Flavour physics after the first run of the LHC

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On behalf of the
LHCb Collaboration
Including also
ATLAS and CMS results

BSM after the first run of the LHC.
Galileo Galilei Institute. Firenze,
10/07/2013

Introduction

The SM is very successful in accurately describing accelerator data, yet it is known to be an incomplete theory (gravity, DM, etc…)

Several alternatives/extension exist (SUSY, compositeness, ED's …) which could be a better approach to nature

Need (new) experimental data to:

Break SM (if possible) at accelerators

Constrain BSM parameters, rule out models inconsistent with data …

Two main approaches at LHC

Direct search of new particles → ATLAS/CMS

Indirect search → LHCb

- Access to BSM physics through its effect in B,D,K, τ decays
- This approach has been very successful in many cases: top quark or Z^0 were inferred from indirect effects many years before direct observation

A nice parallelism ?

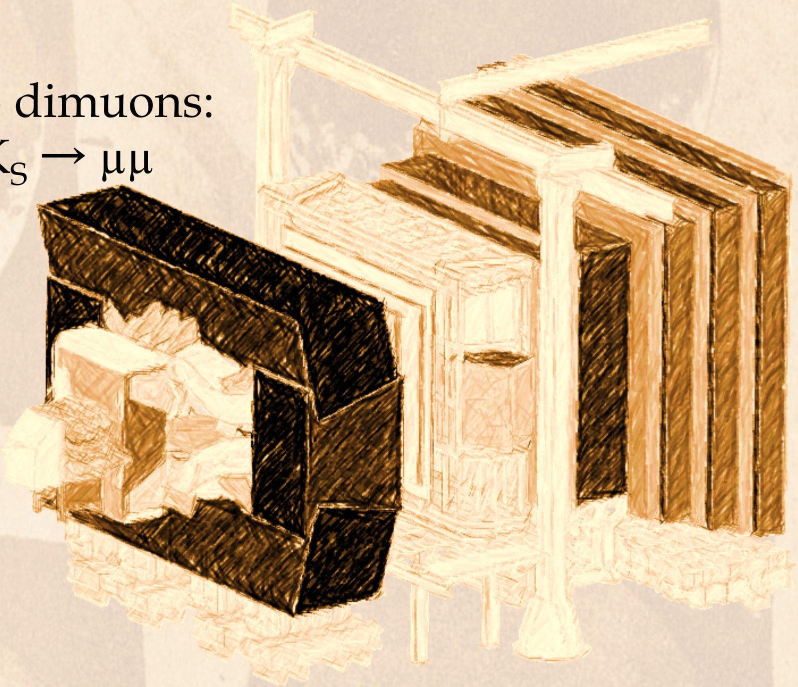
The **Ptolemaic model** was very successful on precisely describe all astronomic data for many years. (very much like **SM**)

Alternate (i.e. **heliocentric**) models existed since Aristarchos (c.III BC), but they predicted unobserved phenomena like parallax -not observed till c.XIX-, which could only fit if one puts the distance of the stars at a very large scale. (very much like **BSM**)

In c.XVII, **Galileo** points the first **telescope** to the sky and observes a series of phenomena that contradicted Ptolemaic model, and favoured heliocentric theories…. (very much like **LHC ??**)

Flavour physics results from LHCb

- Very rare decays
  - Light flavoured mesons decaying into dimuons:
    - $B_s \rightarrow \mu\mu$, $B_d \rightarrow \mu\mu$, $D^0 \rightarrow \mu\mu$, $K_S \rightarrow \mu\mu$
  - Other very rare decays
- Results in CPV
  - Electroweak phase $\phi \downarrow s$
  - First observation of CPV in B_s decays
  - CPV in charm
- The rare decay $B_d \rightarrow K^* \mu\mu$



Nice flavour topics not covered here: radiative decays, measurement of CKM angle γ

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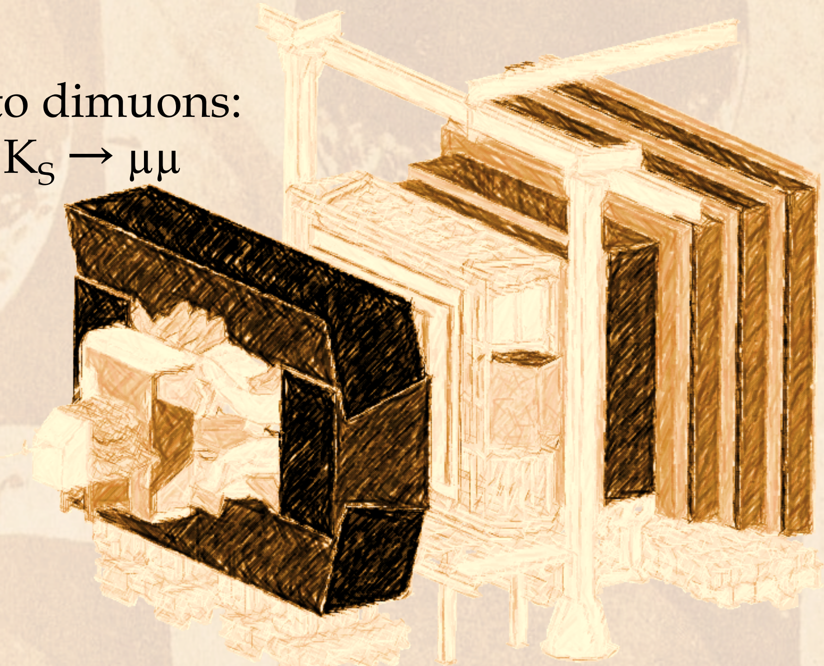
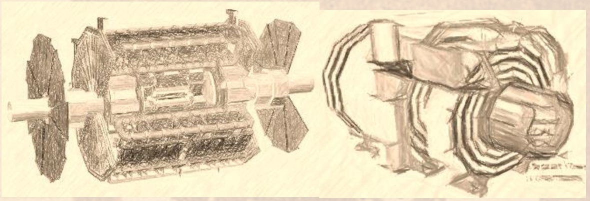
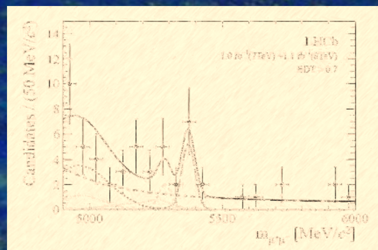
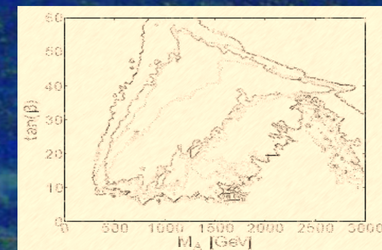
I will also cover some ATLAS and CMS results

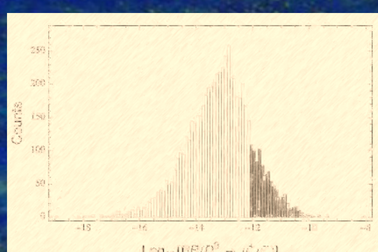


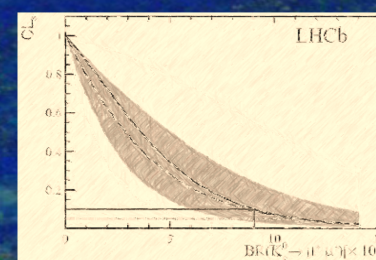






VERY RARE DECAYS





$B_{s(d)} \rightarrow \mu\mu$

These decays are very supressed in SM

$BR(B_s \rightarrow \mu\mu) = (3.54 \pm 0.30)x10^{-9}$ $BR(B_d \rightarrow \mu\mu) = (1.07 \pm 0.10)x10^{-10}$

arXiv:1208.0934.
(time averaged)

… but can be modified by NP. Here you have a rough table of what would imply each potential result (note tha the arrow goes only in one direction)

Scenario	*Would point to*
BR(Bs→μμ) >> SM	*Big enhancement from NP in the scalar sector, SUSY at high tanβ*
BR(Bs→μμ) ≠ SM	*SUSY, ED's, LHT, TC2*
BR(Bs→μμ) ≈SM	*Anything (→ rule out regions of parameters space that predict sizable departures w.r.t SM)*
BR(Bs→μμ) <<SM	*NP in the scalar sector, but full MSSM ruled out. NMSSM (Higgs singlet) good candidate*
BR(Bs→μμ) /BR(Bd→μμ))≠ SM	*CMFV ruled out. New FCNC independent of CKM matrix (RPV-SUSY, ED's ,etc …)*

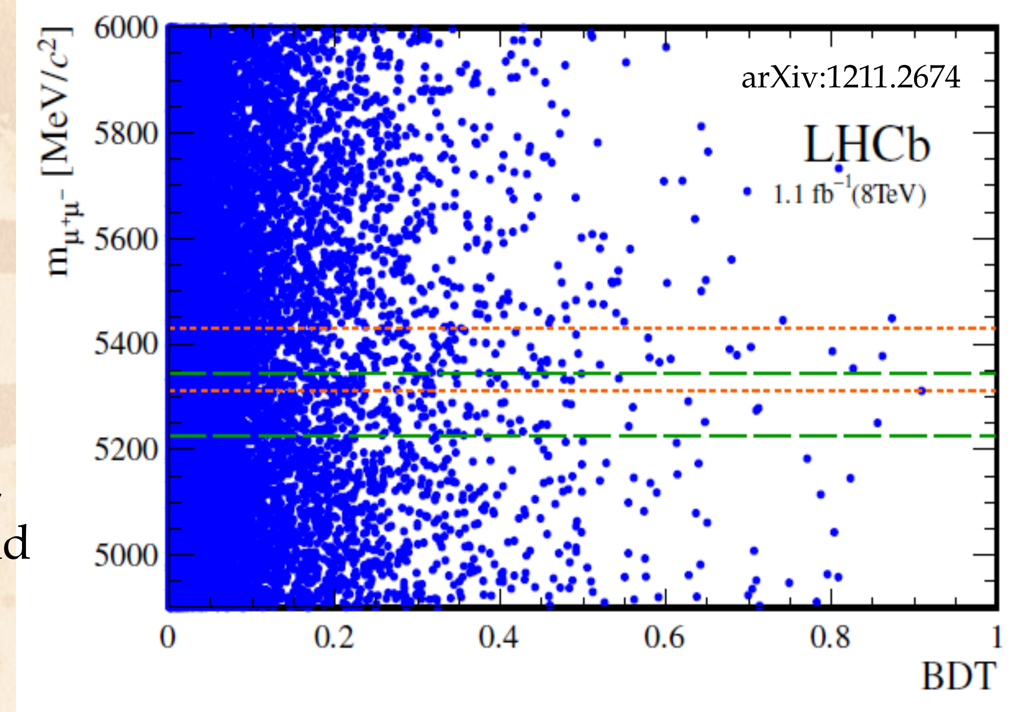
$B_{s(d)} \rightarrow \mu\mu$ (LHCb analysis strategy)

arXiv:1211.2674 PhysRevLett.110.021801

I) Selection cuts in order to reduce the amount of data to analyze.

II) Classification of $B_{s,d} \rightarrow \mu\mu$ events in bins of a 2D space

- Invariant mass of the $\mu\mu$ pair
- Boosted Decision Tree (BDT) combining geometrical and kinematical information about the event.

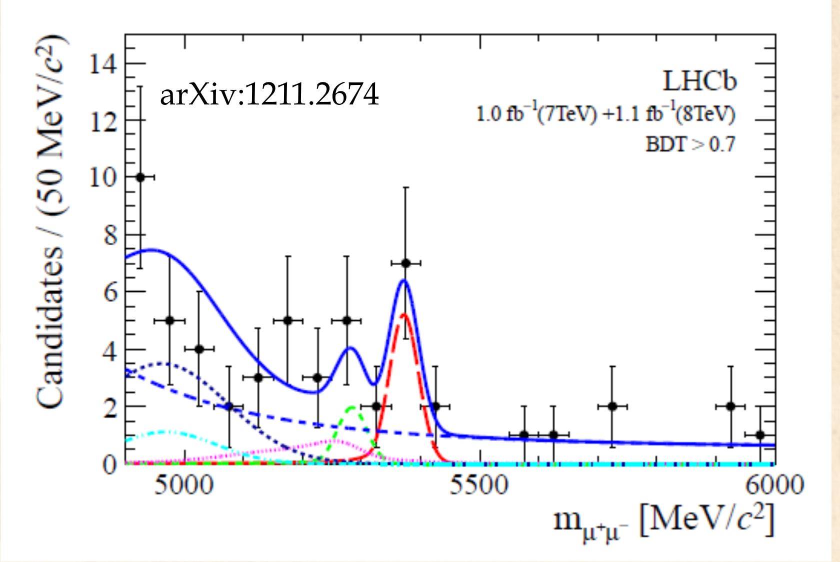


III) Control channels ($B \rightarrow hh$, $B \rightarrow J/\psi K$, mass sideb.) to get signal and background expectations w/o relying on simulation

IV) Use $CL_{s,b}$ for limits and signal significance. Also fit for signal strength

$B_{s(d)} \rightarrow \mu\mu$ (LHCb results)

arXiv:1211.2674 PhysRevLett.110.021801



1 fb^{-1} from 2011 (7 TeV) and 1 fb^{-1} from 2012 (8 TeV) are statistically combined.

We see a 3.5 σ signal in the B_s mode

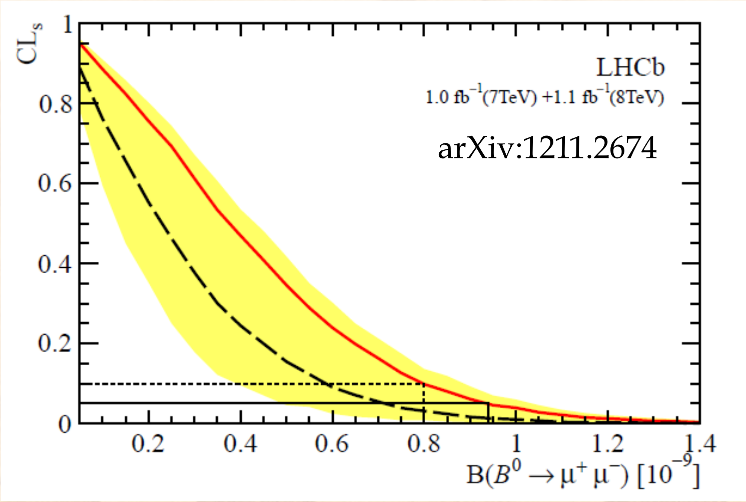
No significant (~1.3 σ) signal (yet) in the B_d

BR($B_s \rightarrow \mu\mu$) fit:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.2\,^{+1.4}_{-1.2}(\text{stat})\,^{+0.5}_{-0.3}(\text{syst})) \times 10^{-9}$$

BR($B_d \rightarrow \mu\mu$) CL_s limits:

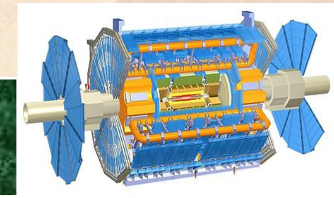
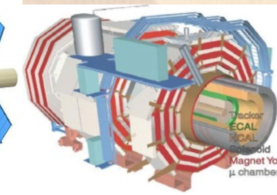
2011+2012	Exp. bkg+SM	5.8×10^{-10}	7.1×10^{-10}
	Exp. bkg	5.0×10^{-10}	6.0×10^{-10}
	Observed	8.0×10^{-10}	9.4×10^{-10}



Update expected (very) soon !

$B_{s(d)} \to \mu\mu$ (ATLAS / CMS/averages)

Both experiments perform cut-based analyses (MVA under development, afaik). Up to now both show less sensitivity than LHCb for the same integrated luminosity (due to trigger/ reconstruction/resolution).

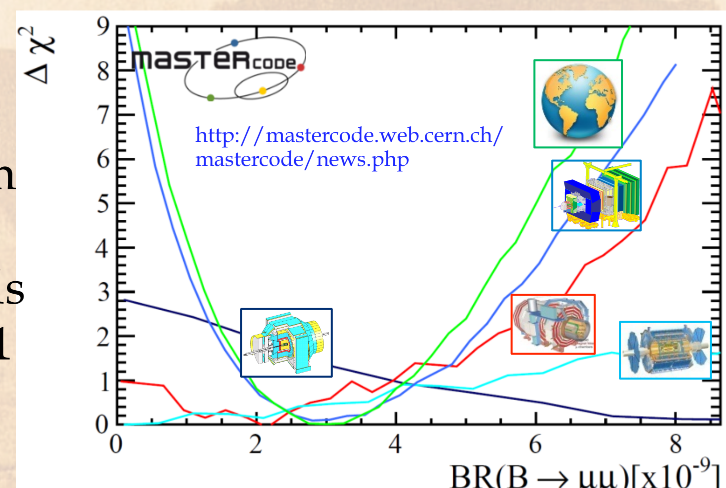
Experiment		
Luminosity (fb^{-1})	2.4	5.0
95%CL_s (B_s) (10^{-9})	22	7.7
95%CL_s (B_d) (10^{-9})	- arXiv:1204.0735	1.8 arXiv:1203.3976

However, for the same time period , ***CMS has been performing almost equally well than LHCb.***

Latest LHC combination is ~old (only 0.4 fb-1 from LHCb)

Mastercode's private/unofficial combination yields

$BR(B_s \to \mu\,\mu)\ [x10^{-9}] \approx 3.0^{+1.2}_{-1.1}$



$B_{s(d)} \rightarrow \mu\mu$ (what does it imply?)

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$BR(B_s \rightarrow \mu\mu) \neq SM$	SUSY, ED's, LHT, TC2
$BR(B_s \rightarrow \mu\mu) \approx SM$	Anything (→ rule out regions of parameters space that predict sizable departures w.r.t SM)
$BR(B_s \rightarrow \mu\mu) << SM$	NP in the scalar sector, but full MSSM ruled out. NMSSM (Higgs singlet) good candidate
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… You expect some constraints at least in SUSY

$B_{s(d)} \to \mu\mu$ *(what does it imply?)*

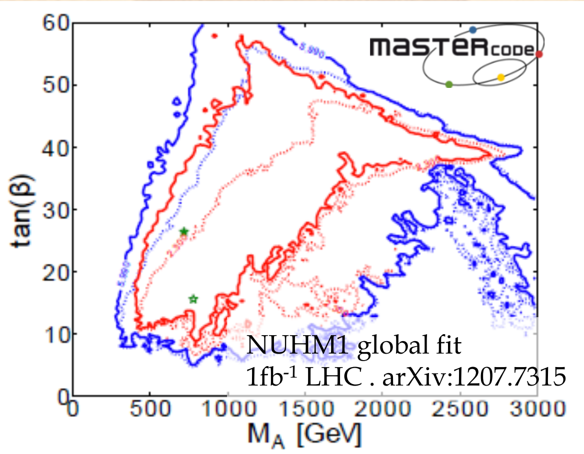
Constraints are model dependent, but the usual tendency is that $B_s \to \mu\mu$ dominates at high $\tan\beta\,/M_A$ Likelihoods of global fits get modified. No big effect expected in the p-value

(Expectations as for 2011)

$$\frac{\mathcal{B}(B_s^0 \to \mu^+\mu^-)_{\rm CMSSM}}{\mathcal{B}(B_s^0 \to \mu^+\mu^-)_{\rm SM}} \approx 1.2^{+0.8}_{-0.2}$$

$$\frac{\mathcal{B}(B_s^0 \to \mu^+\mu^-)_{\rm NUHM1}}{\mathcal{B}(B_s^0 \to \mu^+\mu^-)_{\rm SM}} \approx 1.9^{+1.0}_{-0.9}.$$

arXiv:1112.3564



NUHM1 global fit
1fb^{-1} LHC . arXiv:1207.7315

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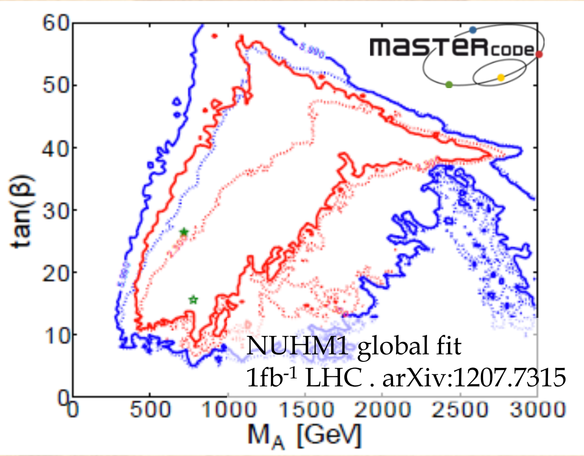


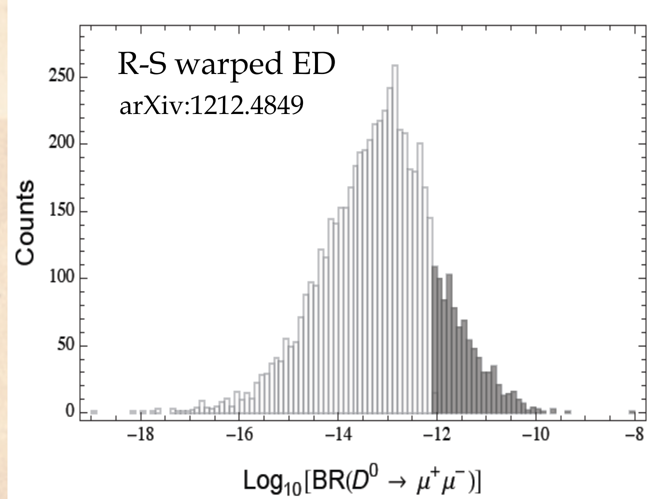
A FAQ: **How big is the SUSY phase space ruled out by $B_s \to \mu\mu$?**
Outside the effect on the likelihoods, the question **has no objective answer**:

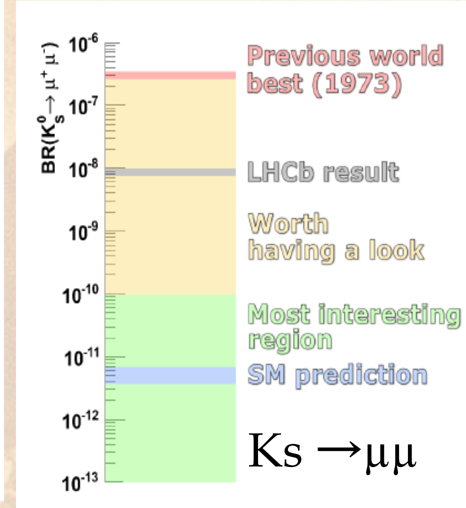
- All values of the fundamental parameters equiprobable? → the excluded volume is O(5%). But this is not invariant under reparameterization

- All the previously allowed BR's equiprovable? → the excluded area is large. But also no reason to consider all BR's are equiprobable a priori (same as above)

- It's a bit like asking which is the fraction of the SM parameter space that has been ruled out up to know by current data

$K_S \rightarrow \mu\mu$, $D^0 \rightarrow \mu\mu$



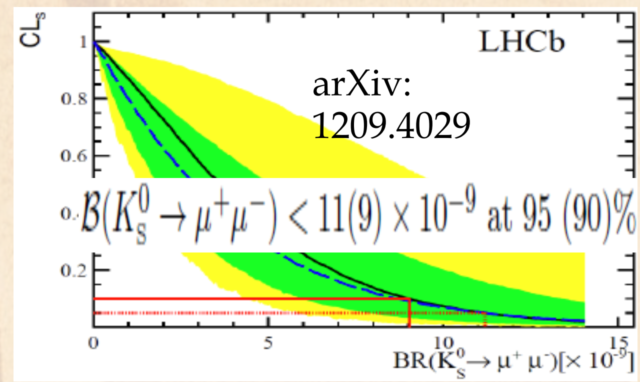


LHCb also sets world best upper limit in other dimuon decays

arXiv:1209.4029 arXiv:1305.5059

Limits at the 10^{-8} – 10^{-9} level

BR($K_S \rightarrow \mu\mu$) is sensitive to different physics than BR($K_L \rightarrow \mu\mu$). Limits at the 10^{-11}, 10^{-12} quite interesting specially if NP is found at NA62



BR($D^0 \rightarrow \mu\mu$) at the 10^{-10} level can be sensitive to ED and RPV.
LHCb will explore those ranges with the upgraded detector.

BR of neutral flavoured mesons into dimuons [x10^{-9}]

$B_s \rightarrow \mu\mu$	$B_d \rightarrow \mu\mu$	$D^0 \rightarrow \mu\mu$	$K_L \rightarrow \mu\mu$	$K_S \rightarrow \mu\mu$
3.2 [redacted] +1.5@ −1.2	<0.94	<7.6	6.84±0.11	11
LHCb	LHCb	LHCb	BNL E871	LHCb

SM BR($K_S \rightarrow \mu\mu$) =(5.1±1.5)x10^{-12}
arXiv:hep-ph/0311084

SM prediction: BR($D^0 \rightarrow \mu\mu$) < 1.6x10^{-11}
(depends on knowledge of BR ($D^0 \rightarrow \gamma\gamma$))

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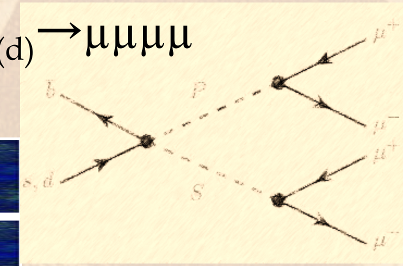
Other very rare decays @ LHCb

$B_{s(d)} \to \mu\mu\mu\mu$

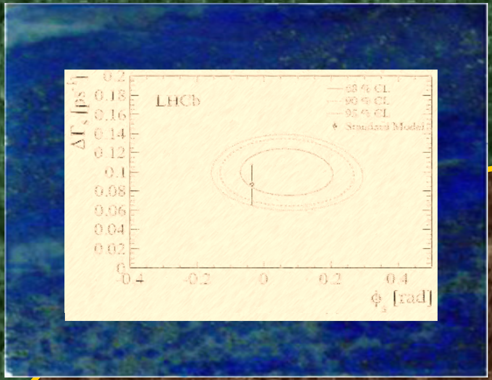


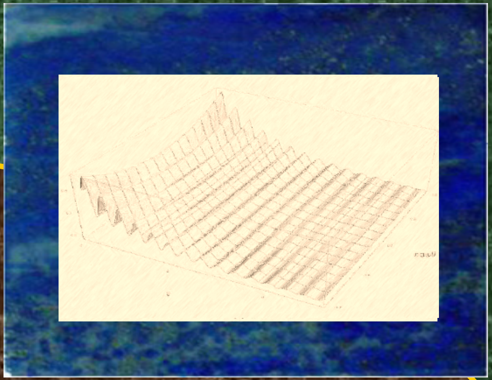
Decay	Main BSM test	95% upper limit
$B_s \to \mu\mu\mu\mu$	Some SUSY scenarios	$<1.6\times10^{-8}$ (arXiv:1303.1092)
$B_d \to \mu\mu\mu\mu$	Some SUSY scenarios	$<6.6\times10^{-9}$ (arXiv:1303.1092)
$\tau \to \mu\mu\mu$	LFV (ex: LHT)	$<8.0\times10^{-8}$ (arXiv:1304.4518) (still below B-factories sensitivity)
$\tau \to p\mu\mu$	LNV, BNV ("")	$<4.4\times10^{-7}$ proton $<3.3\times10^{-7}$ anti-proton (arXiv:1304.4518)
$B_s \to e\mu$	RPV, Pati-Salam LQ…	$<1.4\times10^{-8}$ (LHCb-PAPER-2013-030)
$B_d \to e\mu$	RPV, Pati-Salam LQ…	$<3.7\times10^{-9}$ (LHCb-PAPER-2013-030)
$B \to X\mu^+\mu^+$	4th gen. Majoranas	See arXiv:1201.5600

$M_{\rm LQ}(B^0_s \to e^\pm\mu^\mp) > 106\ \text{TeV}/c^2$

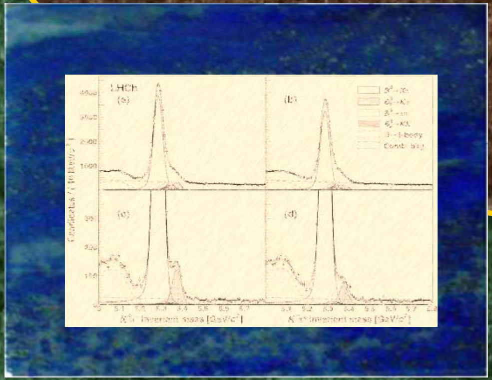
$M_{\rm LQ}(B^0 \to e^\pm\mu^\mp) > 127\ \text{TeV}/c^2$

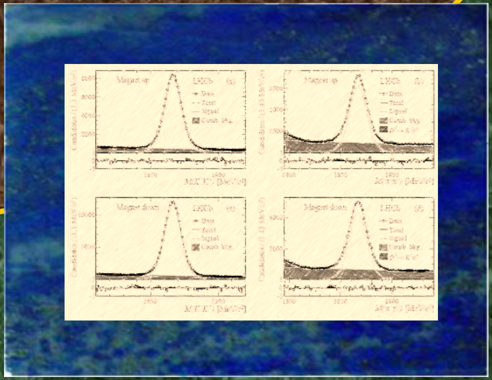
A good example of flavour physics accessing high energy scales



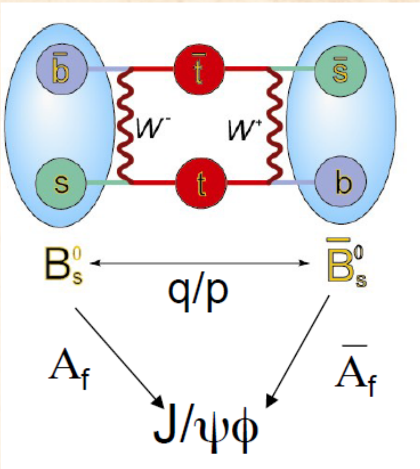


CPV





Φ_s from $B_s \to J/\psi$ ($\to\mu\mu$) KK



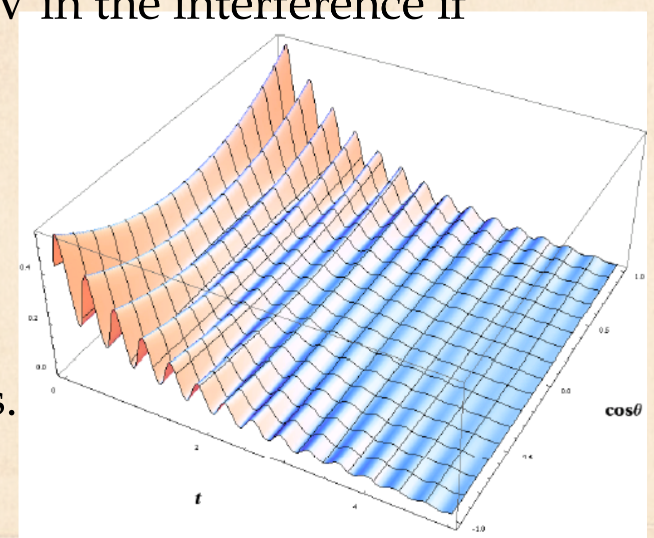
B_s mass eigenstates:

$$|B_L^s\rangle = p|B_s\rangle + q|\bar{B}_s\rangle$$
$$|B_H^s\rangle = p|B_s\rangle - q|\bar{B}_s\rangle$$

Weak eigenstates (mix via box diagram)

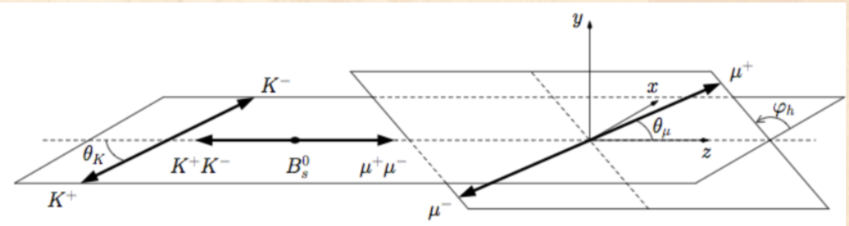
- q/p: complex number. $|q/p| \neq 1 \to$ CPV in mixing
- A_f, A_f complex amplitudes. $|A_f / A_f| \neq 1 \to$ CPV in deca

Even if not CPV in mixing or decay, you can generate CPV in the interference if $\sin(\phi_s) \equiv \sin(-arg(q/p\, A_f / A_f)) \neq 0$



Main (but not only) experimental signature of a non-zero ϕ_s: it generates **wiggles** in the time-dependent angular distribution of the $B_s \to J/\psi\ \phi \to \mu\mu KK$ final state particles. The frequency of the (potential) wiggles is known: Δm_s.

Φ_s from $B_s \to J/\psi\ (\to\mu\mu)\ KK$



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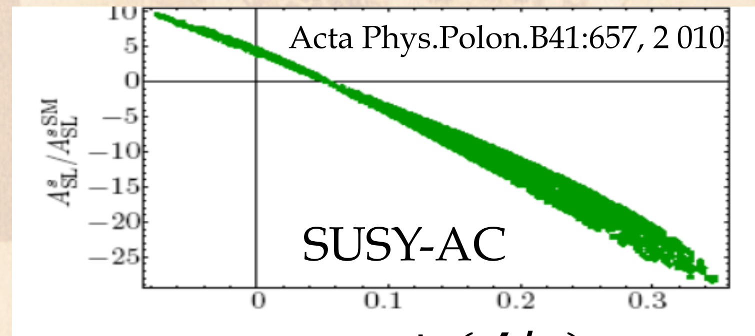
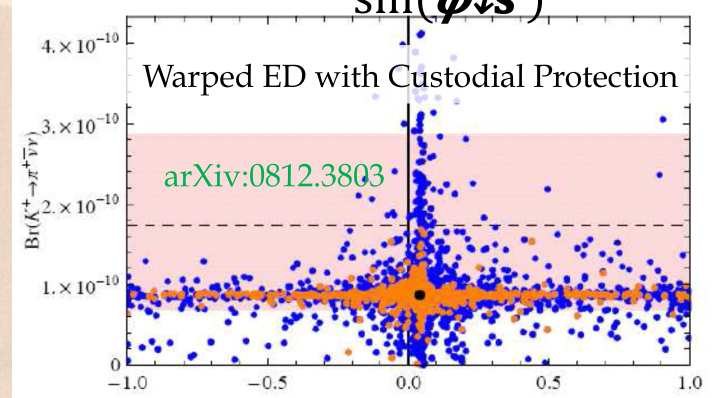
&\quad \left. -\sin(\delta_0-\delta_s)\cos\phi_s \sin(\Delta m t) + \cos(\delta_0-\delta_s)\cos(\Delta m t)\right].
\end{aligned}
$$

wiggles

…and this quantity is sensitive to BSM physics: LHT, non-MFV in SUSY-breaking lagrangian, ED..



$\sin(\phi_s)$

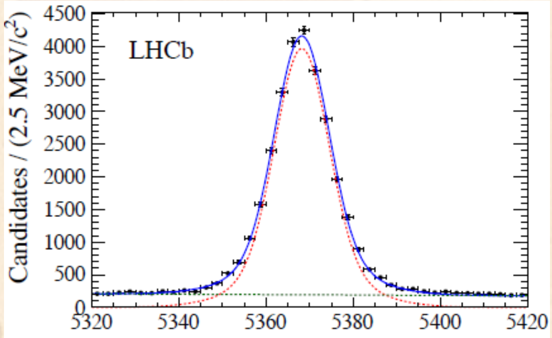


$\sin(\phi_s)$

Φ_s from $B_s \rightarrow J/\psi$ ($\rightarrow\mu\mu$) KK

Analysis strategy: Fit the pdf of previous slide to data, considering experimental effects:

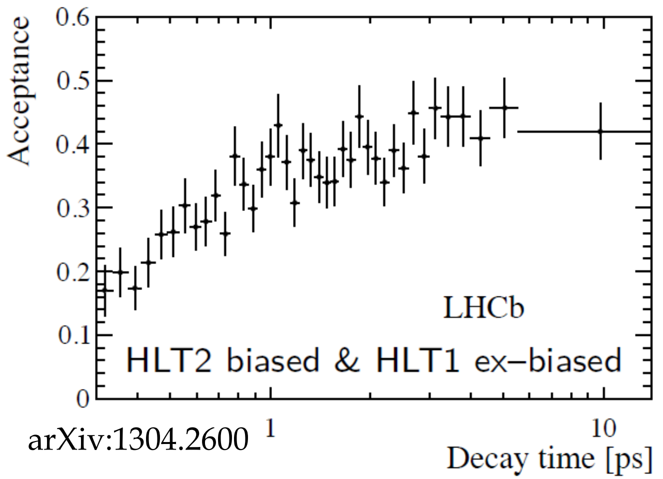
- **Background**: Events are weighted according to position in J/ ψ KK mass spectrum



arXiv:1304.2600

- Angular distributions are distorted on data because of **non-flat angular acceptance**. Simulation (weighted according to kinematics seen on data) is used to correct for this

- **Lifetime acceptance**. Samples from different trigger lines are used to unfold trigger biases. Simulation is used for selection/reconstruction biases

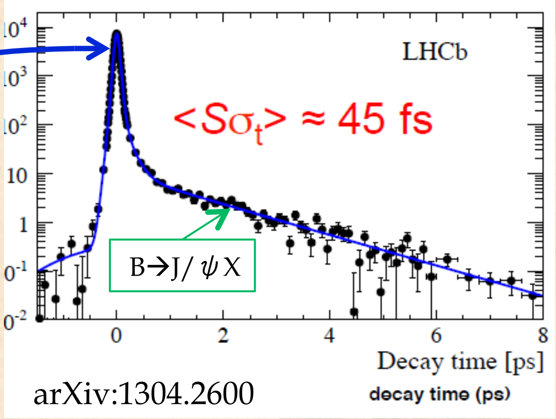


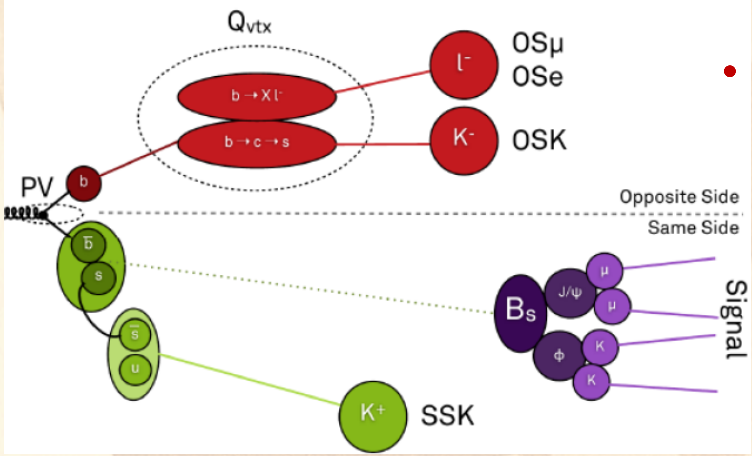
arXiv:1304.2600

Φ_s from $B_s \rightarrow J/\psi$ (→μμ) KK

Analysis strategy: Fit the pdf of previous slide to data, considering experimental effects:

- **Lifetime resolution**: Non-perfect time resolution (45 fs, still much smaller than oscillation period, 350fs) convolved with the pdf. Main effect is a ~25% dilution of the amplitude of the wiggles. Measured on data using prompt J/ψ events

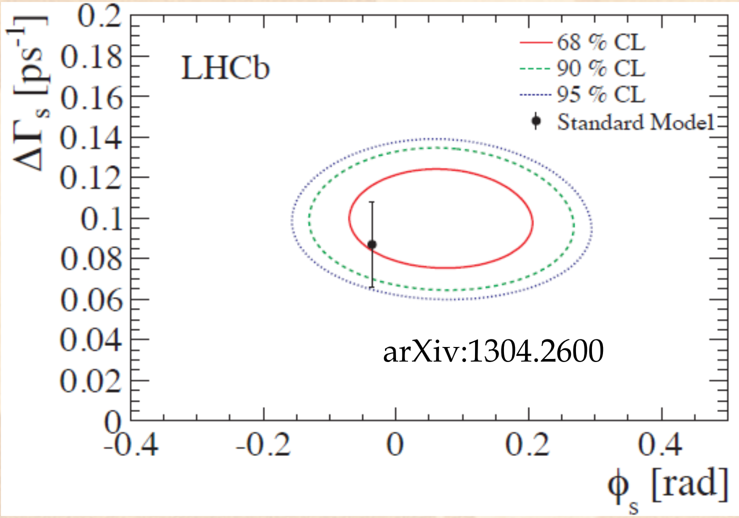




- **Flavour tagging**: The initial flavour of the B_s is determined either by a muon/kaon from the other B, and/or by a kaon from the fragmentation. The performance of these taggers is calibrated with control samples such as $B^+ \rightarrow J/\psi K^+$, $B_d \rightarrow D^{*+} \mu \nu$ and $B_s \rightarrow D_s^- \pi^+$

Φ_s (results)

We perform the fit in bins of KK mass to better deal with non resonant component and, more important, to solve ambiguity of the equations



arXiv:1304.2600

ϕ_s = 0.07±0.09±0.01 rad

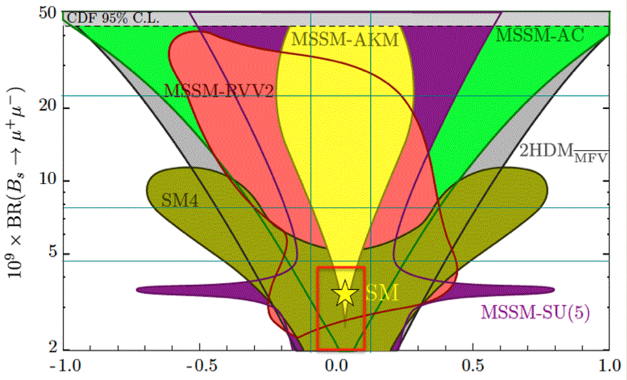
Combined with $B_s \to J/\psi\ \pi\ \pi$

Φ_s = 0.01±0.07±0.01 radians

In good agreement with SM: -0.036±0.002(*)

Which, as in the case of for example $B_s \to \mu\mu$, sets constraints on BSM physics

(Don't get depresed by the plot, rememember comments in the $B_s \to \mu\mu$ case)



arXiv:1107.0266

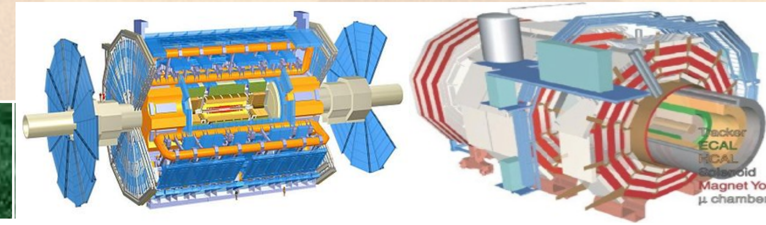
$\sin(\phi_s)$

(*)Penguins ignored

Φ_s (ATLAS/CMS)

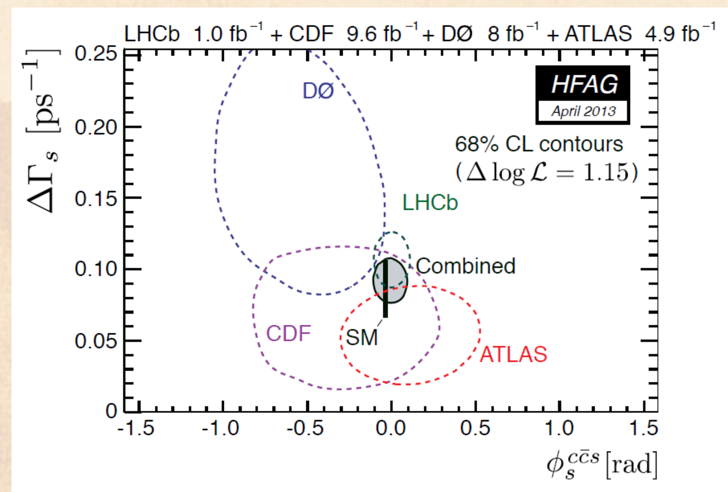
ATLAS and CMS also study $B_s \to J/\psi\ \phi \to \mu\mu KK$, using 5 fb^{-1} each

But only ATLAS reports a ϕ_s measurement

Experiment		
Lumi. (fb^{-1})	4.9	5.0
$\Delta\Gamma_s$ (ps^{-1})	0.053±0.021±0.009	0.048±0.024±0.003
Φ_s	0.12±0.25±0.11 ATLAS-CONF-2013-039	Set to 0 CMS-PAS-BPH-11-006

HFAG private/unofficial combination yields

$$\phi_s \approx 0.00 \pm 0.07 \text{ rad}$$



First observation of CPV in Bs decays

CPV in B →K π cannot be calculated theoretically with accuracy, but combinations of observables allow building stringent SM tests such as:

$$\Delta = \frac{A_{CP}(B^0 \to K^+\pi^-)}{A_{CP}(B_s^0 \to K^-\pi^+)} + \frac{\mathcal{B}(B_s^0 \to K^-\pi^+)}{\mathcal{B}(B^0 \to K^+\pi^-)} \frac{\tau_d}{\tau_s} = 0$$

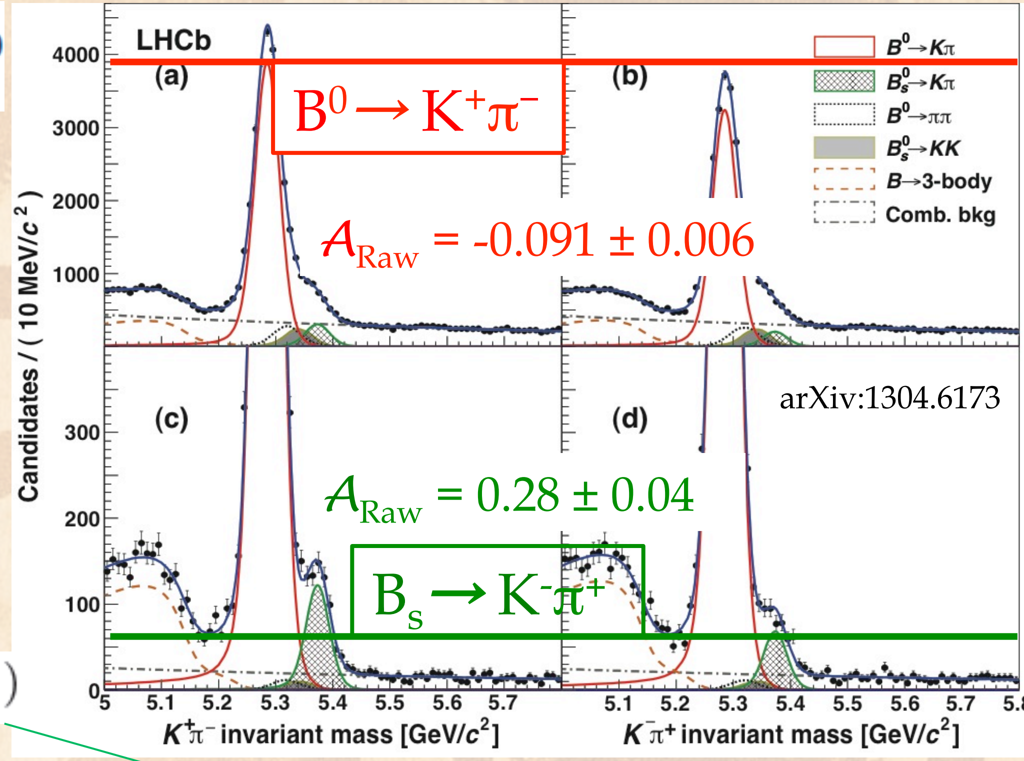
LHCb measures the **raw asymmetries** (difference in observed yields between particle and antiparticle)

These are related to the CP asymmetries by

$$A_{CP} = A_{\rm raw} - A_\Delta$$

being

$$A_\Delta(B^0_{(s)} \to K\pi) = \pm \quad A_{\rm D}(K\pi) + \kappa_{d(s)} A_{\rm P}(B^0_{(s)})$$

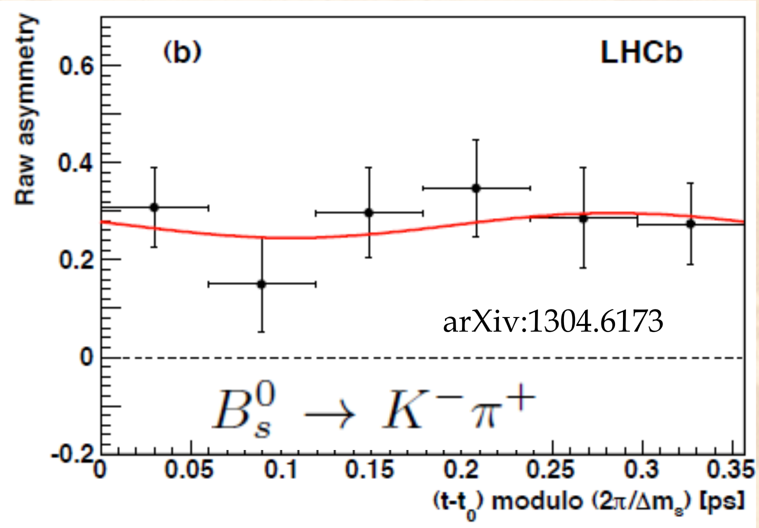


Instrumental asymmetry

attenuation due to oscillation

production asymmetry

First observation of CPV in Bs decays



Detection asymmetries is determined using $D^{*+} \rightarrow D^0 (\rightarrow K \pi) \pi$. Value ~1%

Production asymmetry is obtained from the time dependency of the raw asymmetry

$$\mathcal{A}(t) \approx A_{CP} + A_{\mathrm{D}} + A_{\mathrm{P}} \cos\left(\Delta m_{d(s)} t\right)$$

A_P compatible with 0

Finally, we obtain:

$A_{CP}(B_d \rightarrow K^+ \pi^-) = -0.080 \pm 0.007(\text{stat}) \pm 0.003(\text{syst})$

$A_{CP}(B_s \rightarrow K^- \pi^+) = 0.27 \pm 0.04(\text{stat}) \pm 0.01(\text{syst})$

Which, (for the moment) survives the $\Delta = 0$ test

CPV in charm

We search for a **direct CPV difference** between **$D^0 \to KK$** and **$D^0 \to \pi\,\pi$**

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

$$\Delta A_{CP} \equiv A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+)$$
$$= [a_{CP}^{\rm dir}(K^-K^+) - a_{CP}^{\rm dir}(\pi^-\pi^+)] + \frac{\Delta\langle t \rangle}{\tau} a_{CP}^{\rm ind}$$

Vanishes if a_{CP}^{ind} is 0 or if the time acceptance is independent of the final state

In SM it's **usually** expected to be up to $O(10^{-3})$, although recent works indicate it can be as large as **several per mil**.

2012- status

Experiment	ΔA_{CP}
LHCb	$(-0.82 \pm 0.21 \pm 0.11)\%$
CDF	$(-0.62 \pm 0.21 \pm 0.10)\%$
Belle	$(-0.87 \pm 0.41 \pm 0.06)\%$
BaBar	$(+0.24 \pm 0.62 \pm 0.26)\%$

CPV in charm (D* tag)

I) Count D^0 decaying into charged Kaons and pions

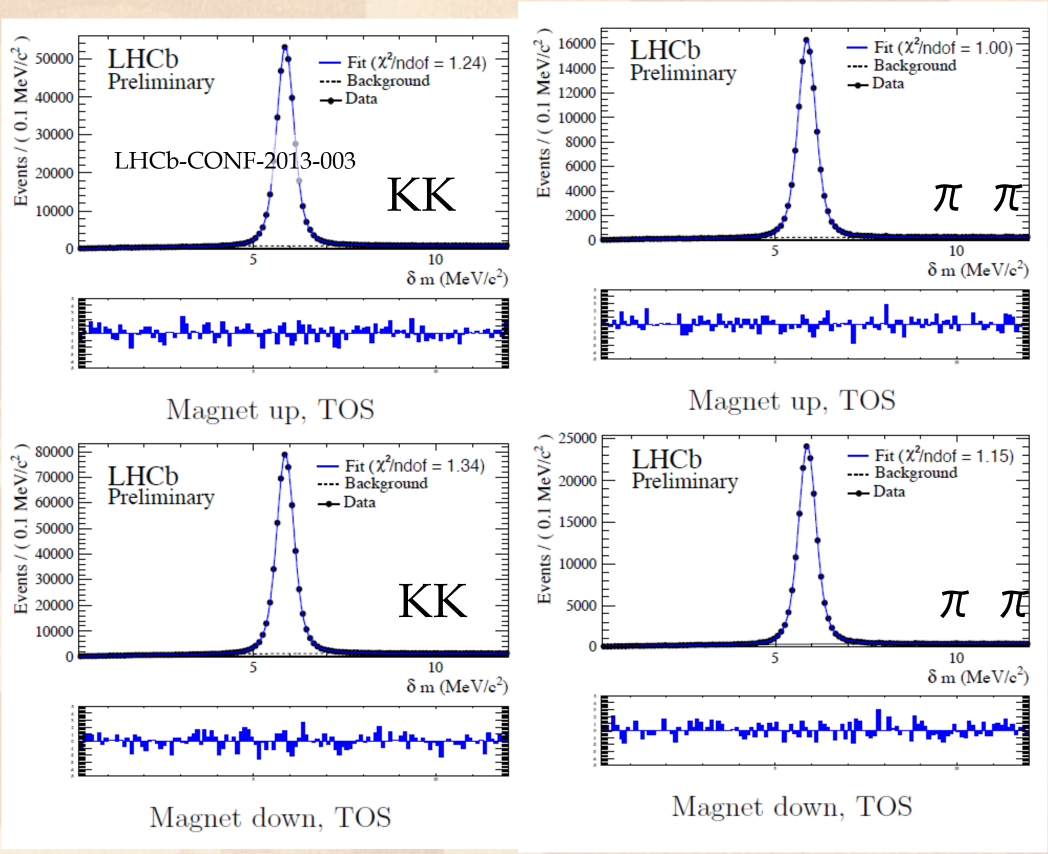
II) Tag the flavour of the D^0 at its production using events from the chain $D^{*+} \to D^0 \pi$, seen as a peak in:

$$\delta m \equiv m(h^+h^-\pi^+) - m(h^+h^-) - m(\pi^+)$$

III) Measure asymmetries

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

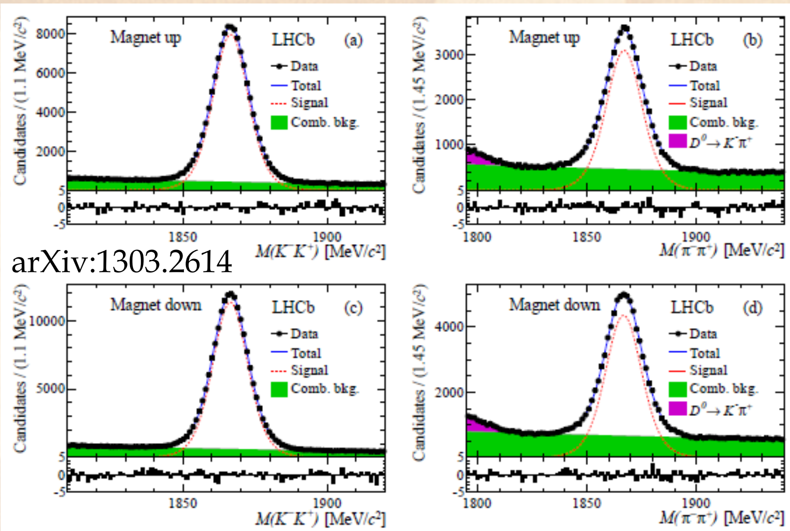
$$\Delta A_{CP} = A_{\rm raw}(K^-K^+) - A_{\rm raw}(\pi^-\pi^+)$$



IV) Weight D^0 phase space to cancel out experimental differences between kaon and pion samples

CPV in charm (lepton tag & combination)

Independent study using D^0's from semileptonic $b \to D^0 \mu X$ decays, where the D^0 flavour is tagged by the accompanying muon of the D^0 meson



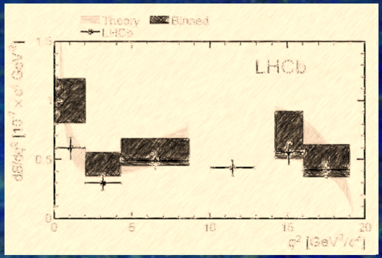
arXiv:1303.2614

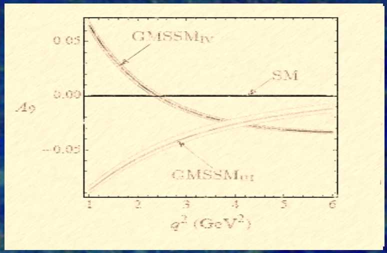
- Similar strategy as for D^{*+} tags, incuding D0 phase space correction
- But different potential systematics/bkgs.
- In addition, existence of wrong tags (O(1%))

$$\Delta A_{CP} = (1 - 2\overline{\omega})^{-1}(A_{\rm raw}(K^-K^+) - A_{\rm raw}(\pi^-\pi^+))$$

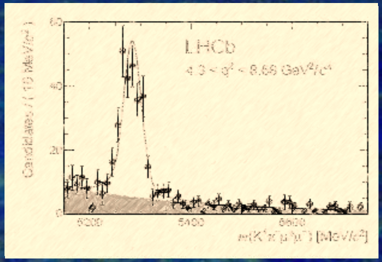
Analysis	Δ A_{CP} (%)
D^{*+} tag	-0.34±0.15 (stat) ± 0.10 (syst)
Muon tag	+0.49±0.30 (stat) ± 0.14 (syst)
Combined	-0.15±0.16 (neglects <t>a_{CP}^{dir} term)

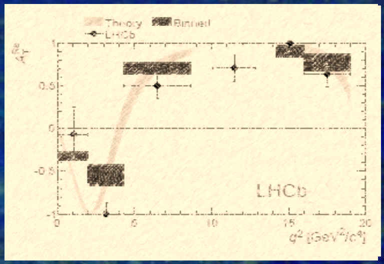
$\chi^2 = 4.85$ (3%)





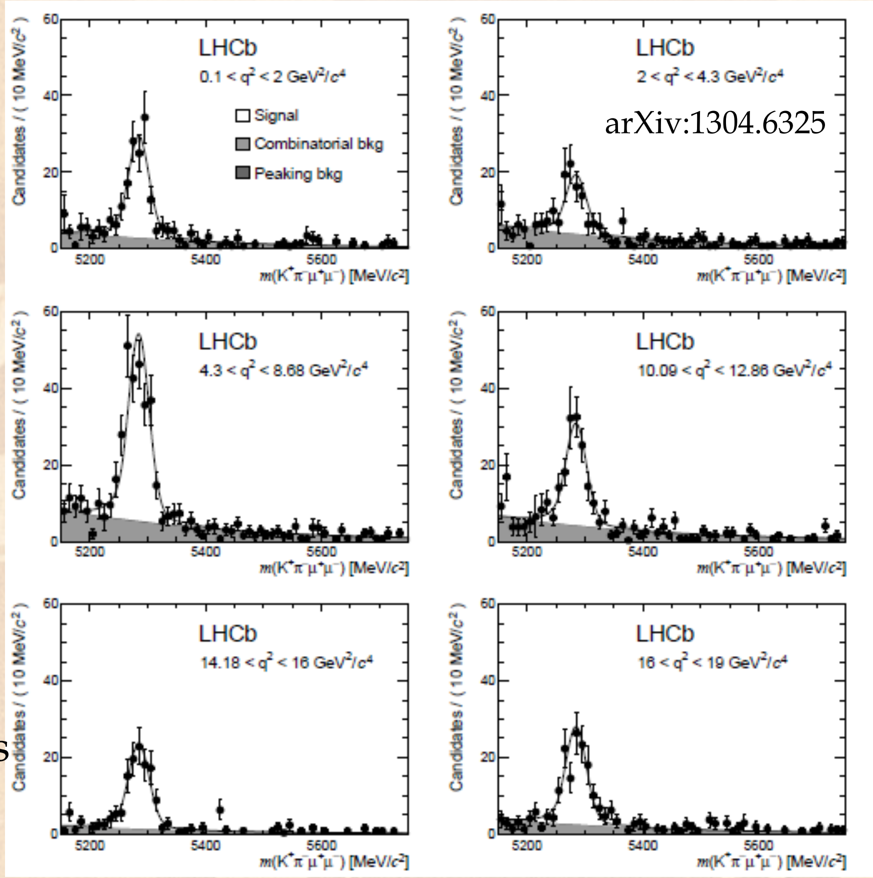
$B_d \rightarrow K^*(\rightarrow K\pi)\ \mu\mu$





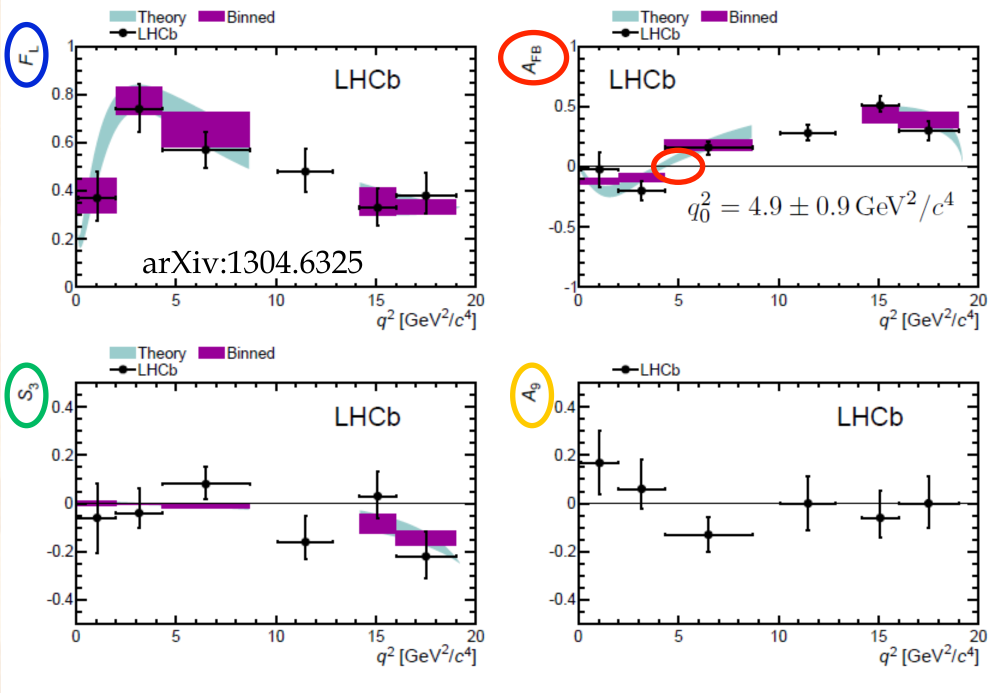
$B_d \to K^*(\to K\pi)\,\mu\mu$ (LHCb analysis strategy)

- $b \to s\mu\mu$ transition (like $B_s \to \mu\mu$)
- We select events using a BDT and special vetoes for specific backgrounds
- Correct (in an event-by event basis) for the effect of reconstruction/selection/trigger using simulation
    - Validated on data via control channels (mainly $B_d \to J/\psi(\mu\mu)\,K^*(K\pi)$)
- Fit yields and angular distributions for observables in bins of q^2 (dimuon invariant mass squared)



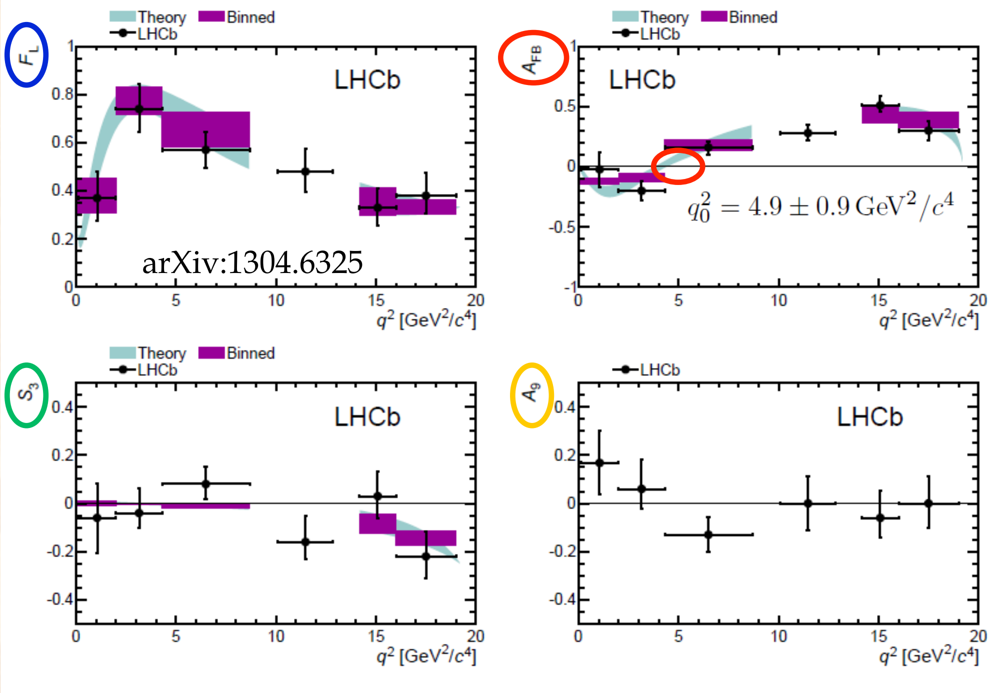
$B_d \to K^*(\to K\pi)\,\mu\mu$ (LHCb angular analysis)

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}} = \frac{9}{16\pi}\Big[F_{\mathrm{L}}\cos^2\theta_K + \frac{3}{4}(1-F_{\mathrm{L}})(1-\cos^2\theta_K) - F_{\mathrm{L}}\cos^2\theta_K(2\cos^2\theta_\ell - 1) + \frac{1}{4}(1-F_{\mathrm{L}})(1-\cos^2\theta_K)(2\cos^2\theta_\ell-1) + S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} + \frac{4}{3}A_{\mathrm{FB}}(1-\cos^2\theta_K)\cos\theta_\ell + A_9(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi}\Big]$$



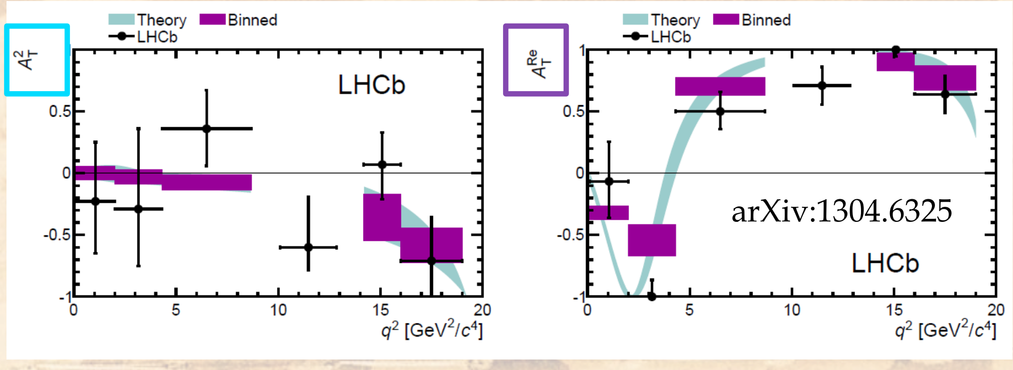
$B_d \to K^*(\to K\pi)\,\mu\mu$ (LHCb angular analysis)

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}} = \frac{9}{16\pi}\Big[F_\mathrm{L}\cos^2\theta_K + \frac{3}{4}(1-F_\mathrm{L})(1-\cos^2\theta_K) - F_\mathrm{L}\cos^2\theta_K(2\cos^2\theta_\ell-1) + \frac{1}{4}(1-F_\mathrm{L})(1-\cos^2\theta_K)(2\cos^2\theta_\ell-1) + S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} + \frac{4}{3}A_\mathrm{FB}(1-\cos^2\theta_K)\cos\theta_\ell + A_9(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi}\Big]$$



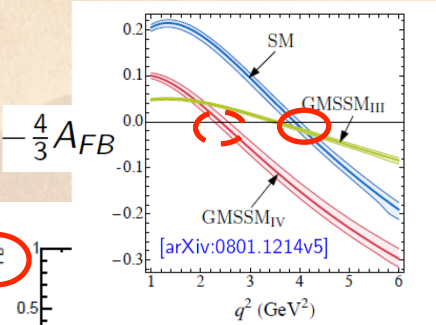
You can also **reparameterize** the fit pdf to get some cleaner observables:

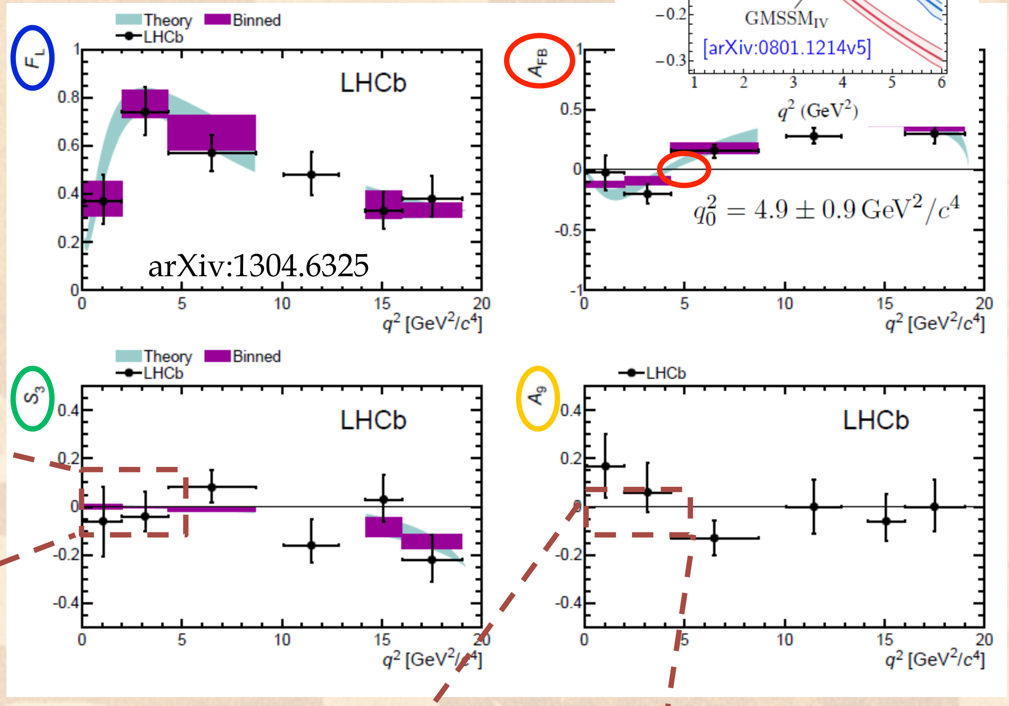
$$A_\mathrm{FB} = \frac{3}{4}(1-F_\mathrm{L})A_\mathrm{T}^\mathrm{Re} \quad \text{and} \quad S_3 = \frac{1}{2}(1-F_\mathrm{L})A_\mathrm{T}^2$$

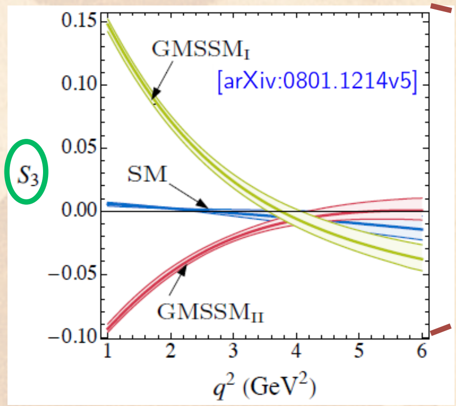


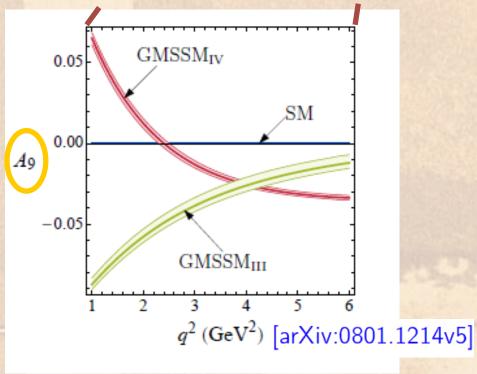
$B_d \to K^*(\to K\,\pi)\,\mu\mu$

… And then you can compare to models



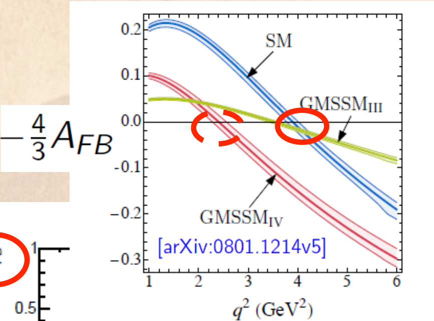


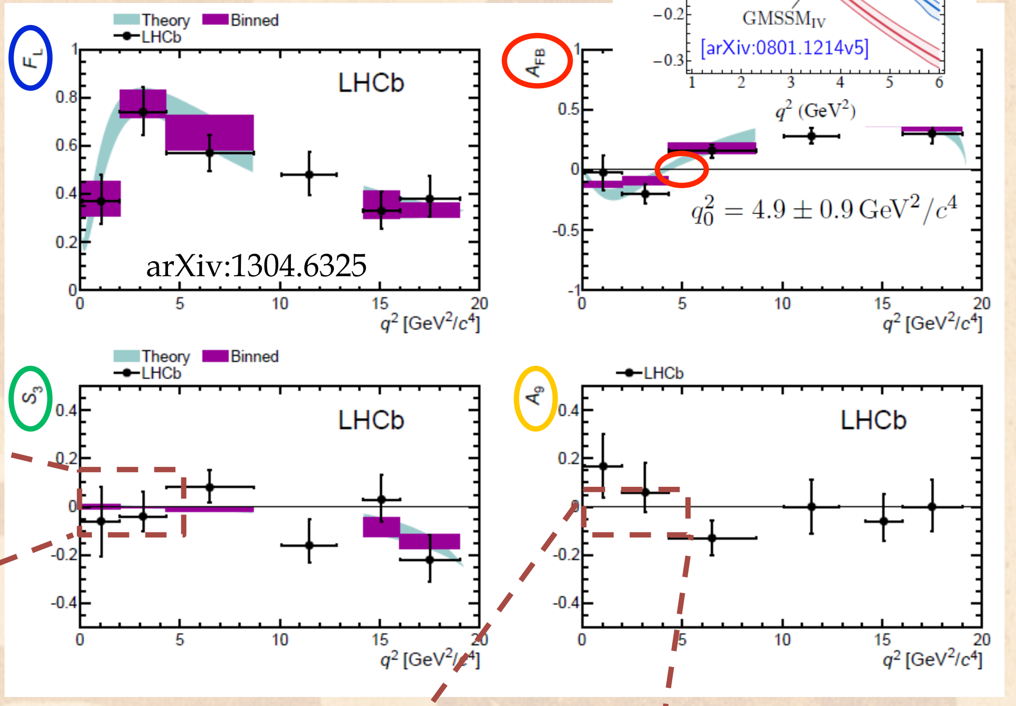


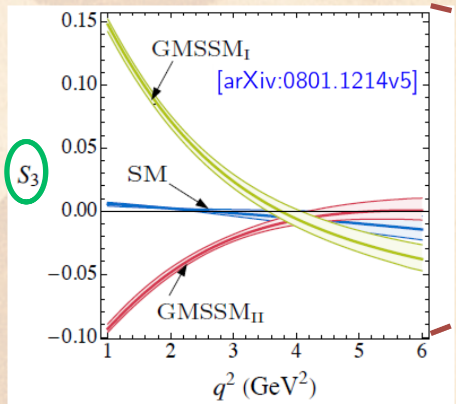


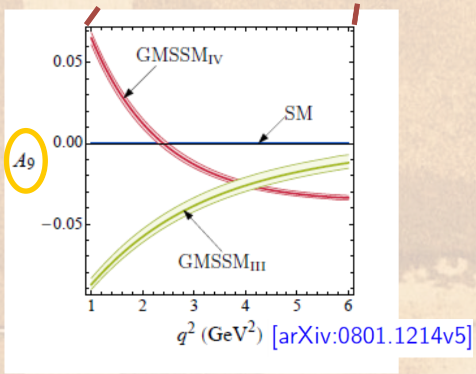
$B_d \to K^*(\to K\,\pi)\,\mu\mu$

… And then you can compare to models







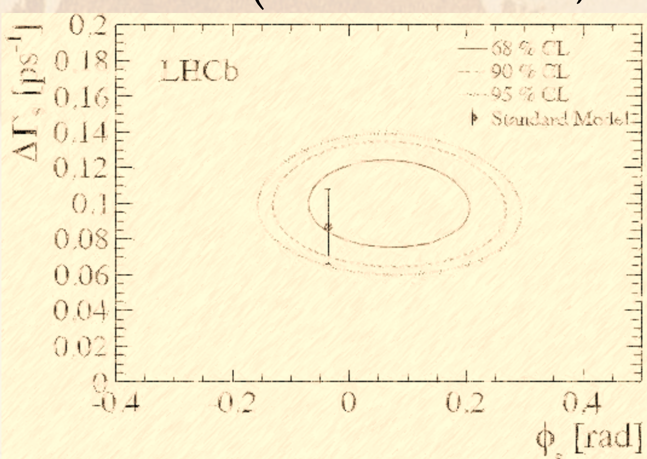


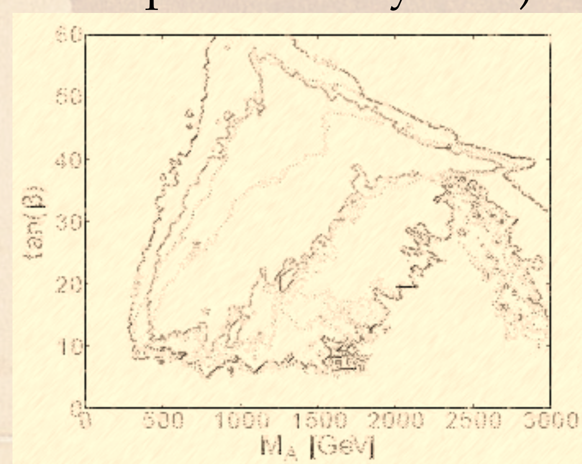
Also CMS has results on this channel, see: CMS-PAS-BPH-11-009

Conclusions

- Flavour experimental data is a powerful test for BSM physics
- LHCb has plenty of results on beauty, charm and strange decays
  - The BSM hint in charm CPV is vanishing ☹
  - Up to now, good agreement with SM. This allows constraining BSM parameter space

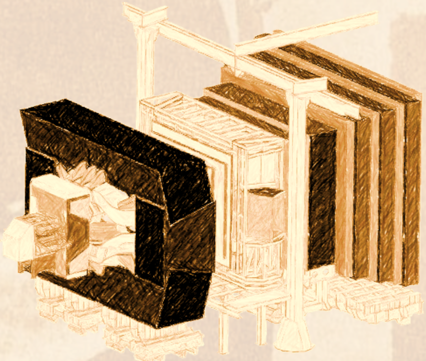
(in other words, we didn't observe planet satellites or parallax…. yet ☺)

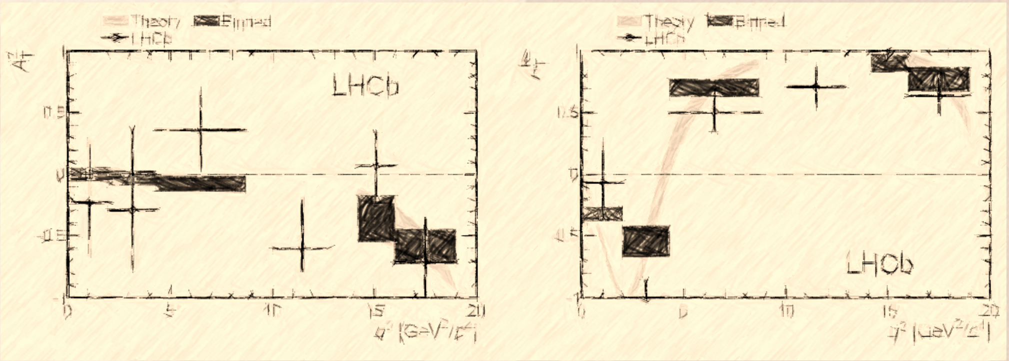




Conclusions

- Most of our results used only 1 fb^{-1} (7 TeV).
- Publications with 3 fb^{-1} collected up to now are in preparation.
- The LHCb upgrade plans to collect 50 fb^{-1} at 14 TeV (equivalent to 100 fb^{-1} at 7 TeV)
- More precision (and new measurements) may finally show BSM (or keep constraining it)





Indirect approach

• Low energy observables can access NP through new virtual particles entering in the loop → indirect search

• Indirect approaches can access higher energy scales and see NP effects earlier:

•3rd quark family inferred by Kobayashi and Maskawa (1973) to explain CP V in K mixing (1964). Directly observed in 1977 (b) and 1995 (t)

•Neutral Currents discovered in 1973, 10 years before observation of Z^0

•☺ Roundness of Earth (Eratosthenes, c.III B.C) discovered ~2300 years before direct observation

Eratosthenes

~2.3 k years till the direct observation…

$K_S \to \mu\mu$

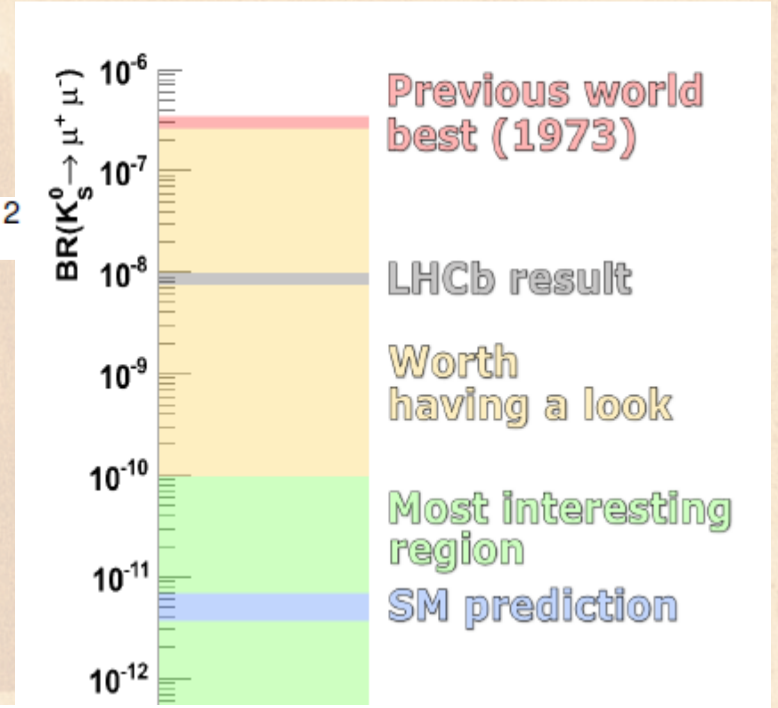
SM prediction : $\mathcal{B}(K^0_S \to \mu^+\mu^-)|^{SM} = (5.1 \pm 1.5) \times 10^{-12}$

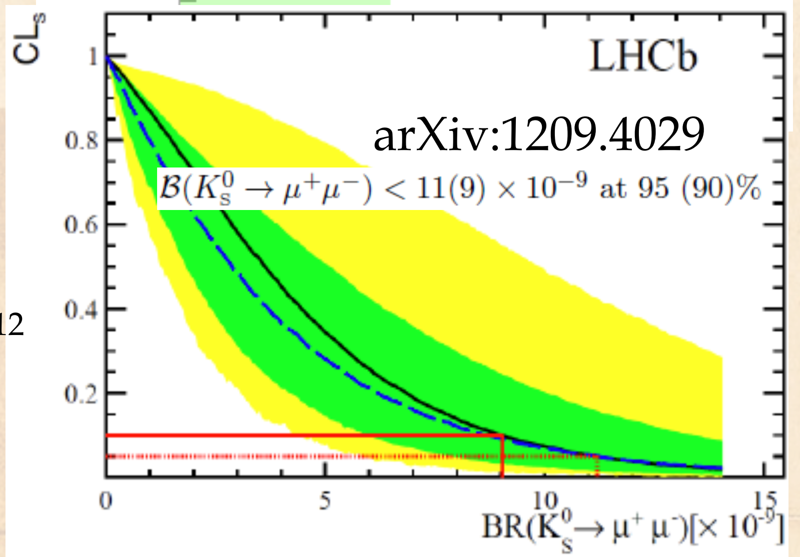
Even if $K_L \to \mu\mu$ has been measured, $K_S \to \mu\mu$ remains interesting because it's sensitive to different physics than $K_L \to \mu\mu$ (see arXiv:hep-ph/0311084)

In particular, if BSM is found in NA62, then limits/ measurements of $K_S \to \mu\mu$ in the 10^{-11}-10^{-12} range can be useful to understand its nature

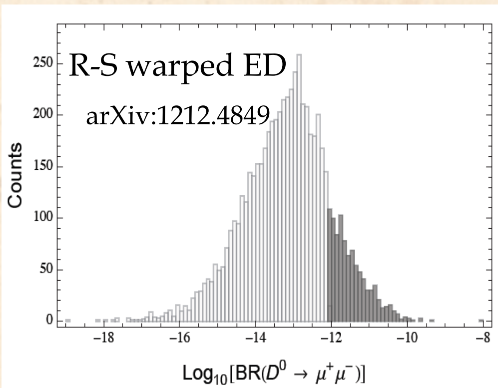
LHCb ($1fb^{-1}$) sets world best upper limit $9(11) \times 10^{-9}$ @90(95)%CL_s

LHCb upgrade might be able to reach the 10^{-11}-10^{-12} range thanks to improved trigger.





$D^0 \to \mu\mu$

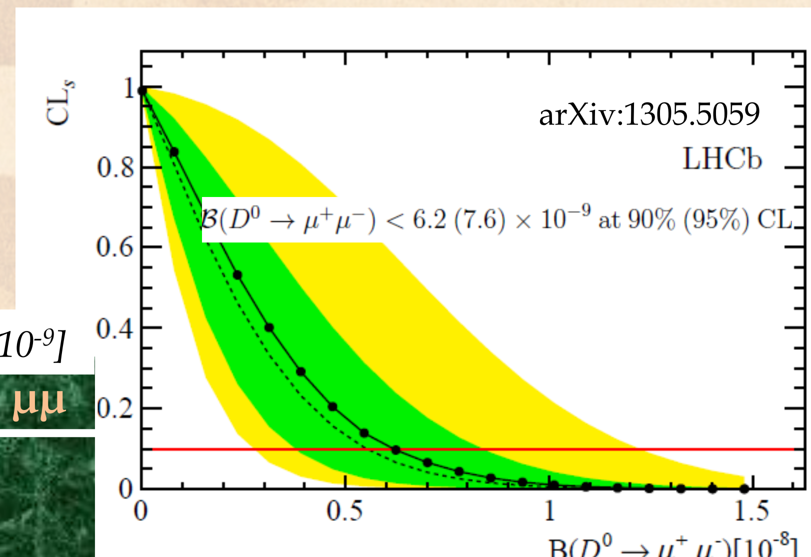


SM prediction: BR($D^0 \to \mu\mu$) < 1.6×10^{-11}
(Precision depends on knowledge of BR($D^0 \to \gamma\gamma$))

BSM physics (RPV, ED's) can enhance it up to the 10^{-10} level

LHCb set an upper limit of $6.2(7.6)\times10^{-9}$ @ 90 (95) %CL_s using 0.9 fb^{-1}

Potential to reach more interesting region with LHCb upgrade



BR of neutral flavoured mesons into dimuons [x10^{-9}]

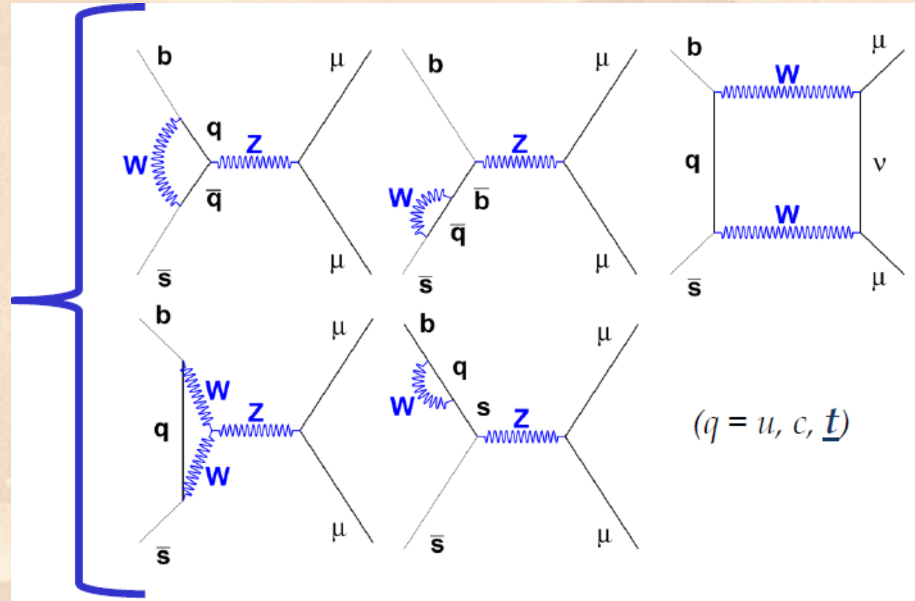
$B_s \to \mu\mu$	$B_d \to \mu\mu$	$D^0 \to \mu\mu$	$K_L \to \mu\mu$	$K_S \to \mu\mu$
3.2 [redacted] +1.5@ −1.2	<0.94	<7.6	6.84±0.11	11
LHCb	LHCb	LHCb	BNL E871	LHCb

$B_{s(d)} \to \mu\mu$

These decays are very supressed in SM

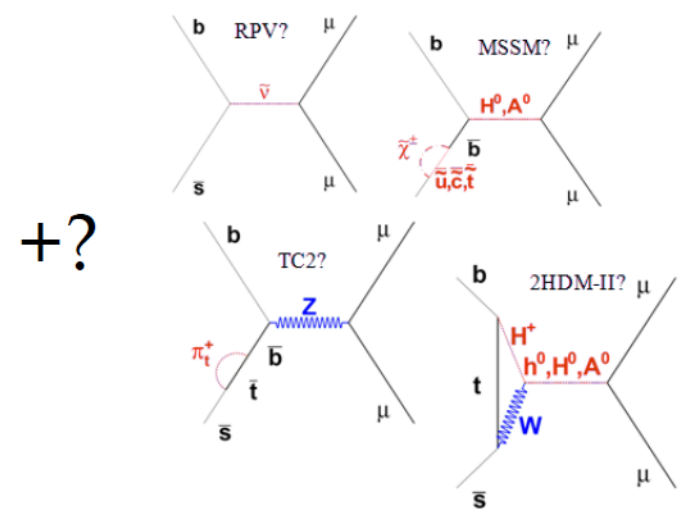
$BR(B_s \to \mu\mu) = (3.54 \pm 0.30)\times 10^{-9}$
$BR(B_d \to \mu\mu) = (1.07 \pm 0.10)\times 10^{-10}$

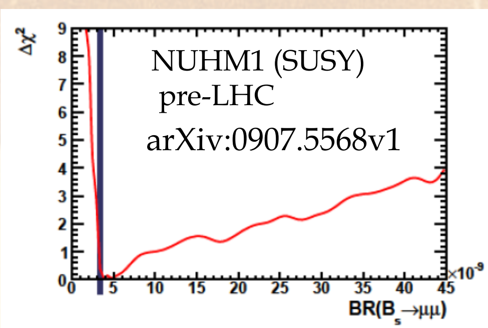
Eur. Phys. J. C72 (2012) 2172, arXiv:1208.0934. *(time averaged)*

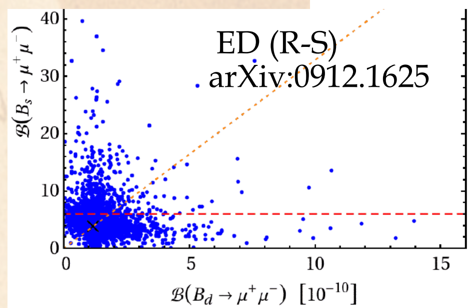


(note also the high TH precision)

But several NP models could sizably modify those values, sometimes by orders of magnitude.







→ Whatever we measure, it impacts NP searches