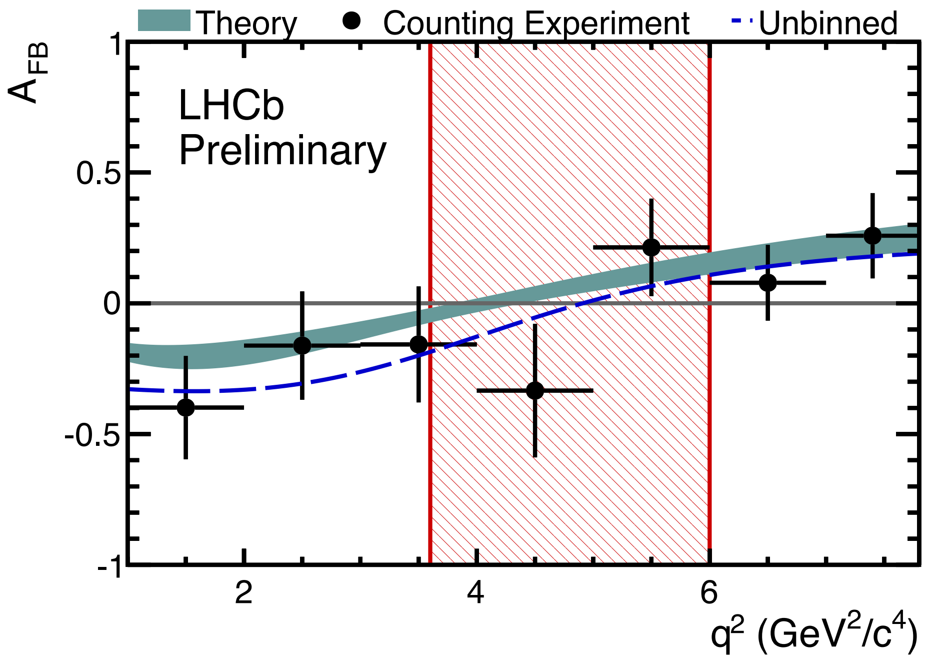
Tensions" seen by others in region $1 < q^2 < 6$ GeV^2/c^4 not confirmed by LHCb

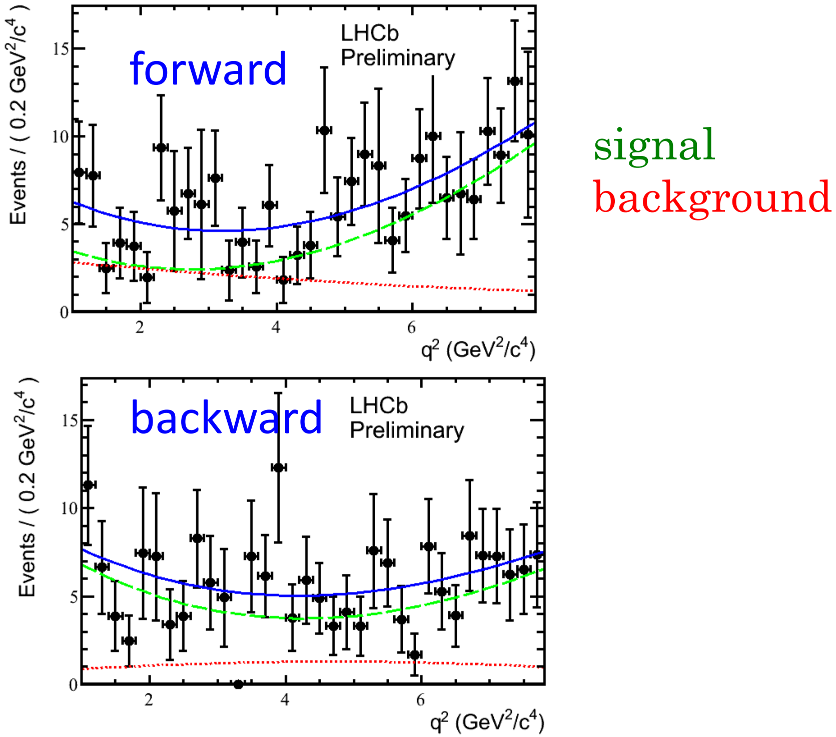
see R. Vazquez's talk

Search for NP in $B \rightarrow K^{(*)} l^+ l^-$

Measurement of the zero crossing of A_{FB} gives access to ratio of Wilson coefficients C_7^{eff}/C_9^{eff}
The zero crossing point is largely free from form-factor uncertainties
Extracted through a 2D fit to the forward and backward-going $m(B^0)$ and q^2 distributions

LHCb: LHCb-CONF-2012-008





LHCb has performed the world's first measurement of the zero-crossing point:

$q_0^2 = 4.9^{+1.1}_{-1.3}$ GeV^2

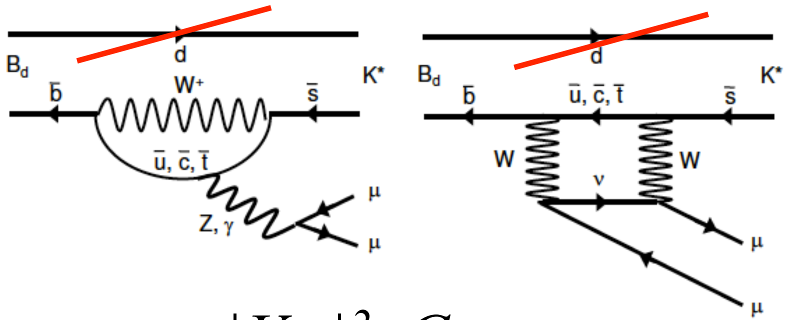
consistent with SM prediction: 4-4.3 GeV^2 [Eur. Phys. J C 41 (2005) 173-188]

see R. Vazquez's , I. Bertram and L.Oakes talks

Search for NP in $B_{s,d} \rightarrow \mu\mu$ decays

$B_{(d,s)} \rightarrow \mu\mu$ is the best way for LHCb to constrain the parameters of the extended Higgs sector in MSSM, fully complementary to direct searches

Main SM diagrams



$\sim |V_{ts}|^2, C_A$

Double suppressed decay: FCNC process and helicity suppressed:

→ very small in the Standard Model but well predicted:

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

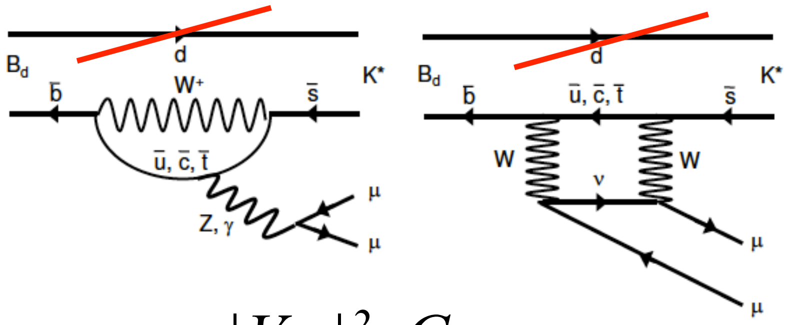
$B_d \rightarrow \mu^+\mu^- = (1.0 \pm 0.1) \times 10^{-10}$

Buras et al., arXiv:1007.5291 and references therein

Search for NP in $B_{s,d} \rightarrow \mu\mu$ decays

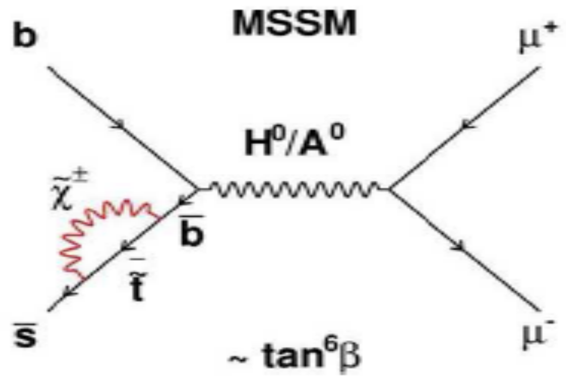
$B_{(d,s)} \rightarrow \mu\mu$ is the best way for LHCb to constrain the parameters of the extended Higgs sector in MSSM, fully complementary to direct searches

Main SM diagrams



$\sim |V_{ts}|^2, C_A$

\+



$\sim C_P, C_S$

Double suppressed decay: FCNC process and helicity suppressed:

→ very small in the Standard Model but well predicted:

$B_s \rightarrow \mu^+\mu^- = (3.2\pm0.2)\times10^{-9}$

$B_d \rightarrow \mu^+\mu^- = (1.0\pm0.1)\times10^{-10}$

Buras et al., arXiv:1007.5291 and references therein

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

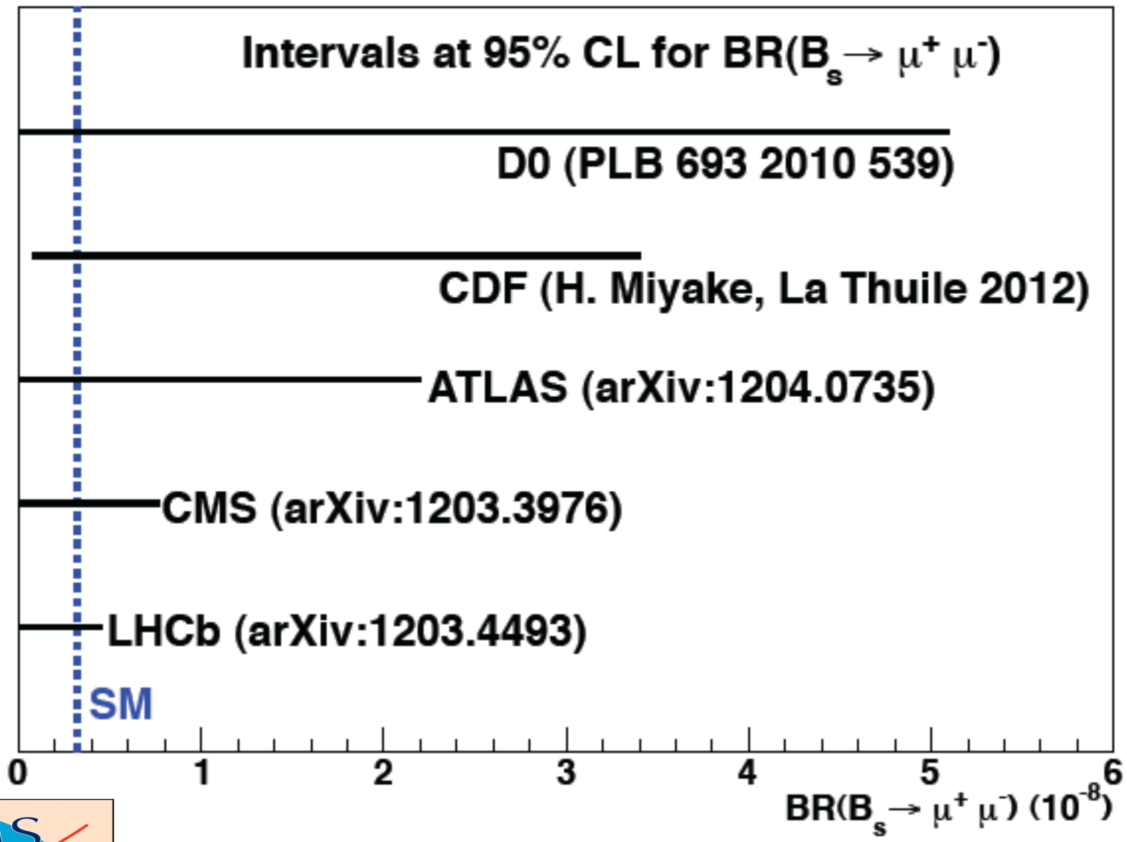
$$(c_{S,P}^{MSSM})^2 \propto \left(\frac{m_b m_\mu \tan^3\beta}{M_A^2}\right)^2$$

MSSM, large tanβ approximation

see R. Vazquez's , I. Bertram and L.Oakes talks

Search for NP in $B_{s,d} \rightarrow \mu\mu$ decays

Nice race all around the world to improve the limit…..



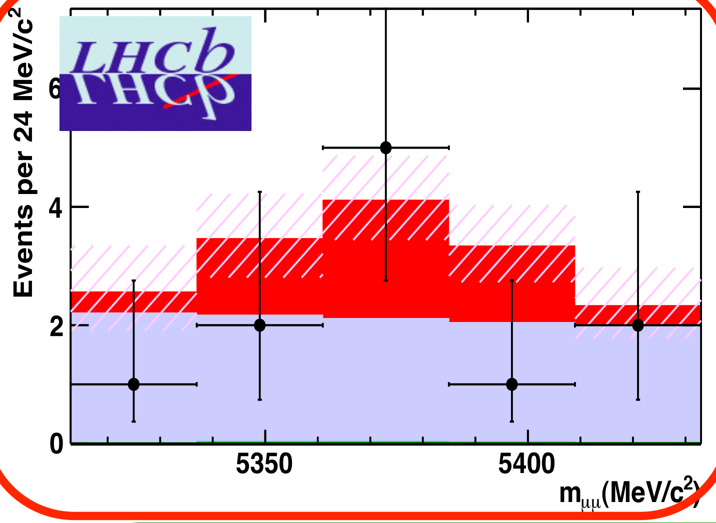
Limit @95%CL	L [fb^{-1}]
D0: < 51×10^{-9}	6.1
CDF: $[0.8,34] \times 10^{-9}$	10
ATLAS:< 22×10^{-9}	2.4
CMS: < 7.7×10^{-9}	4.9
LHCb: <4.5×10^{-9}	1

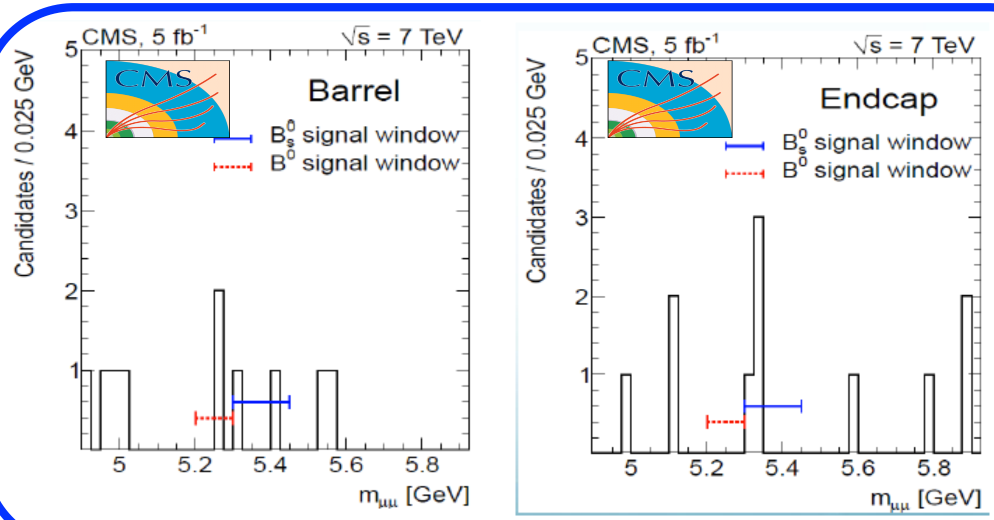
……and now we are really close to the SM value !

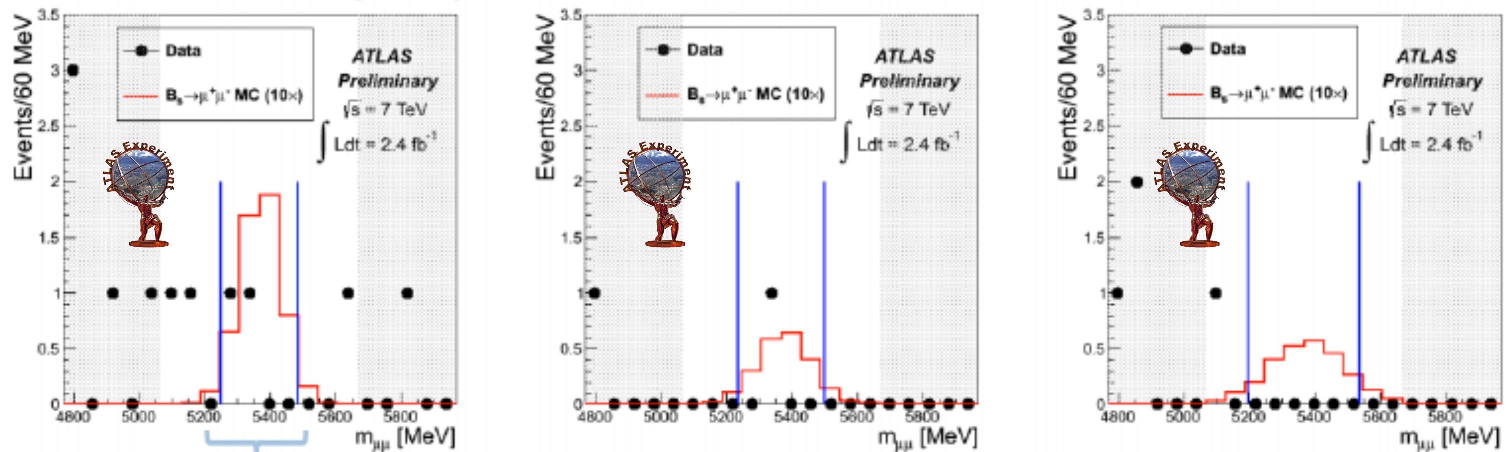
see R. Vazquez's , I. Bertram and L.Oakes talks

Search for NP in $B_{s,d}$→μμ decays

The Bs→μμ signal is slowly emerging from data…







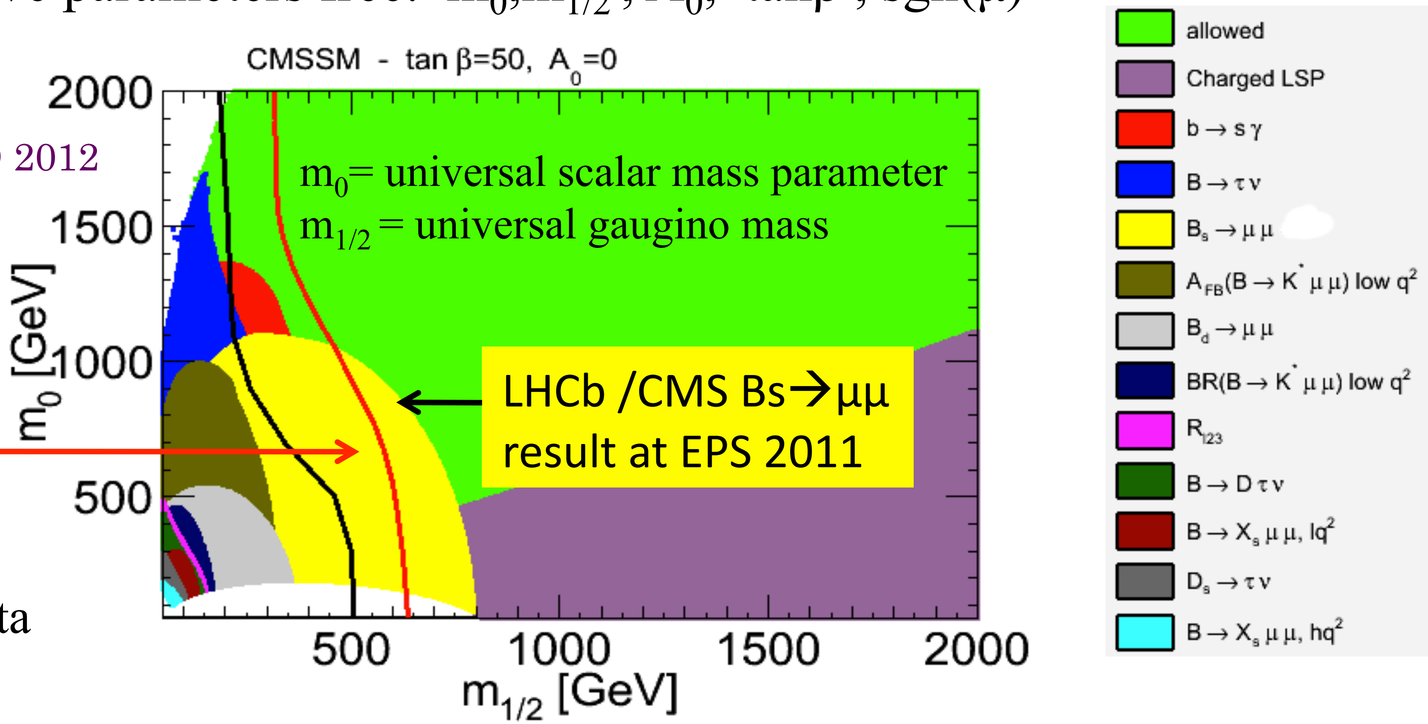
….. But which is the BR? 3 σ observation possible if BR=BR(SM) at the LHC with 2011+2012 data

Impact of $B_s \rightarrow \mu^+\mu^-$ on global SUSY fits

- Global fit include many results:
  - Higgs and SUSY searches at LHC, dark matter searches at XENON100, EW and B physics measurements (such as $b \rightarrow s\gamma$, $B^+ \rightarrow \tau\nu$, $B_s \rightarrow \mu\mu$), g–2
- A constrained version of MSSM, the CMSSM:

→ only five parameters free: $m_0, m_{1/2}$, A_0, $\tan\beta$, $\mathrm{sgn}(\mu)$

N. Mahmoudi
Moriond QCD 2012



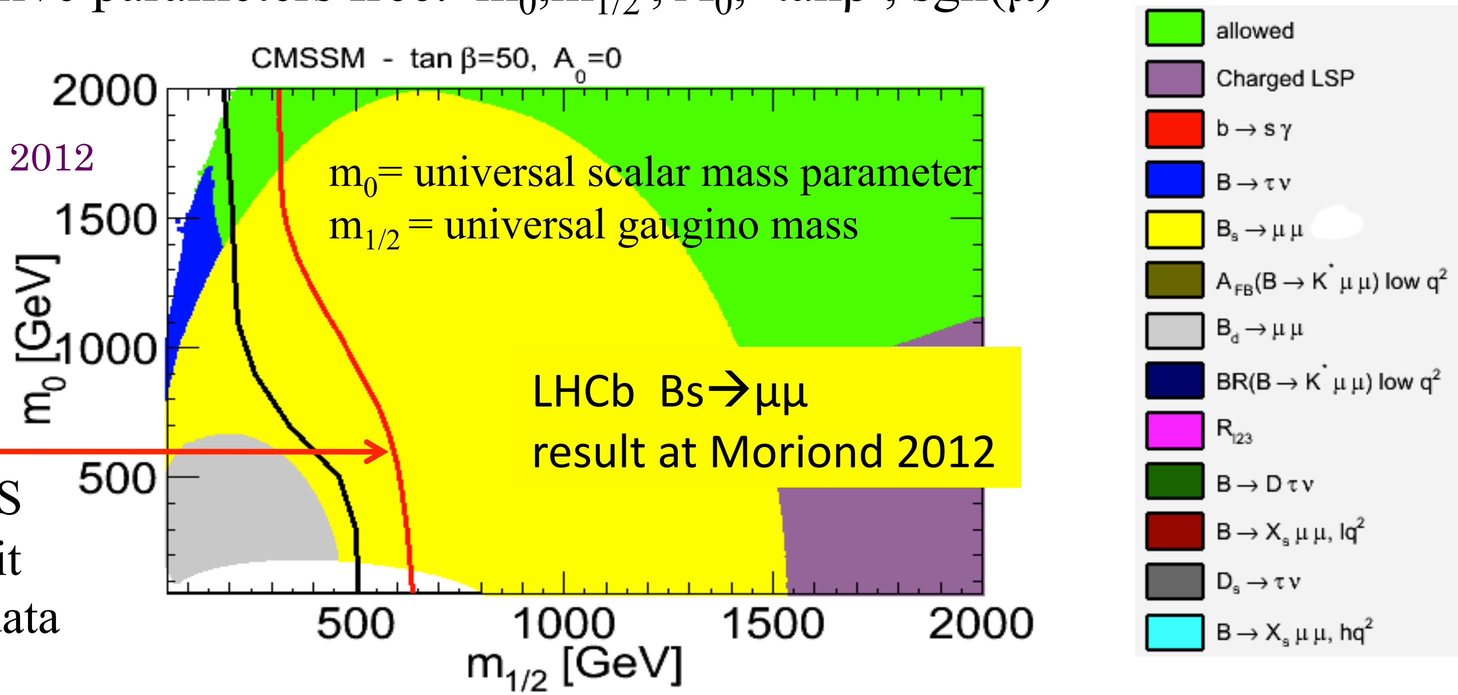
Red line: CMS exclusion limit with 4.4 fb^{-1} data

Impact of $B_s \to \mu^+\mu^-$ on global SUSY fits

- Global fit include many results:
  - Higgs and SUSY searches at LHC, dark matter searches at XENON100, EW and B physics measurements (such as $b \to s\gamma$, $B^+ \to \tau\nu$, $B_s \to \mu\mu$), g–2
- A constrained version of MSSM, the CMSSM:

→ only five parameters free: $m_0, m_{1/2}$, A_0, $\tan\beta$, $\mathrm{sgn}(\mu)$

N. Mahmoudi
Moriond QCD 2012



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

Recent $B_s \to \mu\mu$ results disfavor models with NP at the TeV scale and large $\tan\beta$

Summary & Open Questions

1) $\sin(2\beta)$ vs BR($B \rightarrow \tau\nu$): → BR too high or $\sin(2\beta)$ too low?
2) The "strange" brother: CPV in Bs
→ ϕ_s in agreement with SM predictions
3) New physics in B_s &/or B_d mixing? → A_{sl} needs independent checks
4) The γ angle → more precision needed
5) CPV in charm → NP or SM?
6) EW penguins in agreement with SM predictions → MFV or NP at 10 TeV scale?
7) BR($B_s \rightarrow \mu\mu$):
→ rapidly approaching SM value (maybe lower than SM?)
→ NP at the TeV scale in models with large $\tan\beta$ highly disfavored

Brief history of the Blois castle:

4) XXI^{st} century: Les Rencontres de Blois 2012

- physics model: the Standard Model with the CKM mechanism controlling the interactions between quarks
- anomalies: many

(....which is the end of the story?)

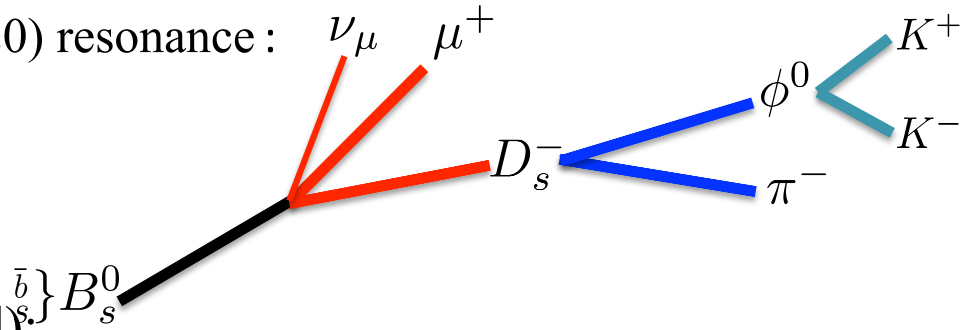
Parallel sessions on Heavy Flavour (Tuesday & Wednesday afternoon)

CP violation in b→s penguin and T,CPT violation at BaBar and Belle – S. Emery
CP violation in the beauty system at LHCb – A. Gomez
CP violation in charm and tau at BaBar and Belle – D. Epifanov
CP violation in the charm system at LHCb – M. Coombes
CKM related measurements (including CPV) at BaBar and Belle – J. Dalseno
Rare beauty and charm decays at LHCb - Ricardo Vazquez Gomez
Recent Heavy Flavor Results from the Tevatron - Iain Bertram
Hadronic B decays at LHCb - Thomas Latham
b-physics with ATLAS and CMS - Louise Oakes

STOP

a_{SL}^{s} @ LHCb

- Exclusive B^0_s channel with Φ(1020) resonance :



- The main formula again (untagged):

$$\frac{\Gamma(D_s^-\mu^+\nu)-\Gamma(D_s^+\mu^-\bar{\nu})}{\Gamma(D_s^-\mu^+\nu)+\Gamma(D_s^+\mu^-\bar{\nu})}=\frac{a_{fs}^s}{2}+\left(a_p-\frac{a_{fs}^s}{2}\right)\underbrace{\frac{\int_{t=0}^{\infty}e^{-\Gamma t}\cos(\Delta M t)\varepsilon(t)dt}{\int_{t=0}^{\infty}e^{-\Gamma t}\cosh(\frac{\Delta\Gamma}{2}t)\varepsilon(t)dt}}_{\text{IF}}$$

- ε(t) is the detector acceptance function.

- The fraction of integrals, IF, has been evaluated as ~0.02

- a_p is at most a few percent. Thus: a_p *0.02 ≈ 10^{-4}.

Method to resolve the ambiguity

[Y. Xie et al., JHEP 09 (2009) 074]

Two-fold ambiguity

$$(\phi_s, \Delta\Gamma_s, \delta_{\parallel} - \delta_0, \delta_{\perp} - \delta_0, \delta_s - \delta_0) \longleftrightarrow (\pi - \phi_s, -\Delta\Gamma_s, \delta_0 - \delta_{\parallel}, \pi + \delta_0 - \delta_{\perp}, \delta_0 - \delta_s)$$

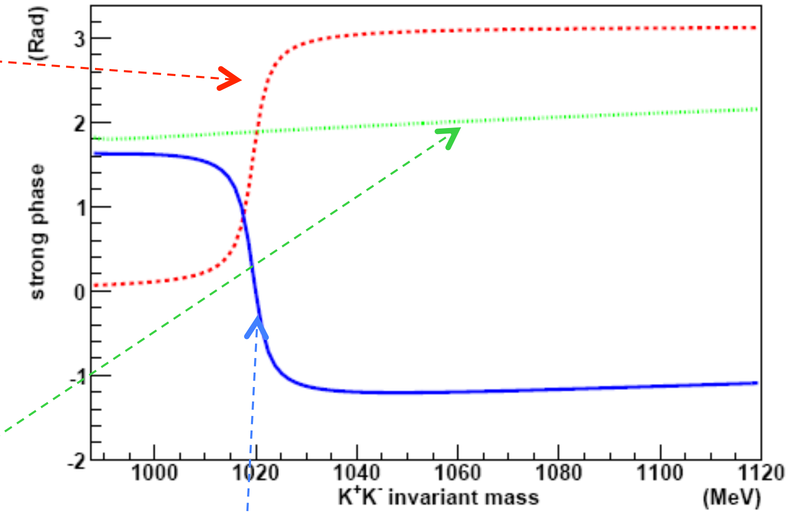
K^+K^- P-wave:

Phase of Breit-Wigner amplitude increases rapidly across $\phi(1020)$ 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 $\phi(1020)$ mass region

Resolution method: choose the solution with decreasing trend of $\delta_S - \delta_P$ vs m_{KK} in the $\phi(1020)$ mass region

The dimuon asymmetry

The central value of the diμasymmetry is larger than *theoretically* possible!

$$
\begin{aligned}
A_{sl}^{Max.} &\approx (0.594 \pm 0.022)(5.4 \pm 1.0) \cdot 10^{-3} \frac{\sin(\phi_d^{SM} + \phi_d^{\Delta})}{|\Delta_d|} \\
&+ (0.406 \pm 0.022)(5.0 \pm 1.1) \cdot 10^{-3} \frac{\sin(\phi_s^{SM} + \phi_s^{\Delta})}{|\Delta_s|} \\
&\approx (-3.1; -4.8[1\sigma]; -9.0[3\sigma]) \cdot 10^{-3} \\
A_{sl}^{D0} &= (-7.8 \pm 2.0) \cdot 10^{-3}
\end{aligned}
$$

A.L. 1108.1218

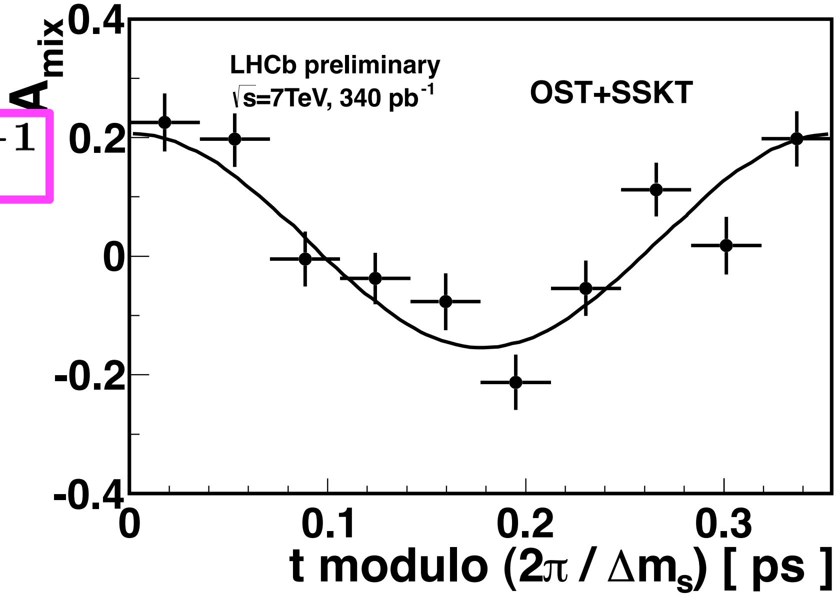
Possible solutions:

- HQE violated by $\mathcal{O}(200\% - 3300\%)$ now excluded!
- Huge new physics in Γ_{12}? - see talk by Uli Haisch
- Contradiction to $B_s \to J/\psi\phi$ from LHCb? - Penguins
- Stat. fluctuation (1.5 σ) of the D0 result? (Actual value is below -4.8 per mille?)
  Independent measurements of semi leptonic asymmetries needed!

B_s mixing frequency ΔM_s

LHCb result obtained with 0.34/fb :

$$\Delta m_s = 17.725 \pm 0.041 \pm 0.026 \ \mathrm{ps}^{-1}$$



$B_s \rightarrow D_s (3)\pi$

Compare older results:

CDF (2006) (PRL97,242003 (2006))

$$\Delta m_s = 17.77 \pm 0.10 \pm 0.07 \ \mathrm{ps}^{-1}$$

LHCb, 37/pb (PLB 709 (2012) 177, arXiv 1112.4311)

$$\Delta m_s = 17.63 \pm 0.11 \pm 0.03 \ \mathrm{ps}^{-1}$$

WA fully dominated by LHCb result
and in agreement with SM predictions:

$$\Delta m_s^{\mathrm{WA}} = 17.731 \pm 0.045 \ \mathrm{ps}^{-1}$$

Δms (SM) = (17.3 ± 2.6) ps-1

Lenz,Nierste arXiv:1102.4274

Experimental precision ahead of theory
→ Improved lattice results needed

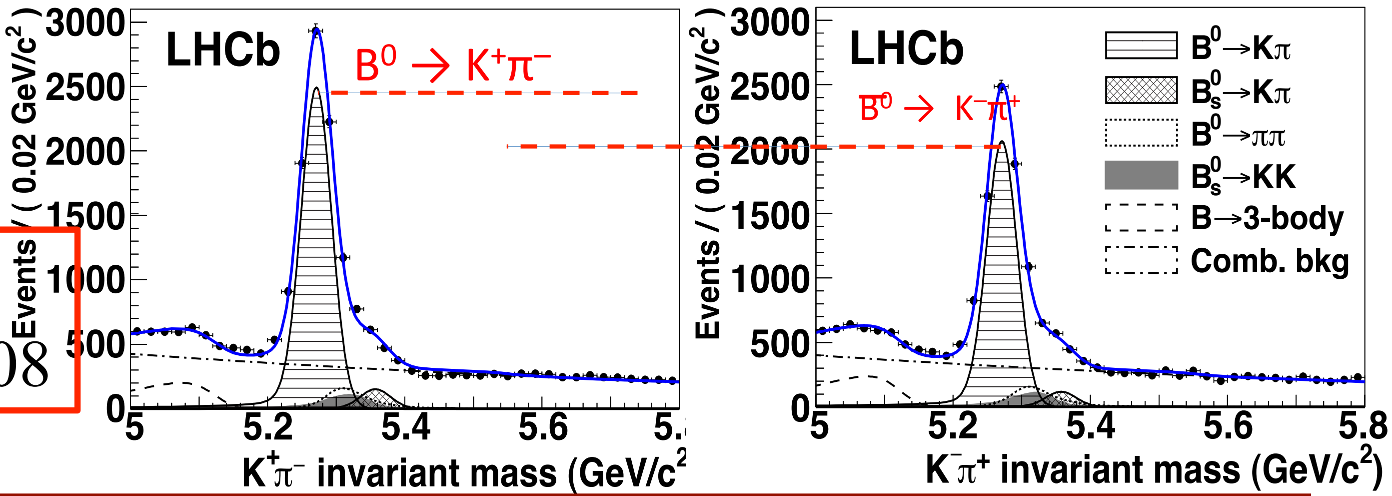
Direct CPV in $B_{(s)} \to K\pi$

LHCb: PRL 108,201601 (2012)
CDF: PRL 106,181802

- With $0.35\ fb^{-1}$:
  - most precise results

$A_{CP}(B^0 \to K\pi) = -0.088 \pm 0.011 \pm 0.008$

$> 6\sigma$

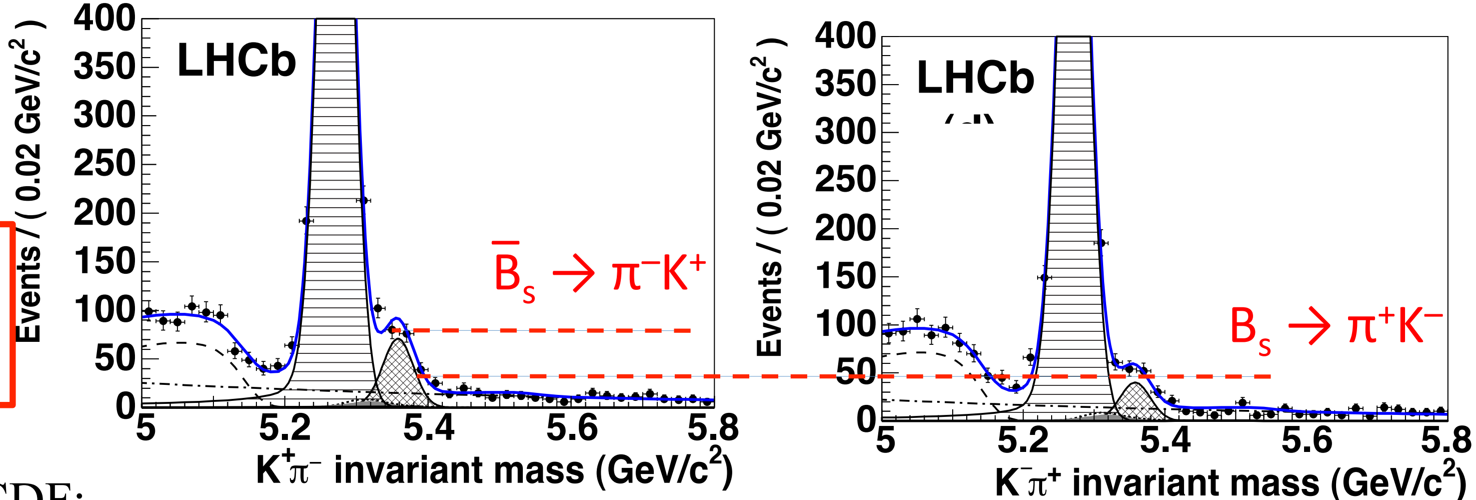


First observation of direct CPV in B decays at a hadron collider

opposite sign,
as expected in SM

3.3σ

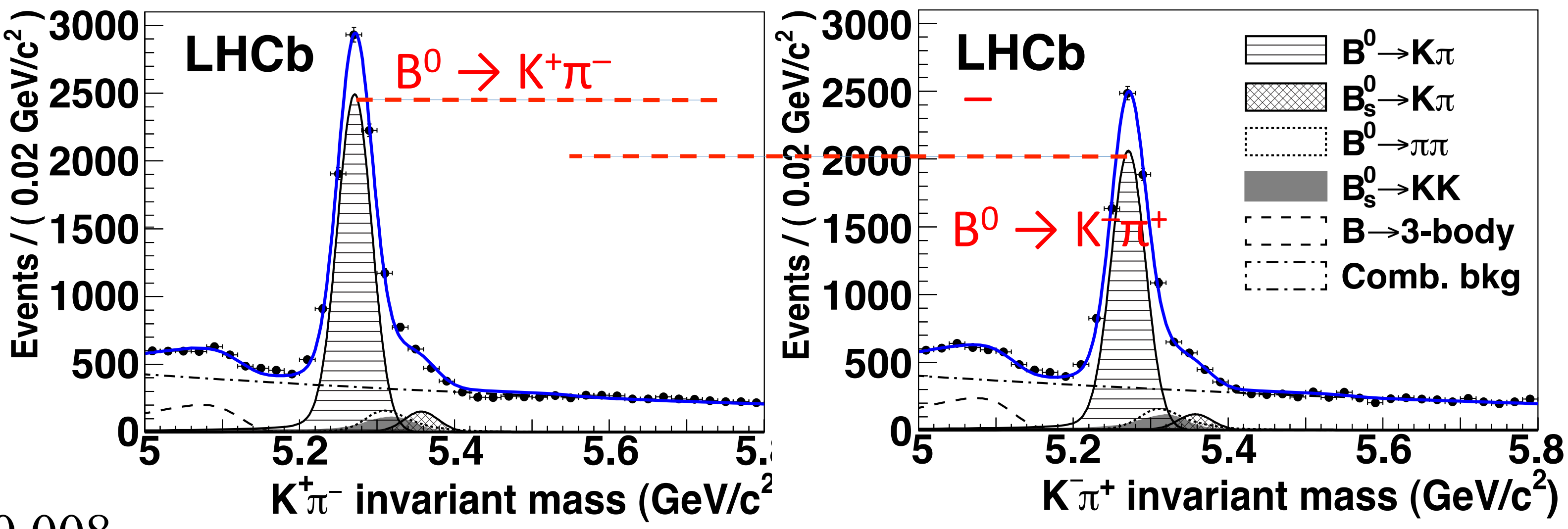
$A_{CP}(B_s \to \pi K) = +0.27 \pm 0.08 \pm 0.02$



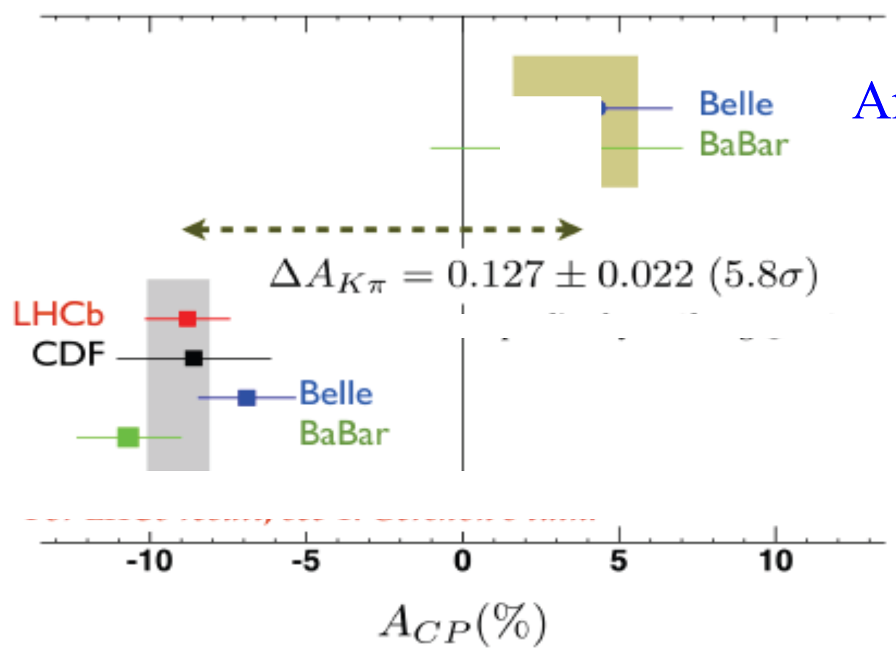
Result compatible with CDF:
$A_{CP}(Bs \to \pi K) = (0.39 \pm 0.15 \pm 0.08)$ CDF

First evidence of direct CPV in B_s decays !

Direct CPV in $B_{(s)} \to K\pi$



$A_{CP}(B^0 \to K\pi) =$
$-0.088 \pm 0.011 \pm 0.008$

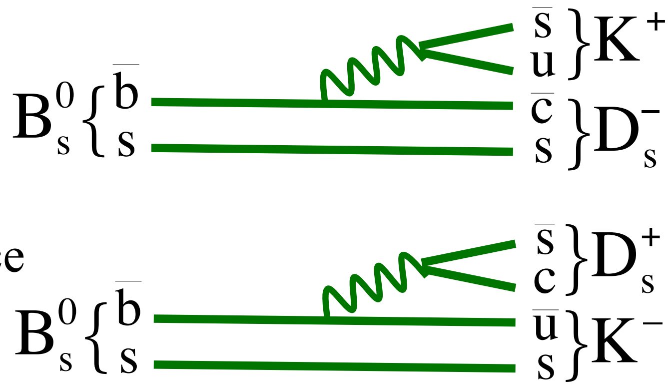


Another point in the $\Delta A(K\pi)$ puzzle…..

1) too large colour-suppressed tree amplitudes?
2) new phase in ew penguins?

Towards γ with $B_s \to D_s K^{\pm}$

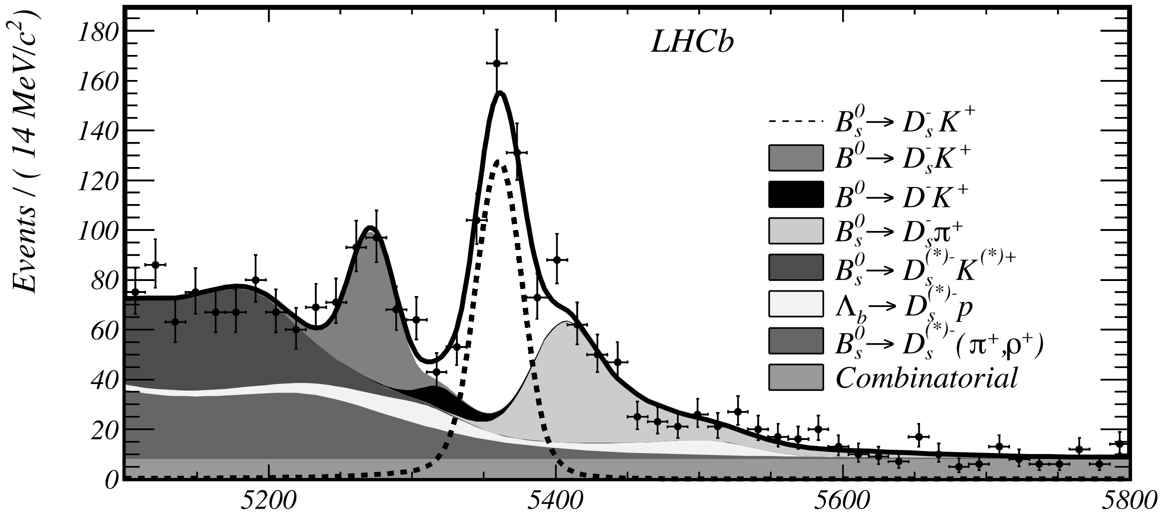
- Two decay amplitudes ($b \to c$ and $b \to u$), interfering via B_s mixing
  - magnitudes of similar order ($\sim\lambda^3$) $\to$ large interference
  - tagged time-dependent analysis can determine weak phase $\phi_s + \gamma$, hence angle γ, in a very clean way



- First analysis (0.35 fb^{-1})

LHCb: arXiv 1204.1237
submitted to JHEP

  - 404 ±26 signal evts
  - determine branching ratio (twice better than world average)



DsK mass (MeV/c²)

$$\mathcal{B}\left(B_s^0 \to D_s^{\mp} K^{\pm}\right) = \left(1.90 \pm 0.12 \pm 0.13 \; {}^{+0.12}_{-0.14}\right) \times 10^{-4}$$

f_s/f_d

For a discussion about γ extraction from $B_{(s)} \to hh'$ decays see A. Gomez's talk

Direct CPV violation in charm: bibliography

Explanations of the LHCb result in SM, and in NP models:

- Isidori et.al. arxiv:1103.5785 ⇒ NP explanation in a model independent way
- Brod et.al. arxiv:1111.4987 ⇒ Large $1/m_c$ suppressed amplitude
- Rozanov et.al. arxiv:1111.5000 ⇒ Large penguin in sequential 4th generation model
- Pirtskhalava et.al. arxiv:1112.5451 ⇒ Badly broken $SU(3)_F$ symmetry
- Cheng et.al. arxiv:1201.0785 ⇒ Large weak penguin annihilation contribution
- Bhattacharya et.al. arxiv:1201.2351 ⇒ CP conserving NP in penguin
- Giudice et.al arxiv:1201.6204 ⇒ Left-right flavour mixing via chromomagnetic operator
- Altmannshofer et.al. arxiv:1202.2866 ⇒ Chirally enhanced chromomagnetic penguins
- Brod et.al. arxiv:1203.6659 ⇒ In SM via s- and d-quark penguin contraction

- Bianco, Fabbri, Berson & Bigi, Riv. Nuovo Cimento 26N7 (2003)
- Grossman, Kagan & Nir PRD 75, 036008 (2007)
- Bigi, arXiv:0907.2950
- Bobrowski, Lenz, Riedl & Rothwild, JHEP 03 009 (2010)
- Bigi, Blanke, Buras & Recksiegel, JHEP 0907 097 (2009)
- Feldmann, Nandi & Soni, arXiv:1202.3795

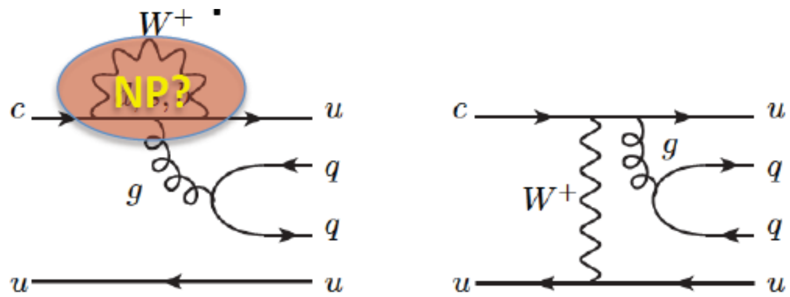
Charm: direct CPV

Direct CP violation can be larger in SM, very dependent on the final state (therefore we must search whenever we can):

Negligible in Cabibbo-favoured modes (SM trees dominate)

In generic singly Cabibbo-suppressed modes:

- up to o(10^{-3}) plausible
- few 10^{-3} possible:



Also direct CPV can be enhanced by NP, in principle to o(%)

[Bibliography too long, see spare slides]

See M. Coombes's & I. Bertram's talks

Direct CPV in $D^0 \to \pi^+\pi^-, K^+K^-$:

CPV in mixing (indirect) can be related to direct CPV via the relation:

$$A_{CP}(h^+h^-) = a_{CP}^{\rm dir}(h^+h^-) + \frac{\langle t \rangle}{\tau} a_{CP}^{\rm ind}(h^+h^-)$$

Considering $\pi\pi$ or KK final states we can build the difference:

$$A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = \Delta a_{CP}\,(\text{direct}) + \Delta\langle t\rangle/\tau \;\; a_{CP}^{\rm ind}$$

HCP 2011: LHCb, 620 pb^{-1} : first evidence (3.5 σ) of CPV in charm:

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

LHCb, PRL 108 (2012) 11602

Moriond 2012: CDF, 9.6 fb^{-1}, also measures the individual asymmetries:

$A_{CP}(KK) = (-0.24 \pm 0.22 \pm 0.09)$ % $\quad$ $A_{CP}(\pi\pi) = (+0.22 \pm 0.24 \pm 0.11)\%$

CDF, PRD 85 (2012) 012009

That seem to indicate equal and opposite effects as predicted by some theorists

See M. Coombes's and I. Bertram's talks

Direct CPV in $D^0 \to \pi^+\pi^-$, K^+K^-:

CPV in mixing (indirect) can be related to direct CPV via the relation:

$$A_{CP}(h^+h^-) = a_{CP}^{\mathrm{dir}}(h^+h^-) + \frac{\langle t \rangle}{\tau} a_{CP}^{\mathrm{ind}}(h^+h^-)$$

<t>/τ = 1 at B factories, ~2.5 at CDF (displaced trigger)

Independent of the final state

Considering ππ or KK final states we can build the difference:

$$A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = \Delta a_{CP}\,(\mathrm{direct}) + \Delta\langle t\rangle/\tau \;\; a_{CP}^{\mathrm{ind}}$$

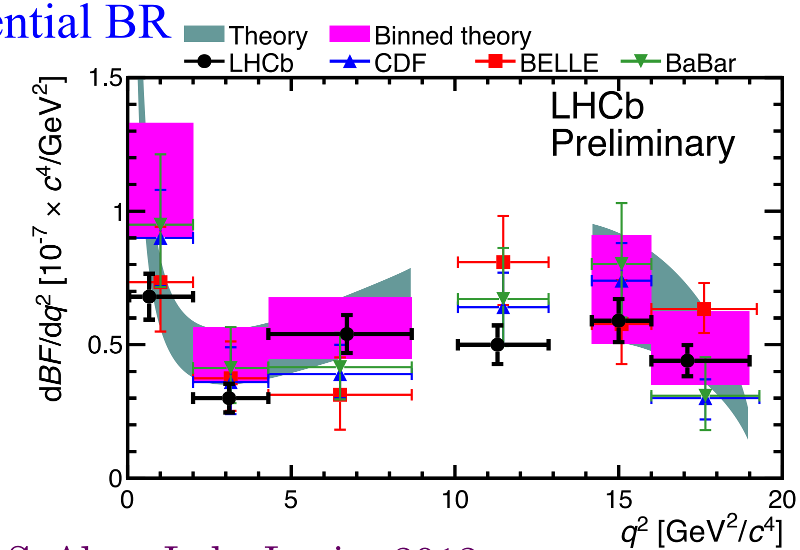
Where: $$A_{CP}(f) = \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\overline{D}^0 \to f)}$$

see R. Vazquez
& S. Emery's talks

Search for NP in $B \rightarrow K^{(*)} l^+ l^-$

Partial BF and angular observables have been measured by Babar, Belle, CDF and LHCb: all show good agreement with SM predictions (within the uncertainties)

Differential BR

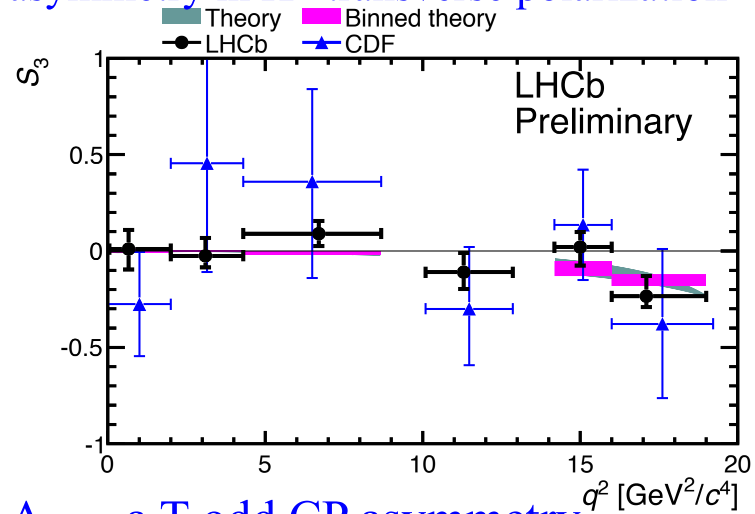


Babar: S. Akar, Lake Louise 2012
Belle: Phys. Rev. Lett. 103, 171801 (2009)
CDF: Phys. Rev. Lett. 108, 081807 (2012)
LHCb: LHCb-CONF-2012-008
Theory predictions:
C. Bobeth, G. Hiller, D. van Dyk, JHEP 07 067 (2011)

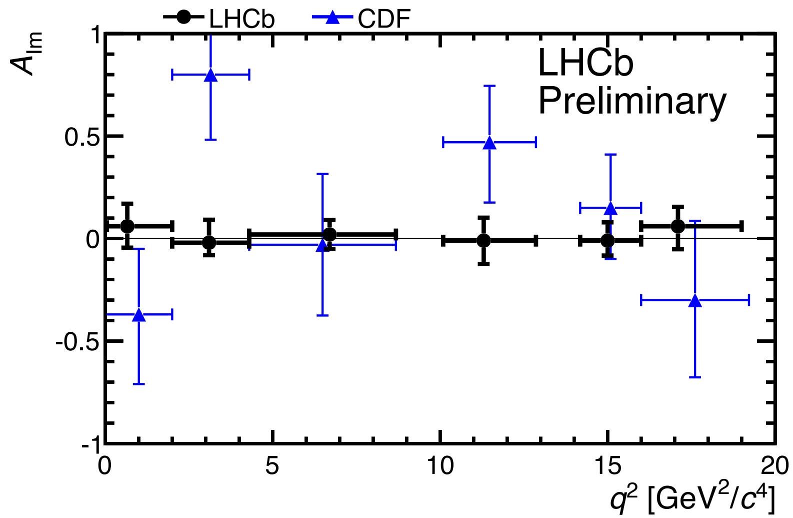
$S_3 \approx A_T^2 (1-F_L)$

asymmetry in K* transverse polarization

q^2= invariant di-leptons mass



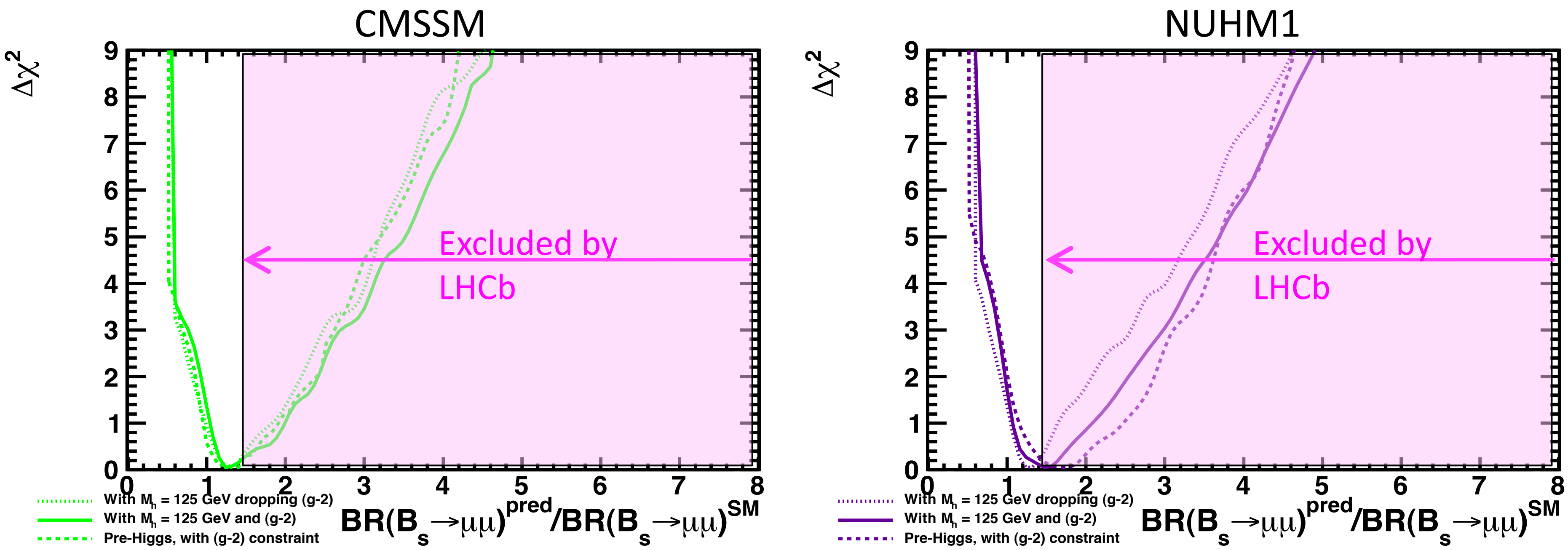
A_{im} : a T-odd CP asymmetry



Impact of $B_s \to \mu^+\mu^-$ on global SUSY fits

- Global fit include many results:
  - Higgs and SUSY searches at LHC, dark matter searches at XENON100, EW and B physics measurements (such as $b \to s\gamma$, $B^+ \to \tau\nu$, $B_s \to \mu\mu$), g–2
- Two variants of the MSSM:
  - $\Delta\chi^2$ profiles for $B_s \to \mu\mu$ (state as of December 2011)

O. Buchmueller et al.
arXiv:1112.3564



Recent $B_s \to \mu\mu$ results disfavor models with NP at the TeV scale and large tanβ