B-PHYSICS AT THE LHC

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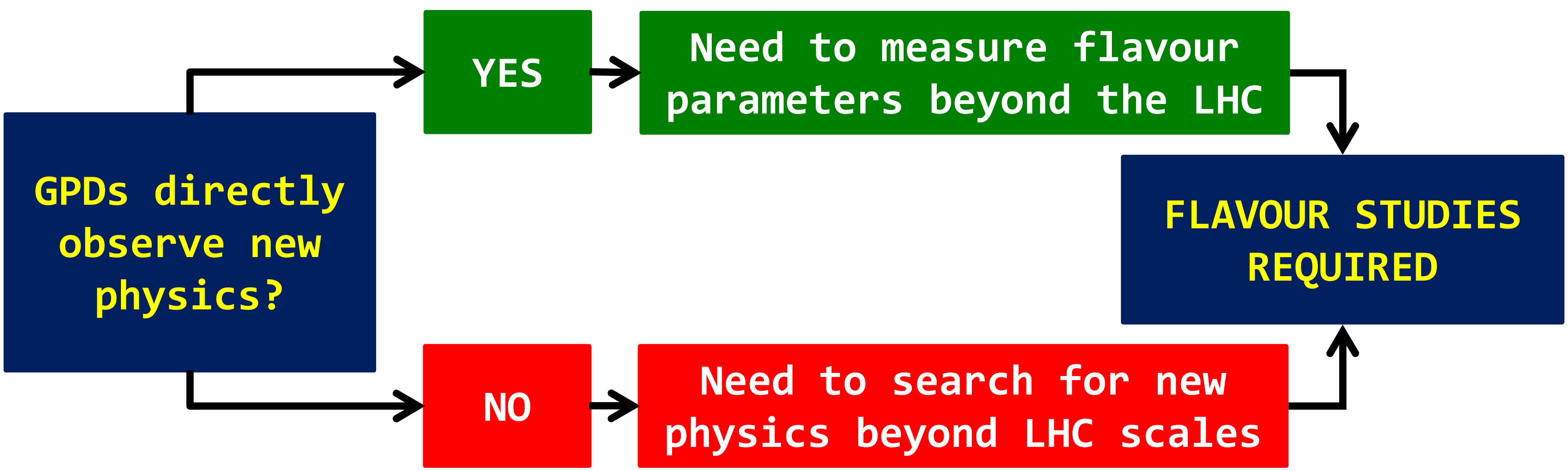
BSM-LHC Workshop 2009

WHY B (FLAVOUR) PHYSICS?

Probe new physics effects by studying decay processes dominated by loop diagrams

Since these only involve "virtual" particles (off mass shell), can probe energies orders of magnitude above the centre-of-mass energy of your experiment!

Discoveries in flavour physics often foreshadow direct discoveries of new physics (e.g. top quark)

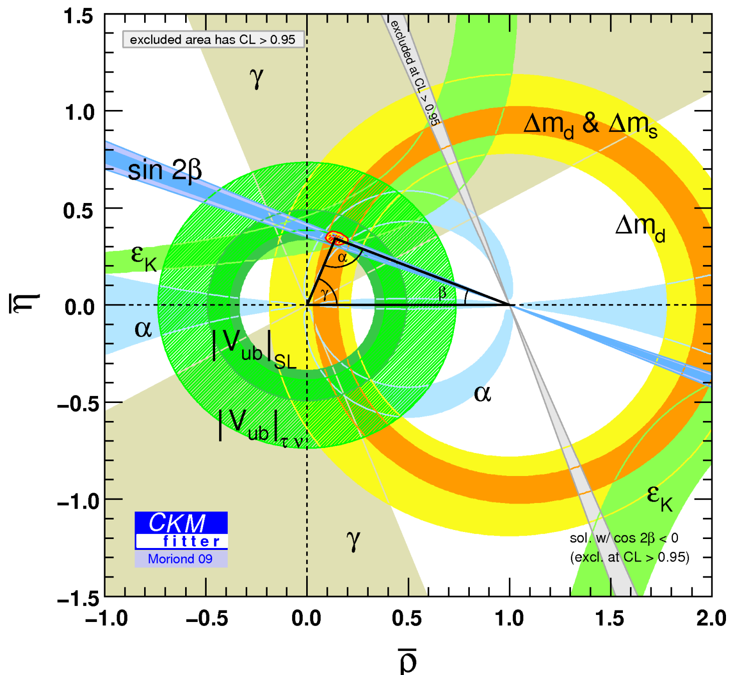


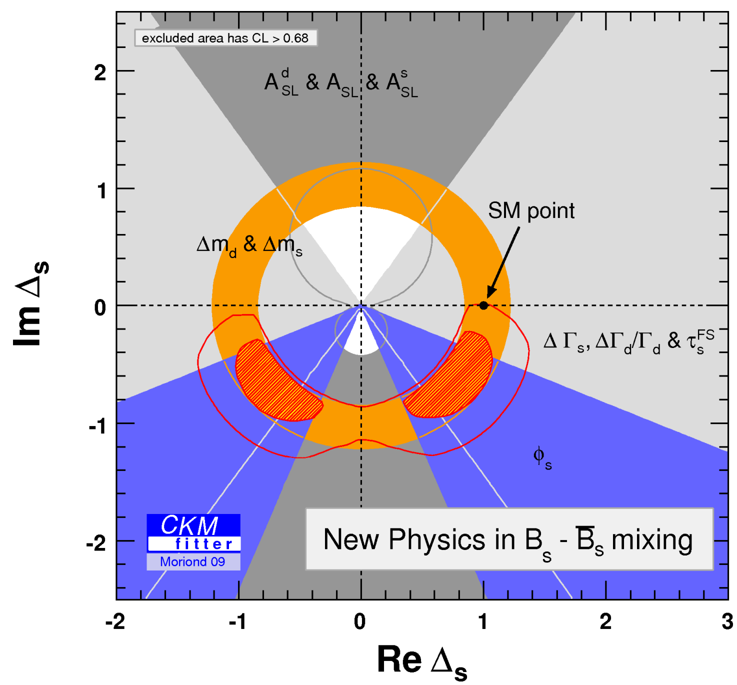
B PHYSICS IN 2009

The CKM picture of CP violation is well established, but there are still possibilities for new physics in precision measurements of The Unitarity Triangle

There is now interesting tension between SM predictions and experiment in B_s mixing

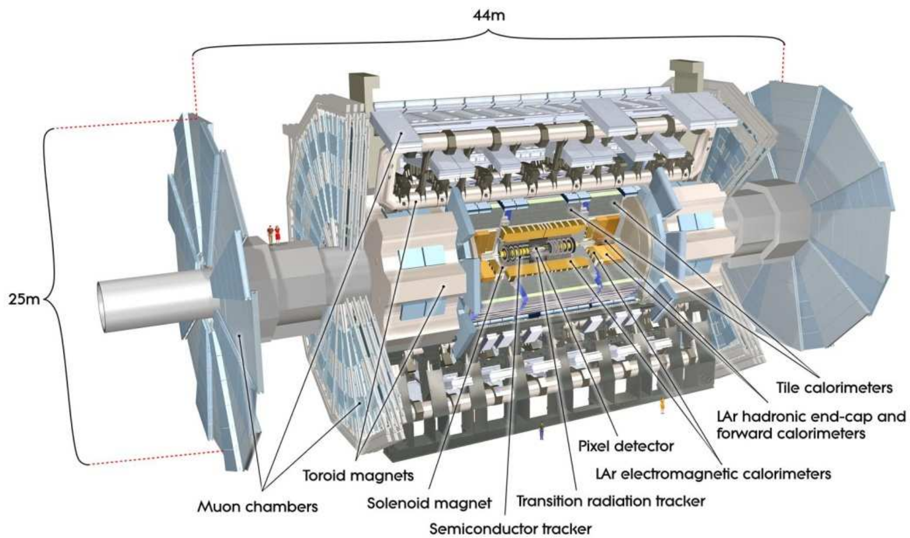
The LHC promises unprecedented statistical sensitivity to all types of B hadron



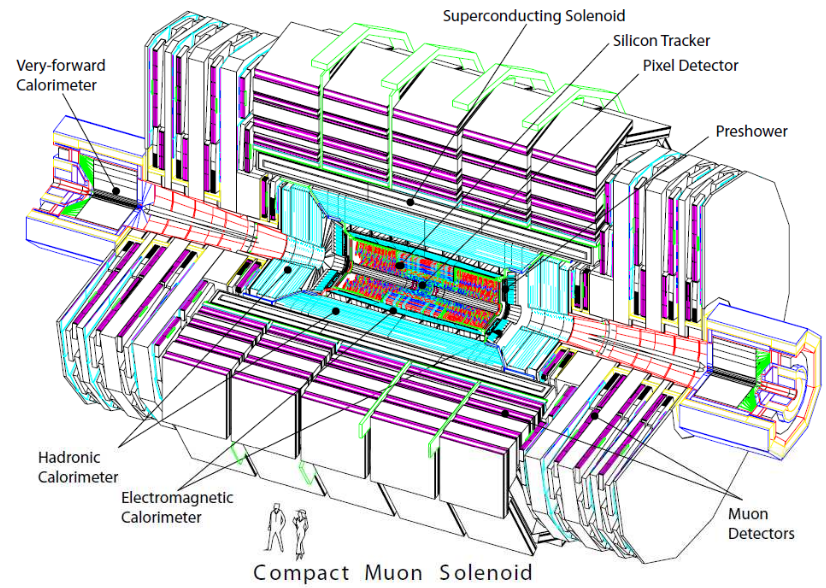


THE LHC GENERAL PURPOSE DETECTORS

ATLAS



CMS



Design luminosity 10^{34} $cm^{-2}s^{-1}$, run at 10^{33} for B-physics

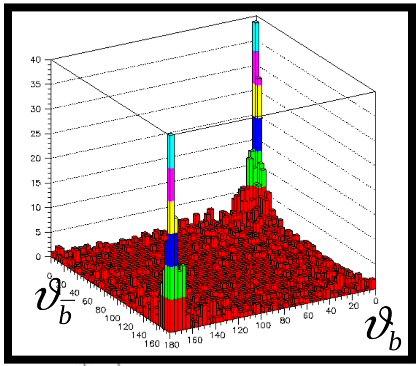
Collect 30 fb^{-1} of data in B-physics run

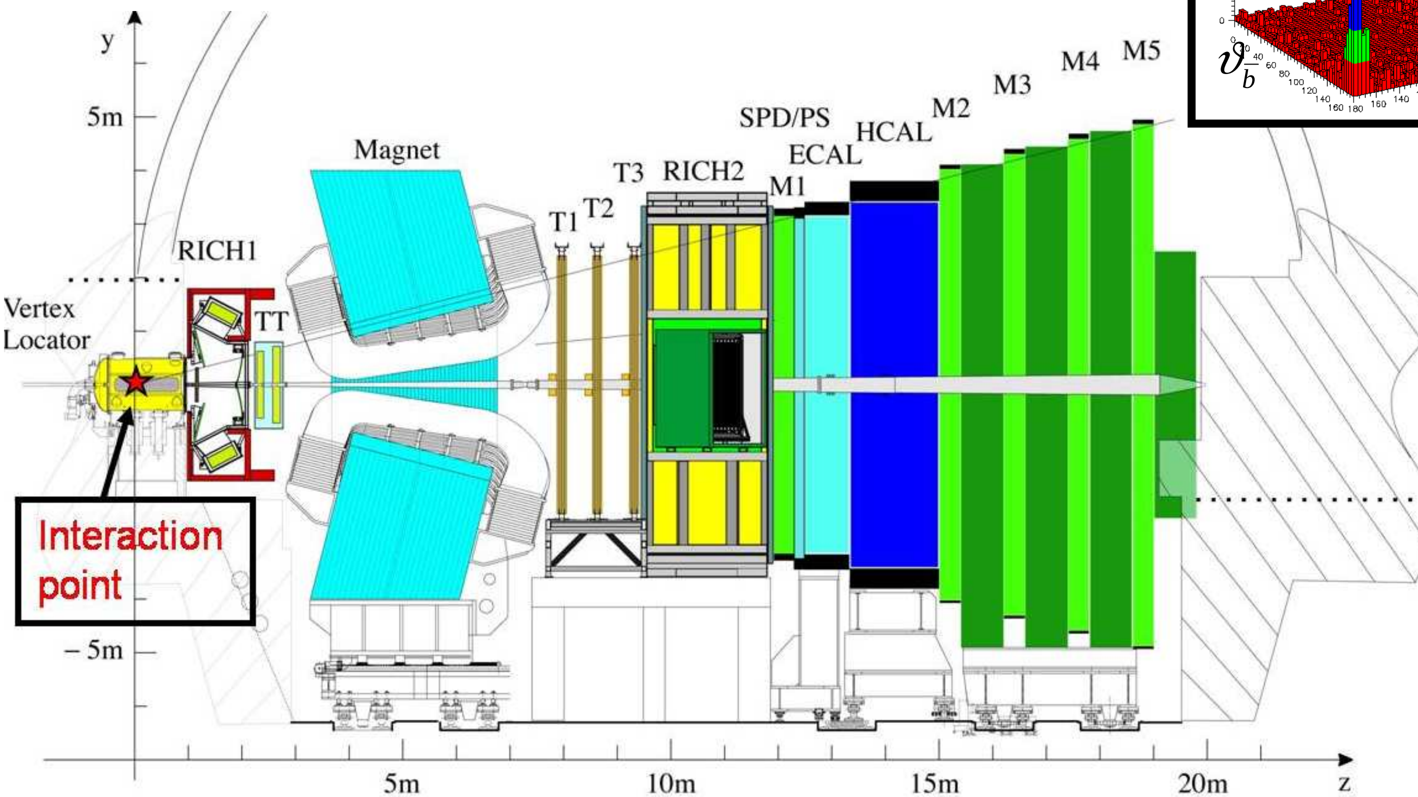
Trigger on high-P_T muons

THE LHCb DETECTOR

Dedicated forward spectrometer for b-physics

- Covers unique η range: 1.9➔4.9
- Most b-hadrons are produced in the forward direction at the LHC





LHCb DETECTOR PERFORMANCE

Produced B mesons are highly boosted

Average B momentum ~80 GeV

Lifetime resolution ~40fs (~3%)

Mass resolution 16-20 MeV

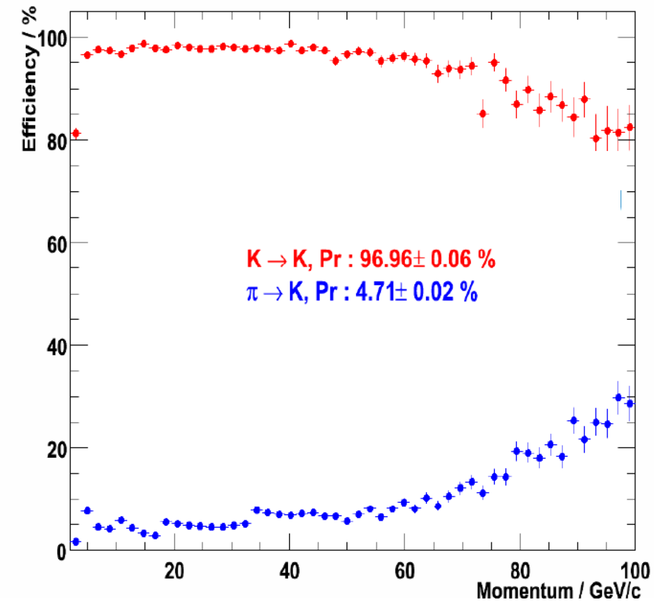
Excellent particle identification

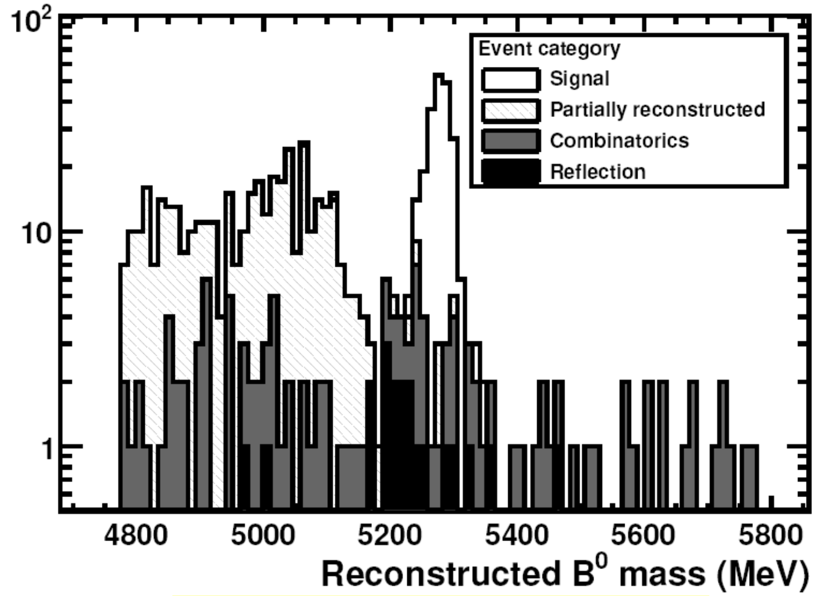
Kaon ID. eff. ~95%

pion mis-ID ~5%

Kaon-pion separation in momentum range of 2-100 GeV

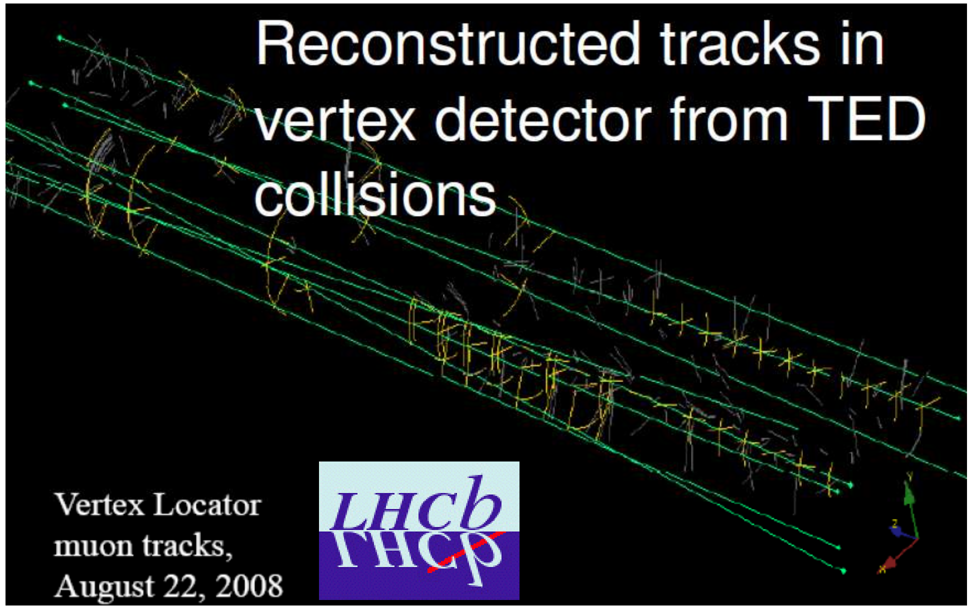
Collect 10 fb^{-1} of data

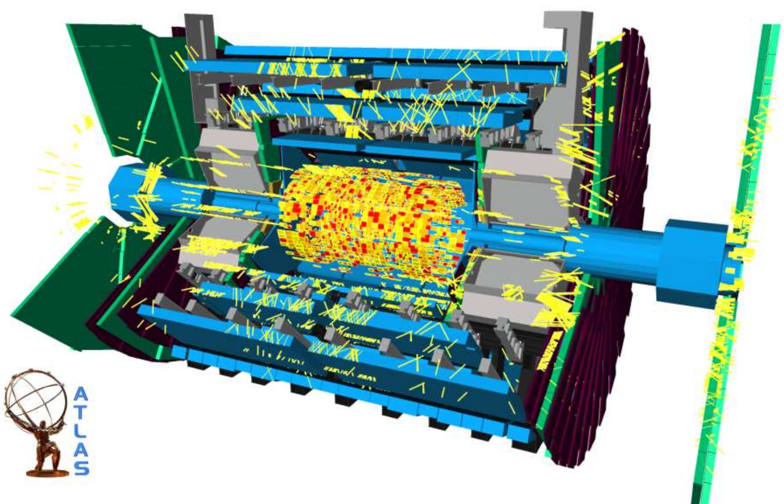


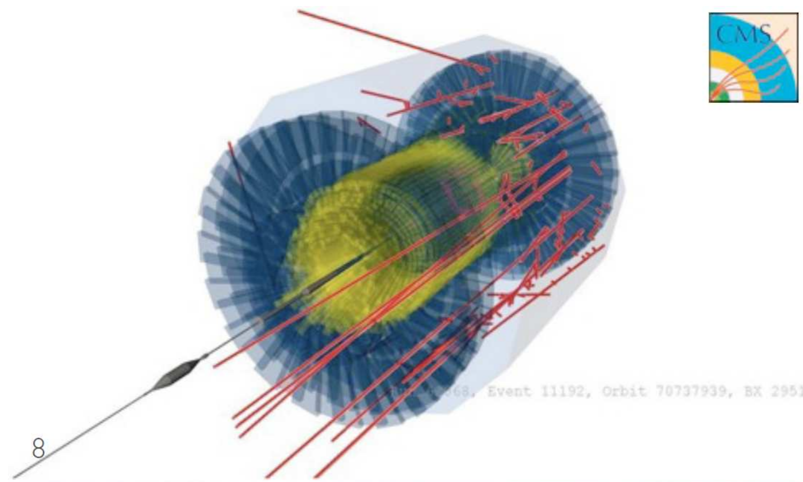


B→Dπ, 300s of data taking

LOOK, THEY ACTUALLY WORK(ED)!







LHC scenario(s) for 2009/10

The LHC is due to restart this year

- Expect sustained physics run in 2010

Likely running scenario?

- 5 TeV on 5 TeV collisions
- Reduced luminosity
- LHCb hopes to collect 200 pb^{-1} of data in 2010

B-PHYSICS MEASUREMENTS AT THE LHC

B-PHYSICS IS A RICH FIELD OF STUDY

The decays of B hadrons offer sensitivity to a wide range of New Physics ➔ we'll look at a few selected highlights

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	Direct CP violation measurements	$B^+ \to D^0 K^+$, $B^0 \to D^0 K^*$

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	Direct CP violation measurements	$B^+ \to D^0 K^+$, $B^0 \to D^0 K^*$
Radiative penguins	CP violation and photon polarization measurements	$B^0 \to K^* \gamma$, $B_s \to \phi \gamma$

$B_s \rightarrow \mu\mu$ MOTIVATION

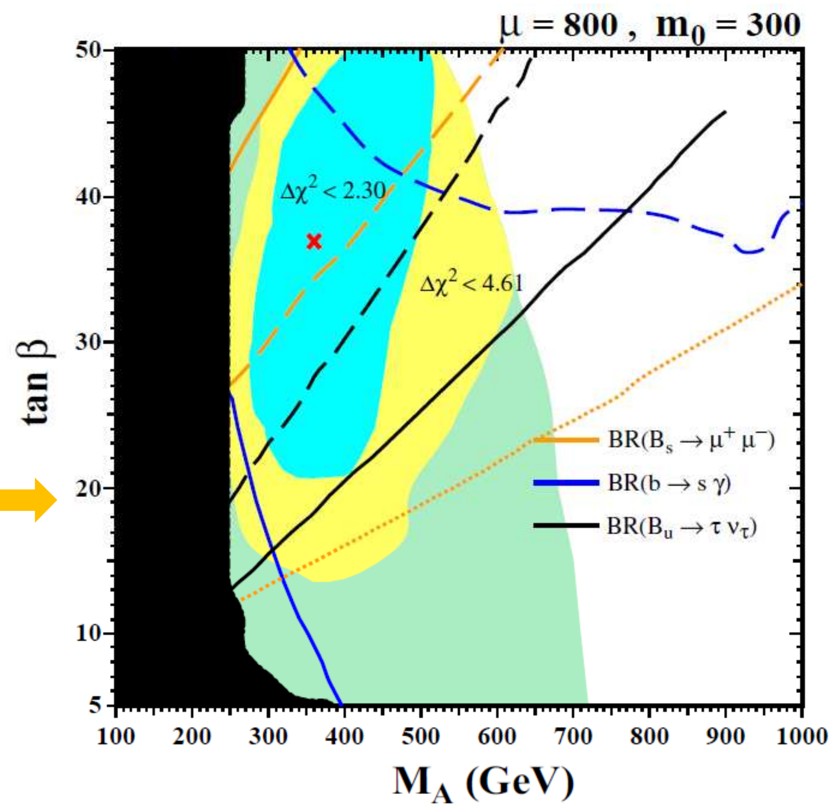
Branching ratio measurement is sensitive to a wide range of New Physics

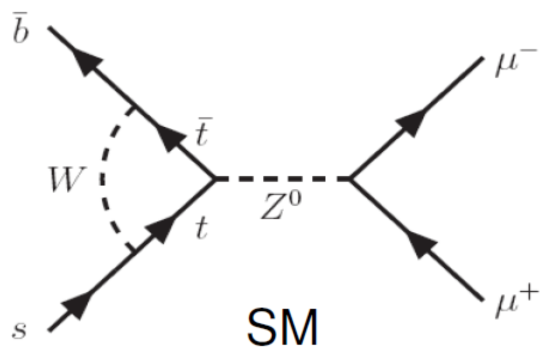
e.g. $\tan^6\beta$ enhancement in MSSM from the second Higgs doublet

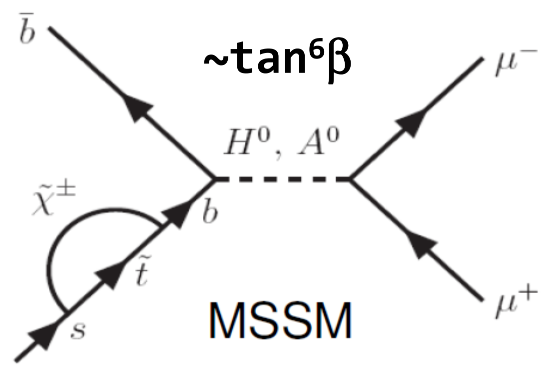
Large discriminating power →

- —— B.R. < 10^{-7}
- - - - B.R. < $2 \cdot 10^{-8}$
- •••• B.R. < $5 \cdot 10^{-9}$

J. Ellis et al., http://arxiv.org/abs/0709.0098







$B_s \rightarrow \mu\mu$ STATUS AND ANALYSIS

Best published limit from CDF analysis of 1.9 fb^{-1} of data

B.R. $B_s \rightarrow \mu\mu < 5.8 \cdot 10^{-8}$ @ 95% C.L.

Ref: PRL 100,101802 (2008)

Analysis challenges

Need to normalize the branching fraction through $B \rightarrow hh$, $B \rightarrow J/\psi K^+$ control channels

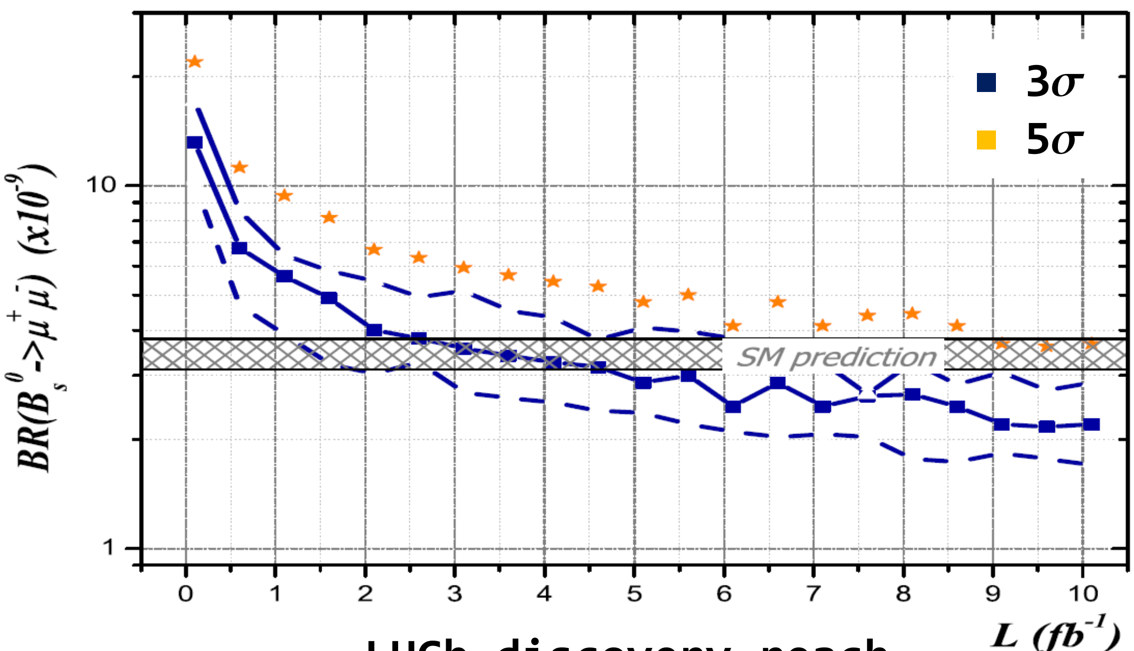
The systematic error is dominated by the uncertainty on B_s/B_d production ratio, hope for help from BELLE

Performance limited by background from muons from **b,c** decays; decays in flight not a limiting factor.

$B_s \rightarrow \mu\mu$ SENSITIVITIES AT THE LHC

	Int. Lumi.	Signal	Background
LHCb	2 fb^{-1}	7.6	22^{+29}_{-14}
CMS	10 fb^{-1}	6.1	14^{+22}_{-14}
ATLAS	10 fb^{-1}	5.7	14^{+13}_{-10}

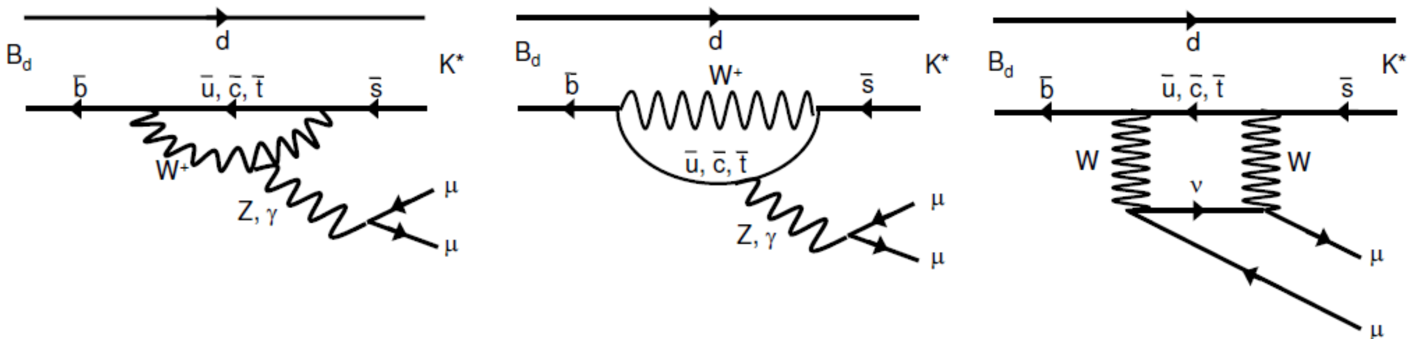
Only in the most sensitive region!
Total signal yield 21 events with a background of 180^{+140}_{-80} events

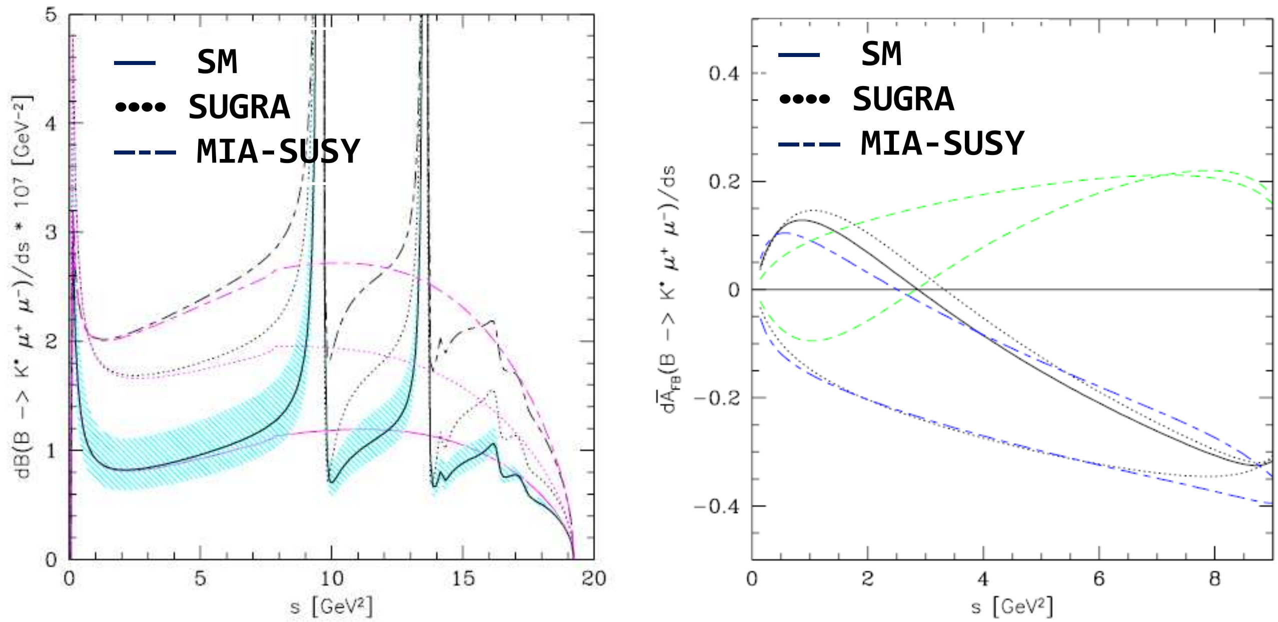


LHCb discovery reach

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

Flavour Changing Neutral Current decay, highly sensitive to many New Physics models

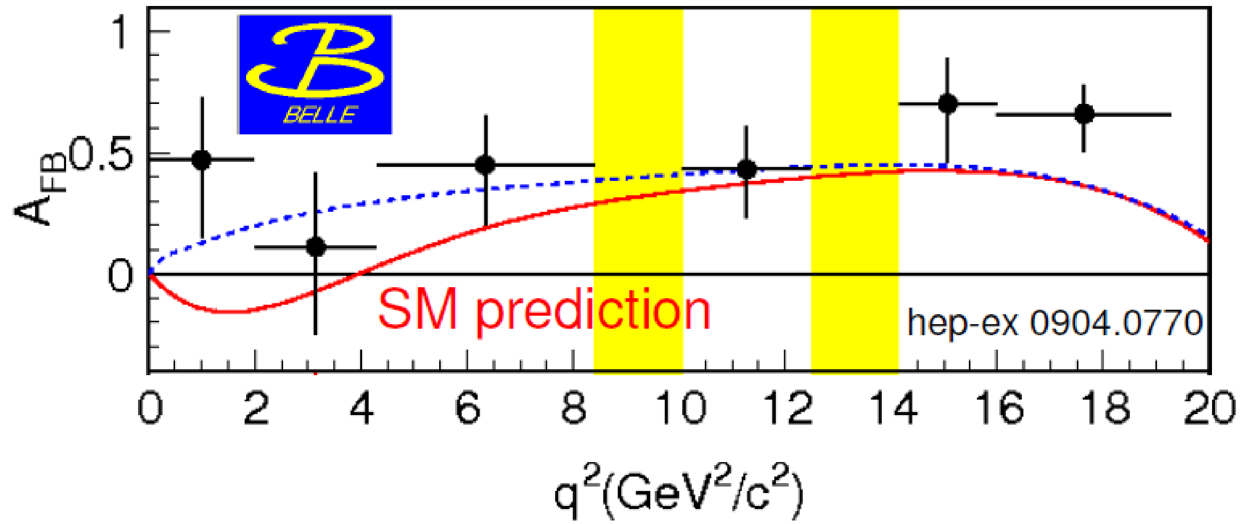




Ref: Phys.Lett.B273 505,1991

$B^0 \rightarrow K^*\mu\mu$ STATUS AND ANALYSIS

BELLE analysis based on ~250 events



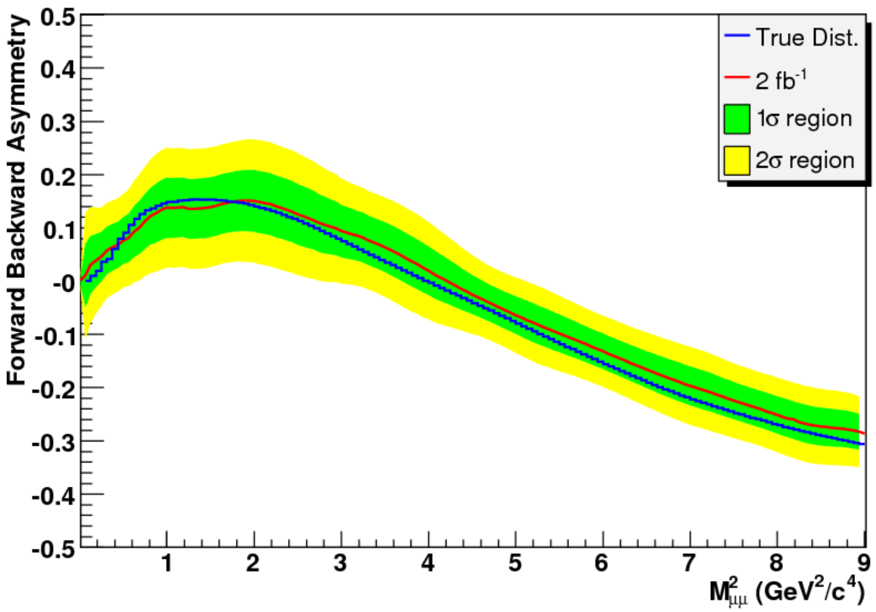
Analysis challenges

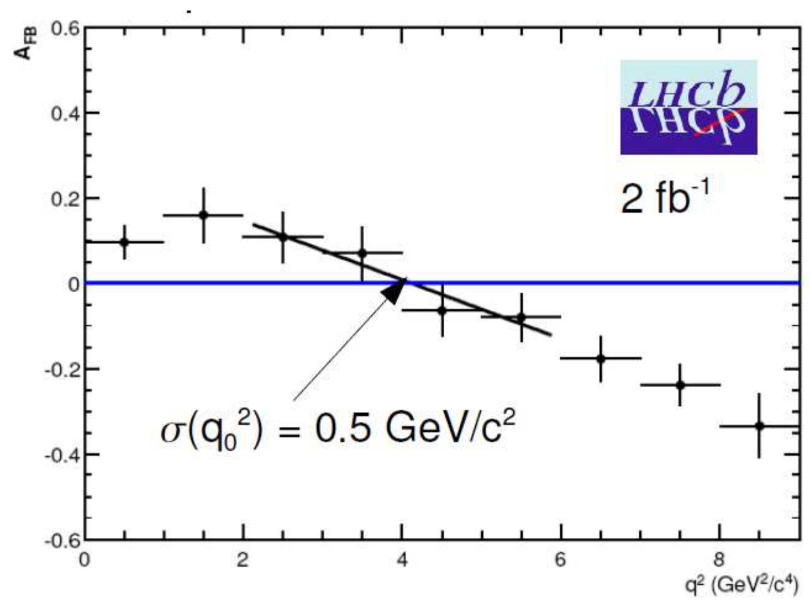
For AFB measurement, need to minimize the impact of cuts on the angular distribution

Performance limited by background from muons from **b,c** decays; decays in flight not a limiting factor.

$B^0 \rightarrow K^*\mu\mu$ SENSITIVITIES AT THE LHC

	Int. Lumi.	Signal	B/S
LHCb	2 fb^{-1}	7100	0.2
ATLAS		Under study	





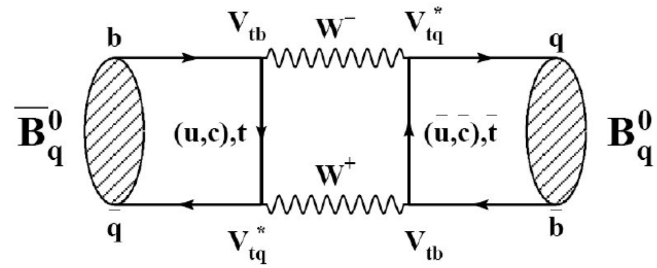
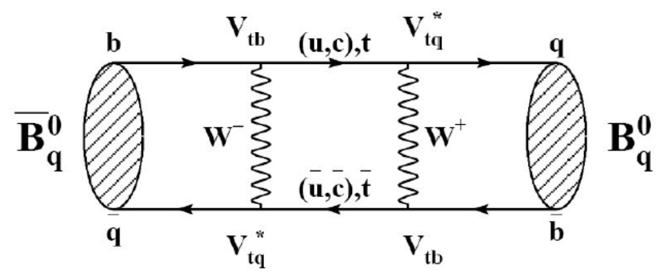
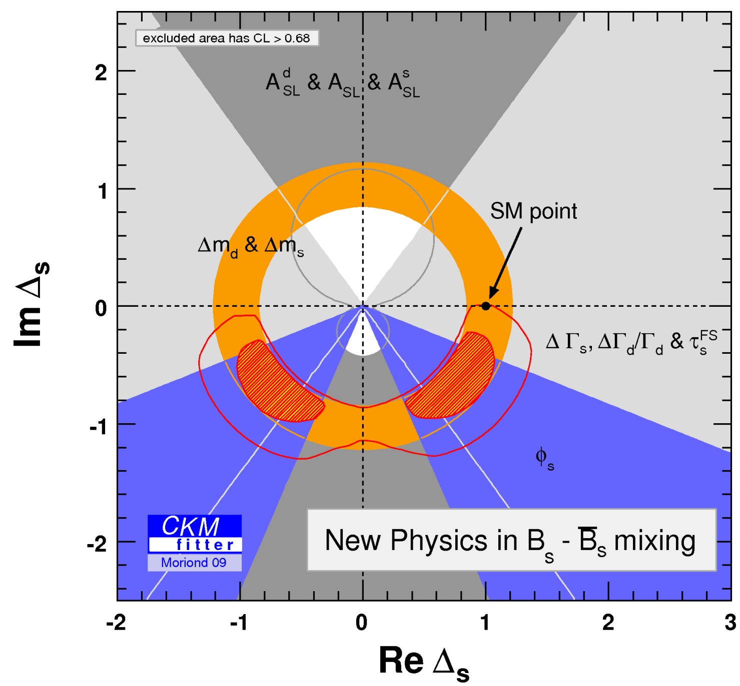
Example LHCb AFB fits with 2 fb^{-1} of data

$B_s \rightarrow J/\psi\ \varphi$ MOTIVATION AND STATUS

Weak mixing phase precisely predicted to be small in SM

SM ϕ_s = -0.037 ± 0.002 rad

Current measurements indicate tension wrt. the SM – resolve this at the LHC

$B_s \rightarrow J/\psi\ \varphi$ ANALYSIS

Measure ϕ_s from time dependant decay rate asymmetries

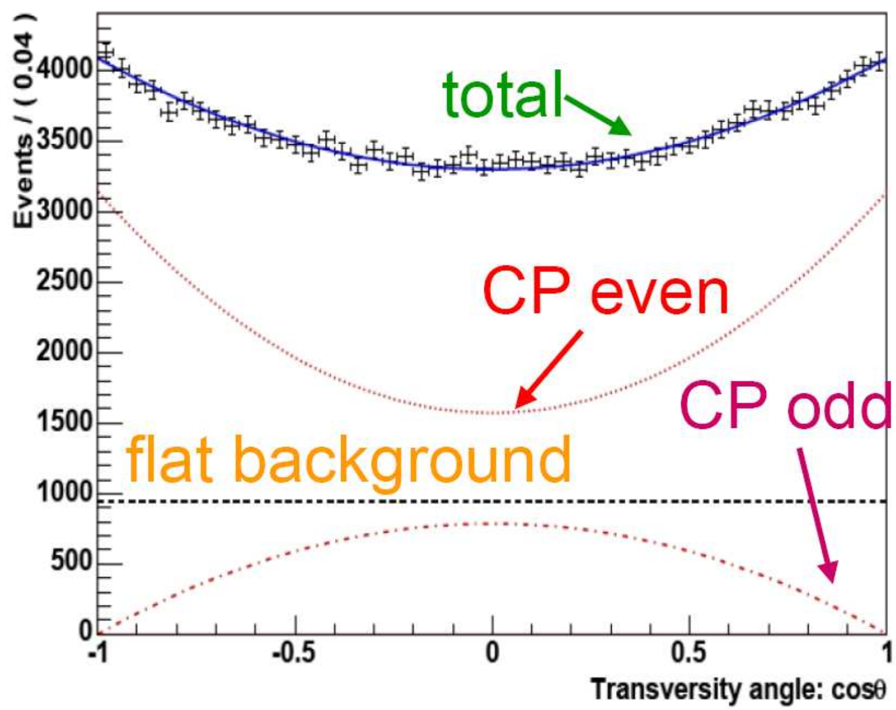
$$A_{CP}(t) = -\frac{\eta_f \sin\phi_S \sin(\Delta m_S t)}{\cosh\left(\frac{\Delta\Gamma_S t}{2}\right) - \eta_f \cos\phi_S \sinh\left(\frac{\Delta\Gamma_S t}{2}\right)}$$

$B_s \rightarrow J/\psi\phi$ is not a pure CP mode

Need angular analysis to disentangle

CP even (η_f = -1)
CP odd (η_f = +1)

contributions



$B_s \to J/\psi\ \phi$ SENSITIVITIES AT THE LHC

Signal datasets

	Int. Lumi.	Signal	B/S
LHCb	2 fb^{-1}	117 k	2.1
CMS	10 fb^{-1}	109 k	0.3
ATLAS	10 fb^{-1}	80 k	0.3

Note that the LHCb sample is lifetime unbiased; background is dominated by prompt charm production

Sensitivities

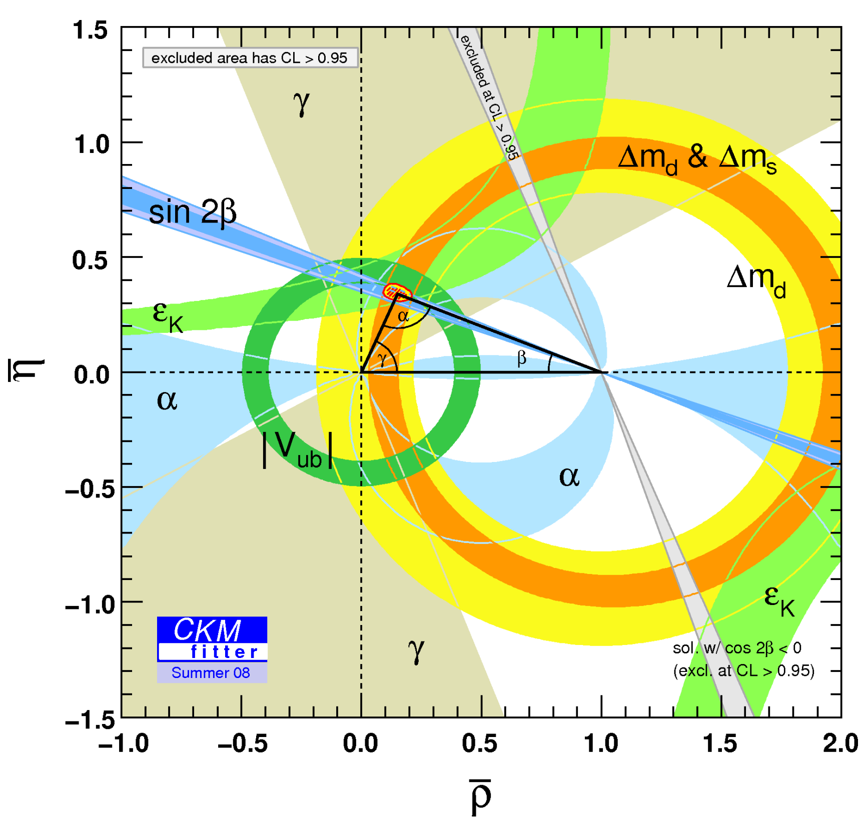
	Int. Lumi.	ϕ_s	$\Delta\Gamma_s$
LHCb	2 fb^{-1}	0.03	0.01
CMS	10 fb^{-1}		0.01
ATLAS	10 fb^{-1}	Under study	

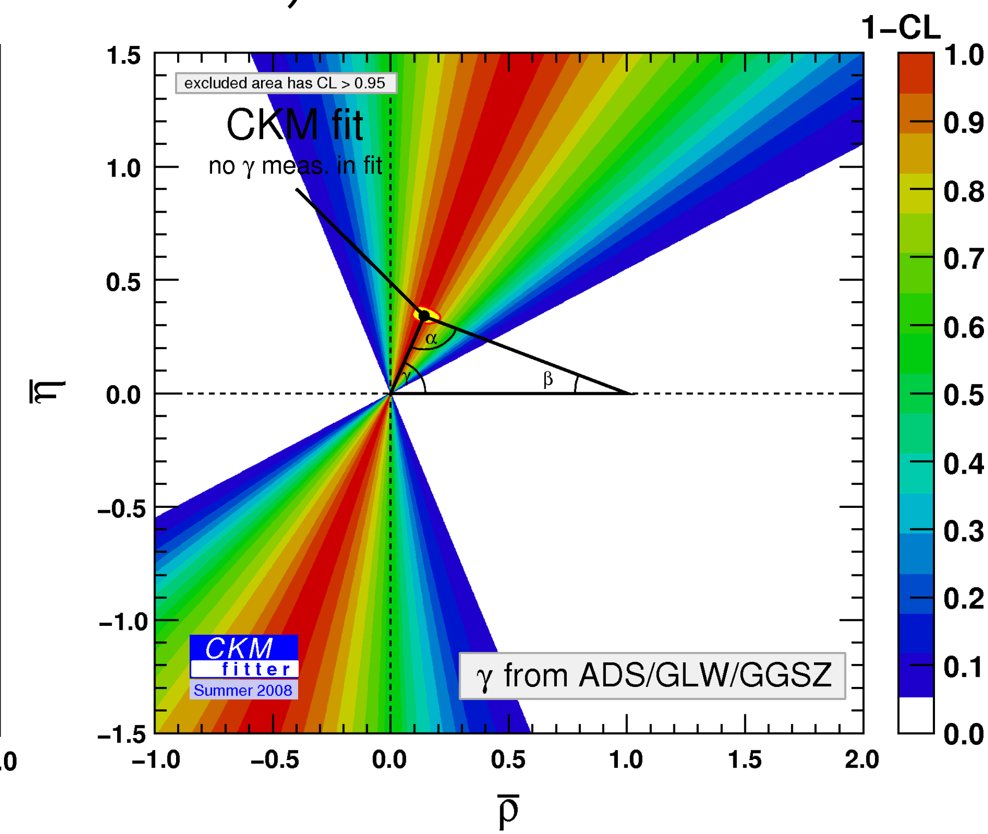
MEASURING THE CKM ANGLE γ

Crucial to overconstrain The Unitarity Triangle!

Best single measurements from Dalitz analyses

BELLE : $\gamma = (76 \pm 13 \pm 4 \pm 9)$
BABAR : $\gamma = (76 \pm 22 \pm 5 \pm 5)$





γ AT THE LHC

Unique to LHCb, with several possible approaches. Some examples are listed below but many other decays are available!

Tree level decays

Direct CP Violation

B➔DK with ADS/GLW method
B➔DK with GGSZ method (Daltiz analysis of **D➔K$_s$$\pi\pi$**)

Time-dependent measurements

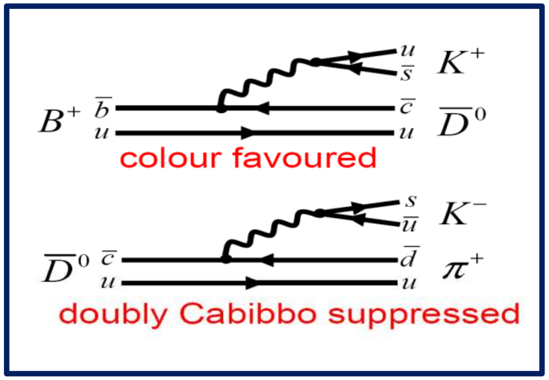
B$_s$➔D$_s$K with **B$_s$➔D$_s$$\pi$** (Probably globally unique to LHCb)
B$_s$➔D$_s$K and **B^0➔Dπ** using U-spin symmetry

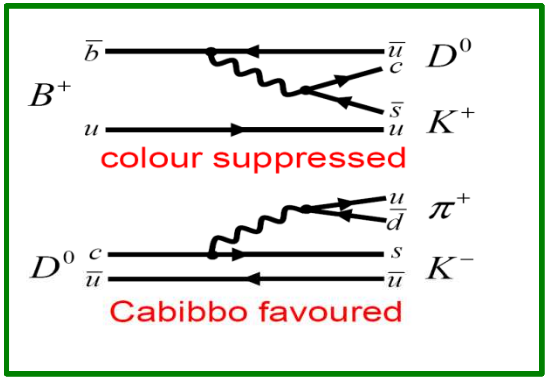
Loop decays

B➔hh using U-spin symmetry

γ FROM TREES – ADS/GLW

Combining colour suppressed B decays with Cabibbo favoured D decays (and vice versa) increases the sensitivity to CP parameters since the interference effects become of order 1.





Charged Modes	Signal yield ($2fb^{-1}$)	B/S
$B^\pm \rightarrow D(K\pi)K^\pm$	84 k	0.6
$B^\pm \rightarrow D_{SUP}(K\pi)K^\pm$	1.6 k	0.6
$B^\pm \rightarrow D(K\pi\pi\pi)K^\pm$	48 k	0.03
$B^\pm \rightarrow D_{SUP}(K\pi\pi\pi)K^\pm$	0.53 k	3.0
$B^\pm \rightarrow D(hh)K^\pm$	11.5 k	1.7

Neutral Modes	Signal yield ($2fb^{-1}$)	B/S
$B^0 \rightarrow D(K\pi)K^*$	4 k	0.25
$B^0 \rightarrow D_{SUP}(K\pi)K^*$	0.36 k	< 7
$B^0 \rightarrow D(hh)K^*$	0.46 k	< 10

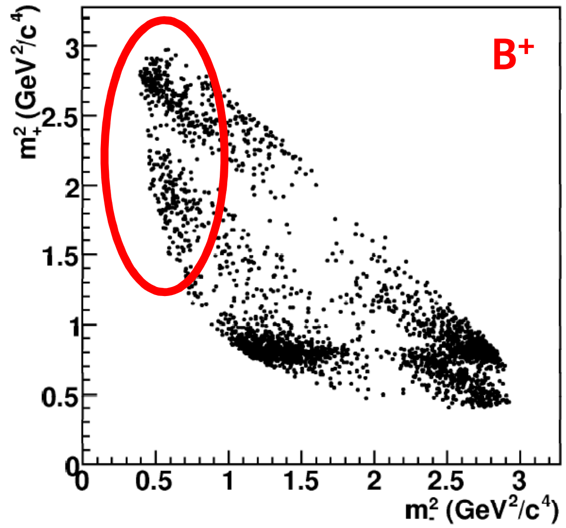
γ FROM TREES – GGSZ

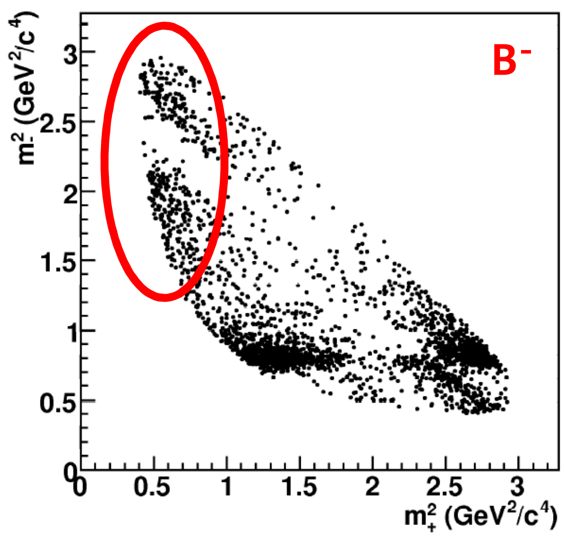
Sensitivity to γ from **differences in the Dalitz plot** for B^+ and B^- decays

Two approaches to the Dalitz analysis

1. **Unbinned fit using a model for the Dalitz space; this approach makes full use of the statistics but incurs a model error. The error depends on the model chosen, typically ~7°.**

2. **Bin the Dalitz space in D strong phase, using external inputs from CLEO-C measurements. Avoids model error at the cost of some statistical power.**





$B^+ \rightarrow D(K_s\pi\pi)K$

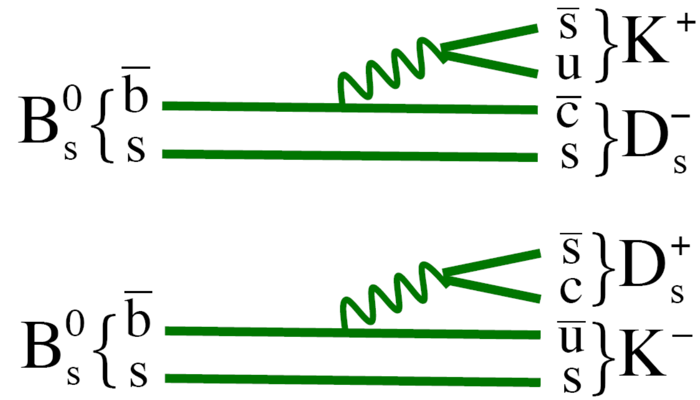
Signal yield = 6800 / $2fb^{-1}$

B/S < 1.5 at 90% C.L.

γ FROM TREES – TIME DEPENDENT CPV

Sensitivity to γ from interference in mixing and decay of $B_s \rightarrow D_s K$

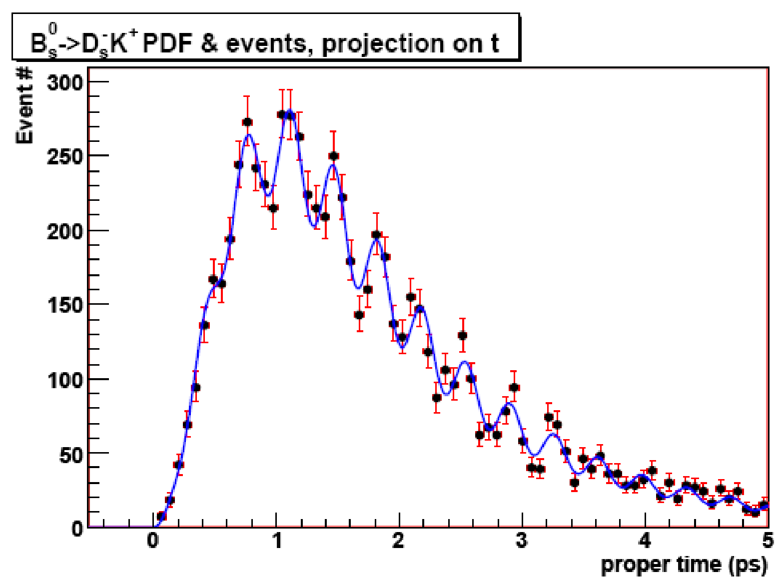
- Use untagged events to eliminate ambiguous solutions
- Simultaneous fit to $B_s \rightarrow D_s \pi$ allows Δm_s and $\Delta\Gamma_s$ to be extracted
- Simultaneous fit to $B \rightarrow D\pi$ may help remove ambiguities if $\Delta\Gamma_s$ small



$B_s \rightarrow D_s K$

Signal yield = 14,000 / $2fb^{-1}$

B/S < 0.45 at 90% C.L.



γ FROM TREES – SUMMARY

Perform global fit in order to obtain the maximum sensitivity to γ

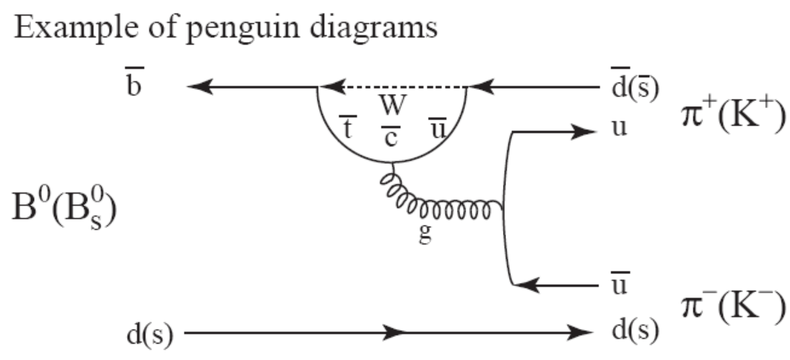
The numbers below are for the total (statistical + systematic) error

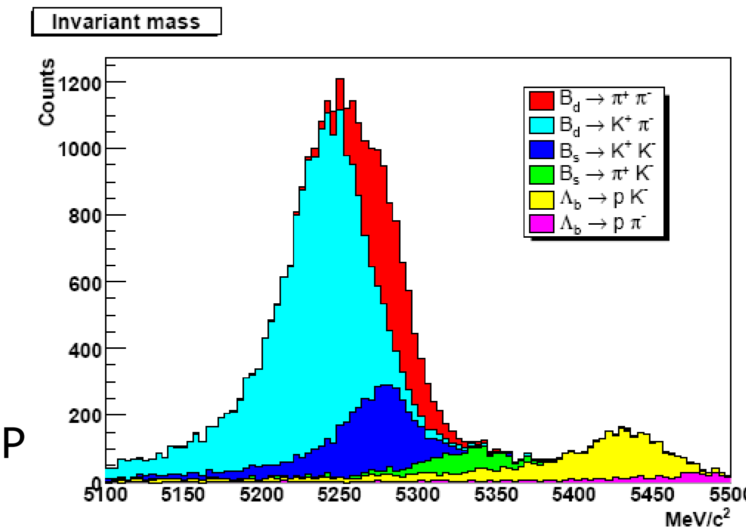
Sensitivity to γ

After 0.5 fb^{-1} : 8-10°

After 2 fb^{-1} : 4-5°

γ FROM LOOP DECAYS

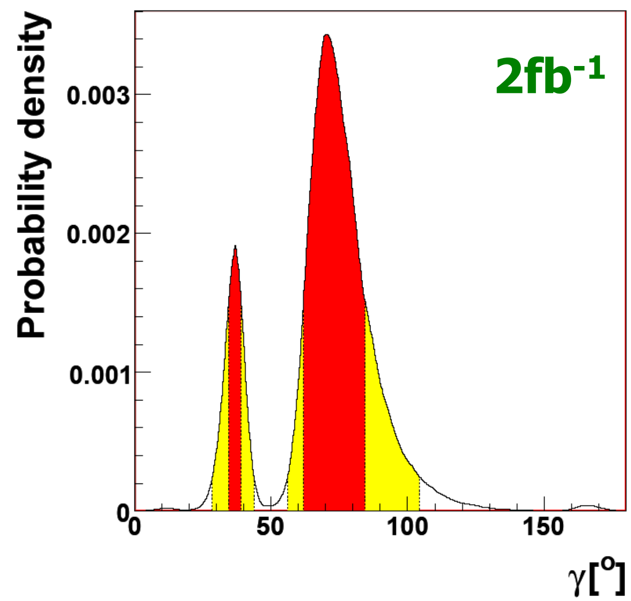




Sensitivity to γ from time-dependent CP asymmetries in B➔hh decays

LHCb particle ID system allows the decay modes to be separated

Use U-spin symmetry between B^0 and B_s decays to constrain the problem



Sensitivity to γ

After 2 fb^{-1} : 7°

RADIATIVE DECAYS AT THE LHC

Loop decays, the sensitivity to possible New Physics comes from many different observables

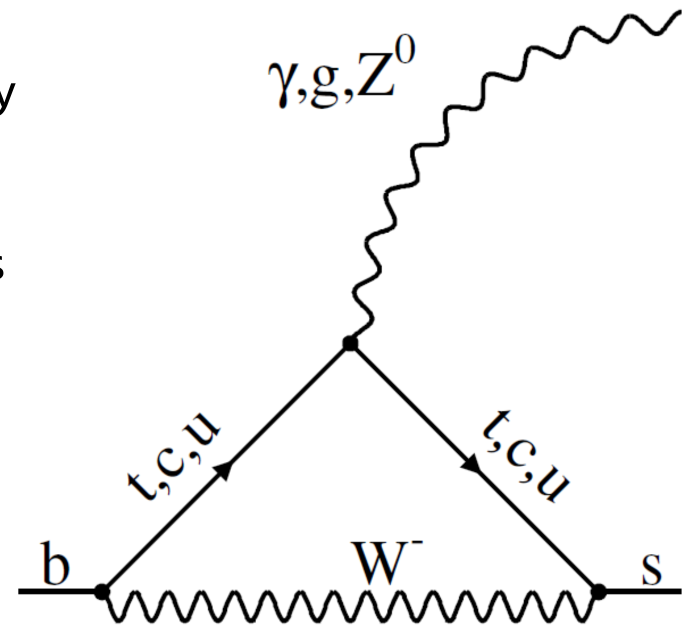
Detailed theoretical predictions available!

Interesting early measurements

Direct CP asymmetry in $B \rightarrow K^{*}\gamma$

Ratio of $B_s \rightarrow \phi\gamma$ and $B \rightarrow K^{*}\gamma$ rates

Long term aims: photon polarization and CP violation measurements



	Signal Yield (2fb^{-1})	B/S
$B^0 \rightarrow K^{*}\gamma$	70 k	0.6
$B_s \rightarrow \phi\gamma$	11 k	< 0.6
$B^+ \rightarrow \phi K\gamma$	7 k	< 2

TO FINISH, A DIGRESSION INTO CHARM

The LHC is a charm factory!

For example, 80% of B+ mesons decay via a D0

Prompt charm production may be an order of magnitude higher

Study mixing and CP violation in charm decays – potential for early (2010) measurements!

D0→hh with 5s of minimum bias data at LHCb