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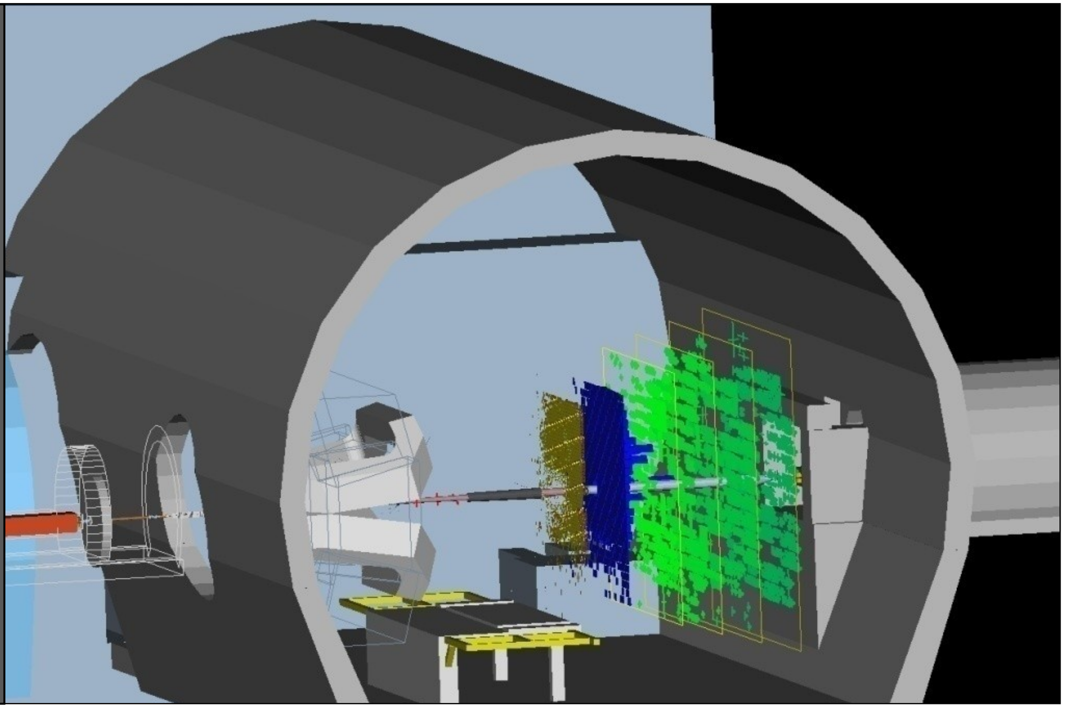


Beam induced “splash” in LHCb

LHC*b*

New B physics ideas

Ulrik Egede @

Interplay of Collider and Flavour Physics, 2nd meeting

17 March 2009

Physics case for LHC*b*

Find New Physics through its indirect effects in Heavy Flavour physics

Measure CP violation in B and D decays which is not compatible with the single complex phase in the CKM matrix.

Find deviations from Standard Model expectations in exclusive Flavour Changing Neutral Current decays.

This presentation

- Will look at some new developments in how we can do analysis in LHCb
- In **bold red** I will pinpoint areas where clarifications or additional work is required from theory side.
- Some different scenarios for physics in the next few years and how LHC*b* can provide interpretation
- The physics case for an upgrade of LHC*b*

$B_d \to K^{*0}e^+e^-$ as powerful as $B_s \to \varphi\gamma$

- In the SM the electroweak penguin for $b \to s\gamma$ and $b \to sl^+l^-$ are dominated by the left handed current
- We search for New Physics by looking for a large right handed component.
  - Time dependent CPV analysis of $B_d \to K^{*0}\gamma$ from B-factories
  - Time dependent analysis of $B_s \to \varphi\gamma$ at LHCb
  - Angular analysis in $B_d \to K^{*0}\mu^+\mu^-$
- New development to look at $B_d \to K^{*0}e^+e^-$
  - Has so far only been considered for ratio with respect to muon channel
  - Inherently much harder as trigger with electrons is difficult compared to muons

$B_d \to K^{*0}e^+e^-$ as powerful as $B_s \to \varphi\gamma$

Look in region $(30\ \text{MeV})^2 < q^2 < (1\ \text{GeV})^2$

- Contributions not coming from virtual photons are very small in this region.
- **We can ignore the vector mesons in this region?**

In angle between di-lepton and K* plane (φ) we fit for A_T^2.

- Not dependent on longitudinal part which we can't calculate

$$\frac{d\Gamma}{d\varphi} = \frac{\Gamma}{2\pi}\left(1 + \frac{1}{2} F_T A_T^{(2)} \cos 2\varphi + A_{\Im} \sin 2\varphi\right)$$

- In SM limit we have

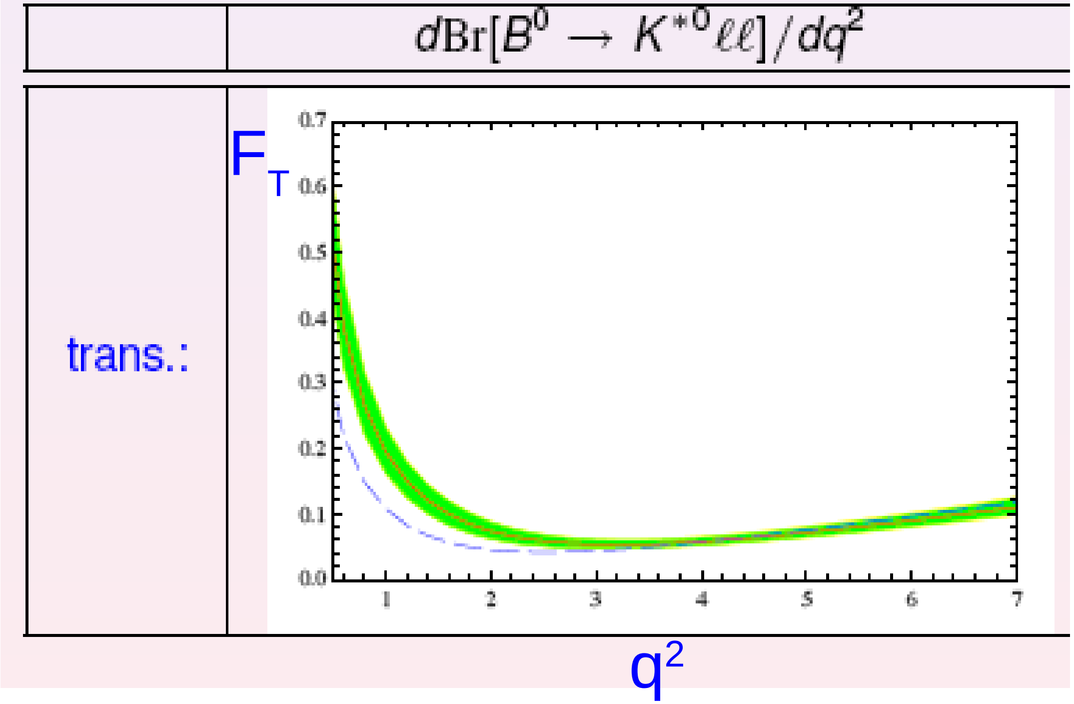
$$H_{+1} \ll H_{-1} \quad \Rightarrow \quad A_T^2 \approx -2\Re\left(\frac{H_{+1}}{H_{-1}}\right)$$

- so A_T^2 is just the fraction of right handed current in amplitude.

$B_d \to K^{*0}e^+e^-$ as a competitor to $B_s \to \varphi\gamma$

- Due to $F_T=1-F_L$ factor in front of A_T^2 the sensitivity improves rapidly at low q^2
- Differential decay rate also rising at low q^2
- Current estimate of resolution with 2 fb^{-1}:
  - $\sigma(H_{+1}/H_{-1}) \sim 0.1$
- For $B_s \to \varphi\gamma$ we estimate
  - $\sigma(H_{+1}/H_{-1}) = 0.11$

Feldmann CKM08



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

It is estimated that the S-wave contamination in the $B_s \to J/\psi\ \phi$ decay will be at the 5-10% level. [arXiv:0812.2832]

A problem:

- If ignored will lead to $2\beta_s$ measurement ~15% closer to zero.
- Including in fit add 2 extra parameters and leads to reduction in resolution of 20%

An advantage

- Can measure CP violation in $B_s \to J/\psi\ f_0$ decay
  - Less statistics (by a factor 5?)
  - No angular analysis required as $P \to V\ S$ decay.
  - **Is angular analysis required due to rescattering of KK/ππ final state?**
- Can measure sign of $\cos(2\beta_s)$

$B_s \rightarrow J/\psi\ \phi$

Measurement of $\cos(2\beta_s)$

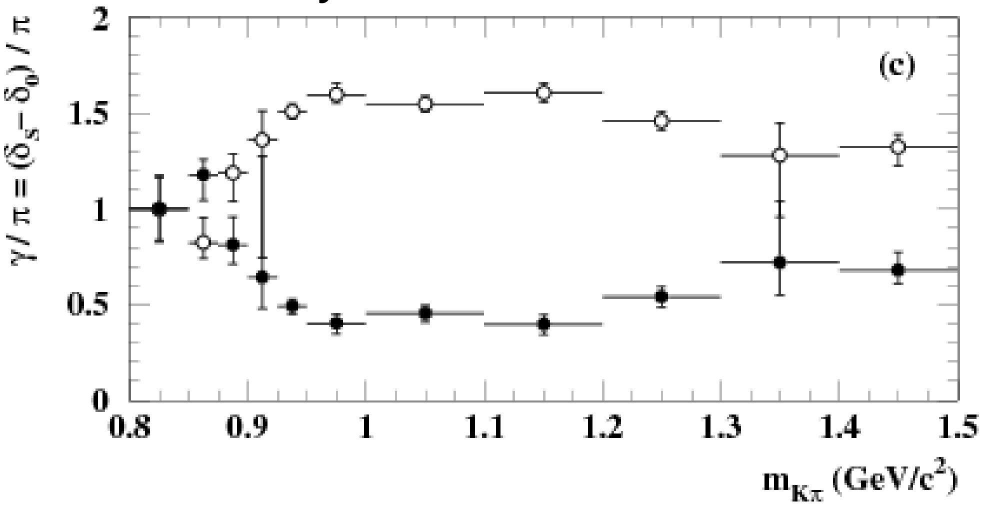
Bin measurements in invariant KK mass and look at phase shift between P and S wave.

- 2 possible solutions depending on sign of $\cos(2\beta_s)$
- Pick the one where phase shift is as expected through P-wave resonance.

Require a few changes in analysis strategy but seems possible.

Example from $B_d \rightarrow J/\psi\ K\pi$ analysis

BaBar, Phys.Rev.D71:032005,2005



$B_d \rightarrow (K\pi)\mu^+\mu^-$

The $B_d \rightarrow (K\pi)\mu^+\mu^-$ has the same S-wave problem.

What is the fraction?

- BaBar measure 7% from $B_d \rightarrow J/\psi\, K\pi$

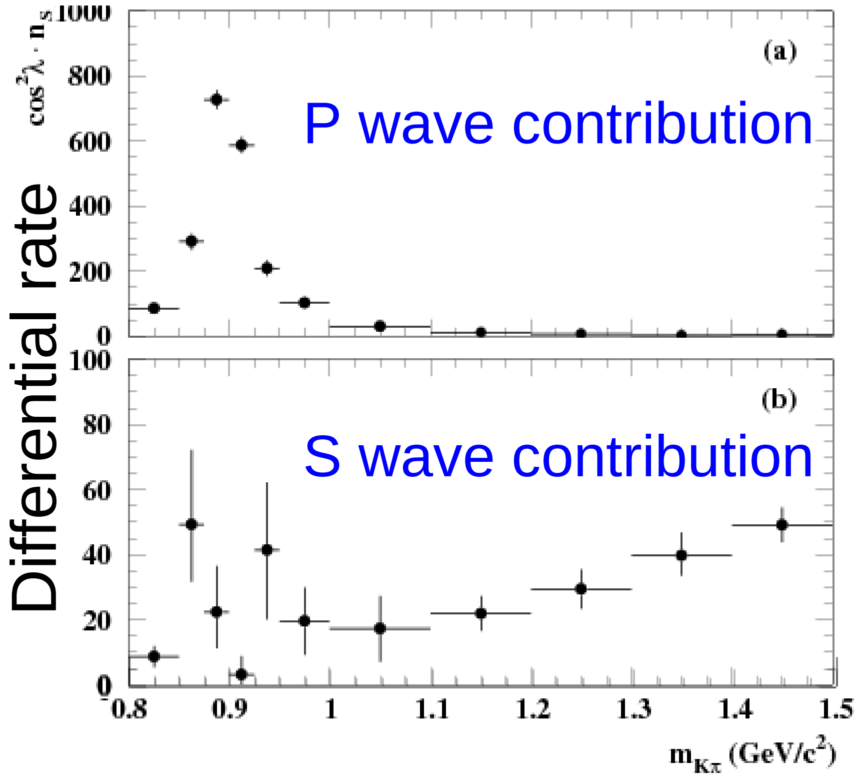
Can we straight transfer this number?

Need to include this in formalism.

Will taking this into account increase errors in SM prediction?

Example from $B_d \rightarrow J/\psi\, K\pi$ analysis

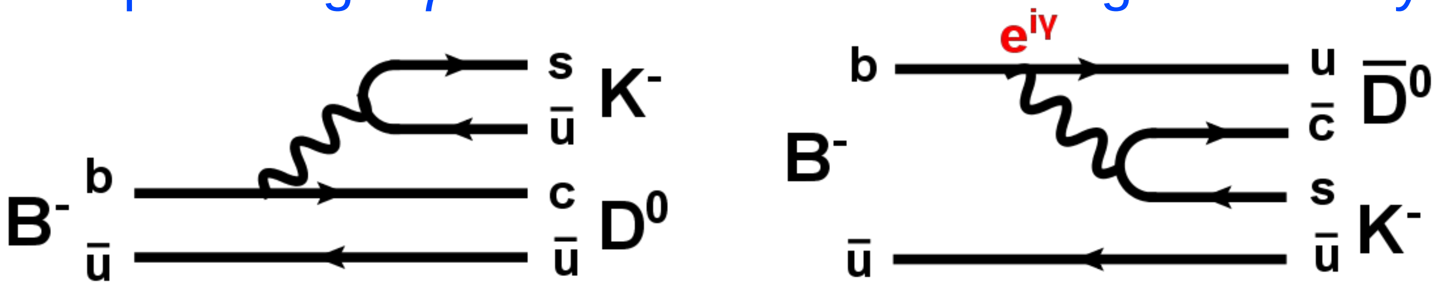
BaBar, Phys.Rev.D71:032005,2005



CP angle γ

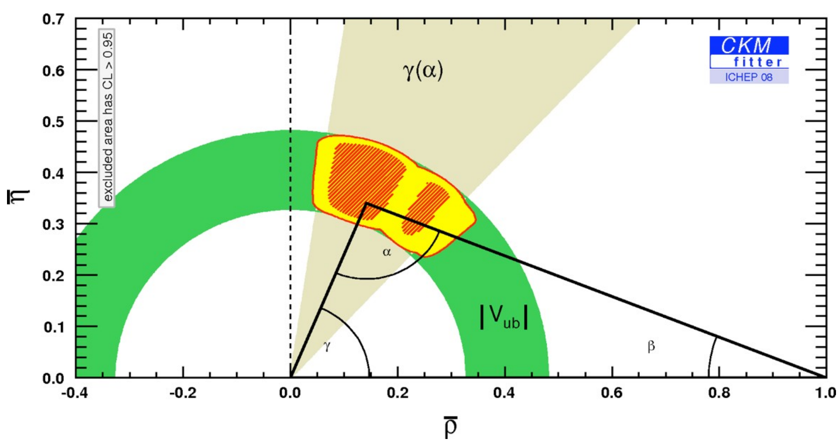
A direct test of CP violation contribution from New Physics

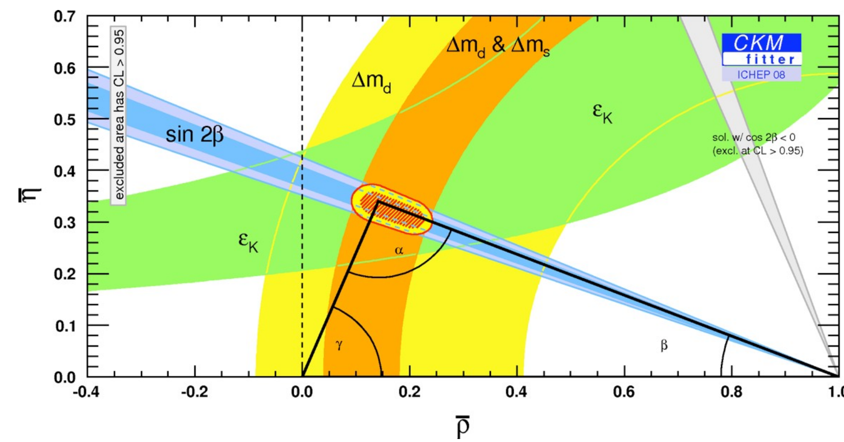
Compare angle γ measured from interfering tree decays



which should always take the value from the CKM matrix

to angle measured from indirect constraint





Looking at $B \to DK\pi$ Dalitz decay

Take advantage of interference between the many $B \to D^*K$ and $B \to DK^*$ resonances [arXiv:0810:2706].

For each point in the Dalitz plot we have

$$\frac{\sqrt{2}A(B^0 \to D_E K^{*0})}{A(B^0 \to \bar{D}^0 K^{*0})} - 1 = r_B e^{i(\delta_B+\gamma)} \equiv x_+ + iy_+$$

$$\frac{\sqrt{2}A(\bar{B}^0 \to D_E \bar{K}^{*0})}{A(\bar{B}^0 \to D^0 \bar{K}^{*0})} - 1 = r_B e^{i(\delta_B-\gamma)} \equiv x_- + iy_-.$$

Similar ratios for the D_{DCS} decays

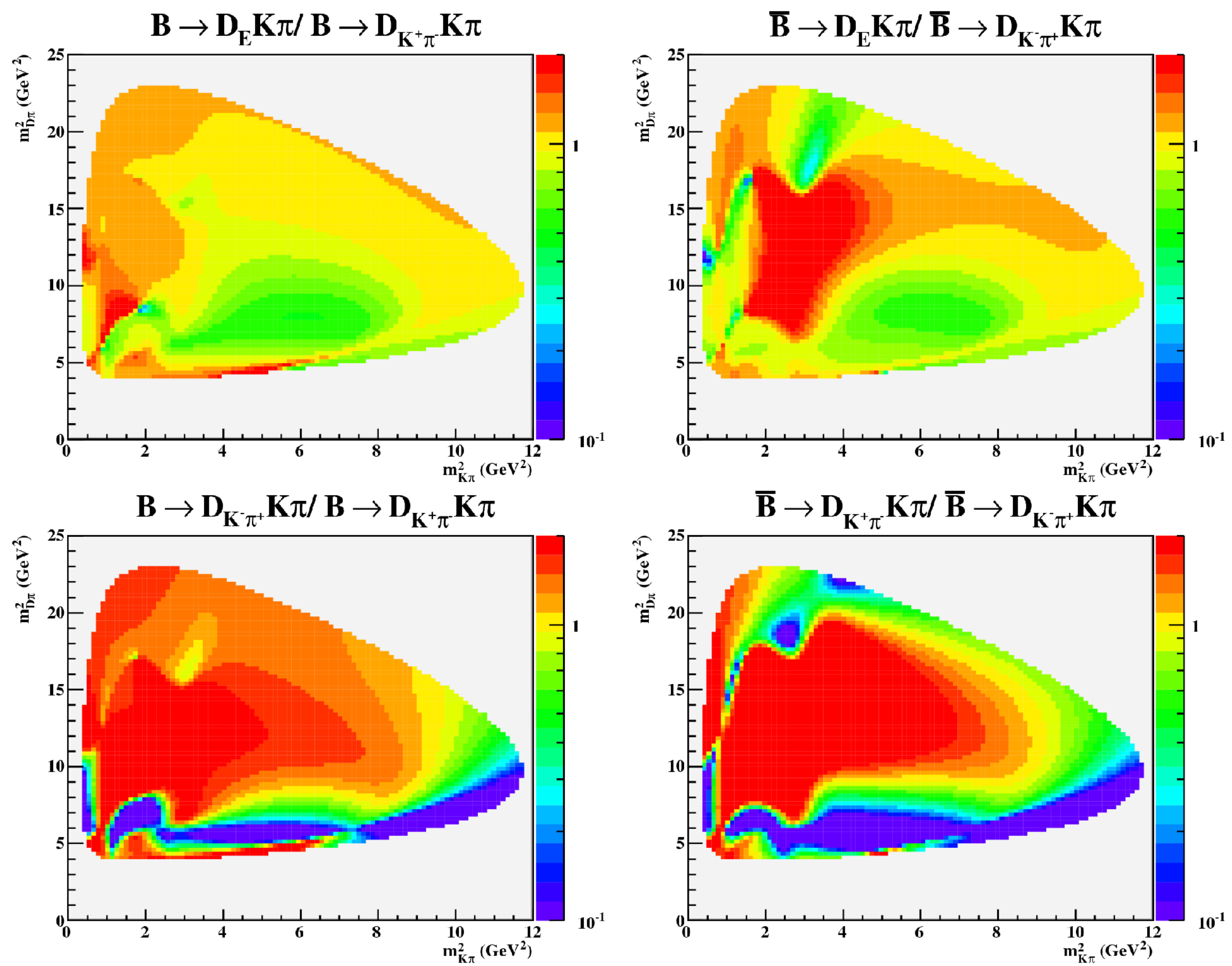
No full sensitivity study yet, but the quasi-two body analysis of $B \to DK^*$ gives $\sigma(\gamma)=9^o$ with 2 fb^{-1}.

Here we only add information so resolution should be even better.

Looking at $B \rightarrow DK\pi$ Dalitz decay

- Toy Monte Carlo illustration of method.
  - Information on γ is in difference between D_E pairs and between D_{DCS} pairs
- Allows extraction of γ with just a single $\gamma \rightarrow \gamma+\pi$ ambiguity.

$r_B=0.4 \quad \delta_B=0^o \quad \gamma=60^o$



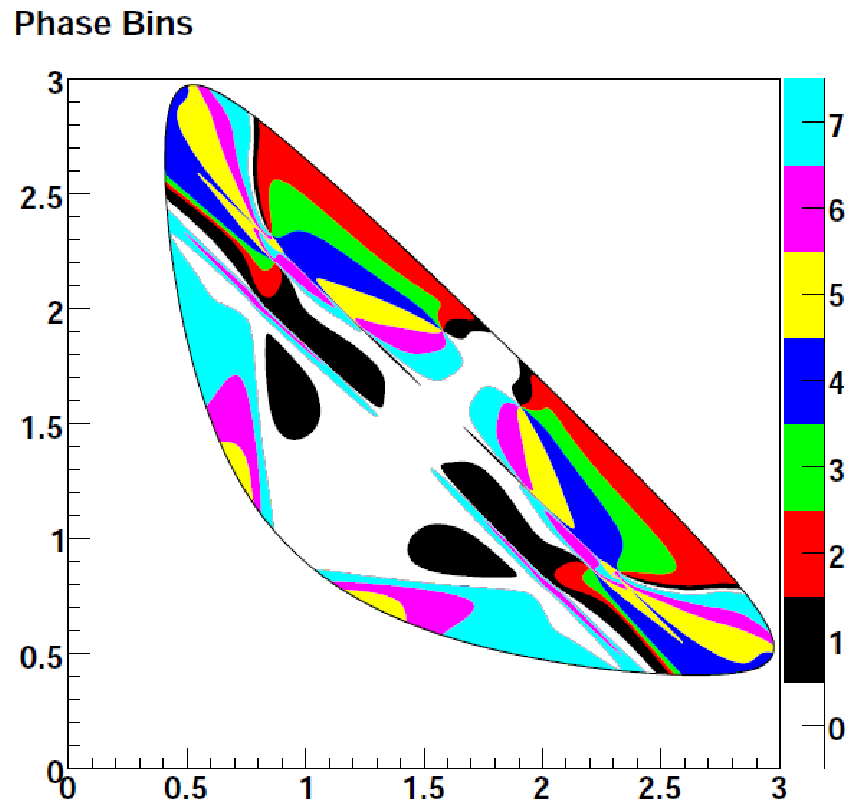
Constraints from CLEO-c

The shared D final state can also be $D/\overline{D} \to K_s^0 \pi^+ \pi^-$

This is the most sensitive γ analysis from B-factories

Approach based on a fit to the resonances in the Dalitz plot leave a 10° systematic error

Not a problem now but will limit precision at LHCb



Can instead use binned analysis [arXiv:0810.3666]

Shape bins to have same strong phase

Extract this phase from CLEO-c data

Reduces systematic error to 2°.

The SM Higgs and nothing else

Imagine CMS/ATLAS see a SM Higgs and nothing else.

In LHC*b* we can expect

- $B_s \rightarrow \mu^+\mu^-$ discovered at SM level
- CP angle γ at value from combined fits
- $B_d \rightarrow K^{*0}\mu^+\mu^-$ zero point at SM value

or much more exciting with squarks masses ~10 TeV

- Non-SM expectations in B_s box diagram from $B_s \rightarrow J/\psi\ \varphi$
- $B_d \rightarrow K^{*0}\mu^+\mu^-$ deviations in zero point of A_{FB}.
- Both would be evidence of New Physics beyond limit for direct production.

A SUSY spectra is discovered

ATLAS and CMS might discover a host of new states but many different theory models are possible

- $B_s \rightarrow \mu^+\mu^-$ will set very strict constraints on the Higgs sector of SUSY
- CP measurements investigate the flavour structure
  - **Can this help to understand what kind of symmetry suppress the "natural" FCNC level?**
- $B_d \rightarrow K^{*0}\mu^+\mu^-$ will investigate handedness of SUSY couplings

Evidence of extra dimensions

The Appelquist, Cheng and Dobrescu model gives new flavour couplings, but no new phases

Strong effect on $B_s \rightarrow \mu^+\mu^-$ from modified Z^0 penguins

Buras, Springer & Weiler; Nuclear Physics B 660 (2003) 225–268

Branching ratios for rare decays in the ACD model and the SM as discussed in the text

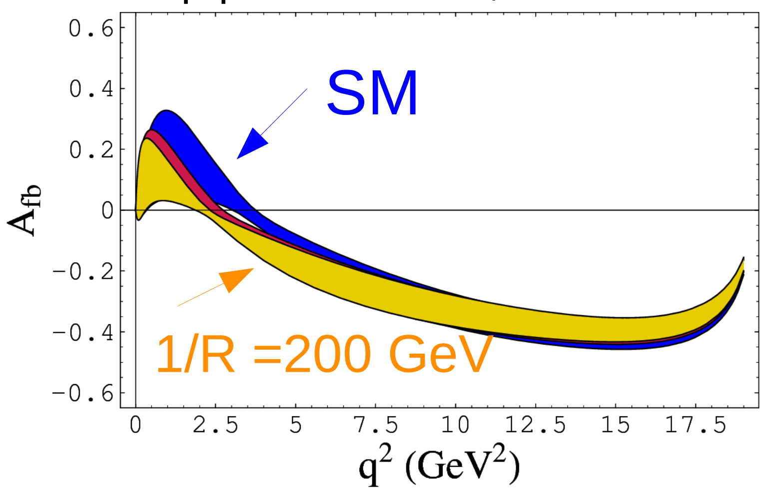
$1/R$	200 GeV	250 GeV	300 GeV	400 GeV	SM
$\mathrm{Br}(B_s \rightarrow \mu^+\mu^-) \times 10^9$	6.18	5.23	4.78	4.27	3.59

$B_d \rightarrow K^{*0}\, \mu^+\mu^-$ is also sensitive in A_{FB} zero point

As no new phases, *CP* violation measurements will stay at SM values.

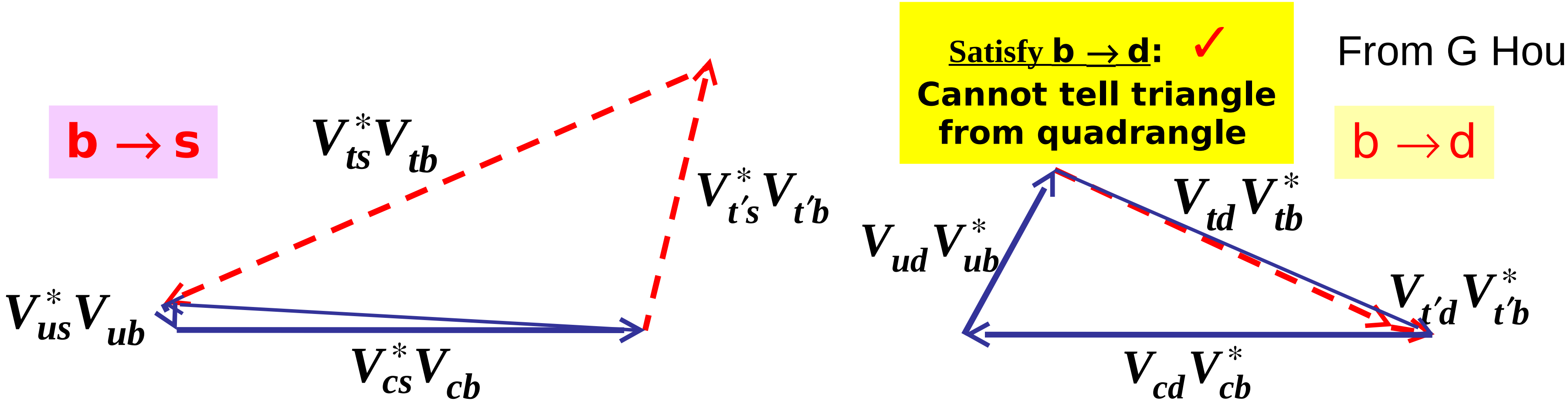
Any other signatures in flavour physics?

hep-ph/0609134v1, Fazio



A 4th generation

ATLAS/CMS will discover signals compatible with a set of heavier quarks.



Could show very large effects for CP violation in B_s box

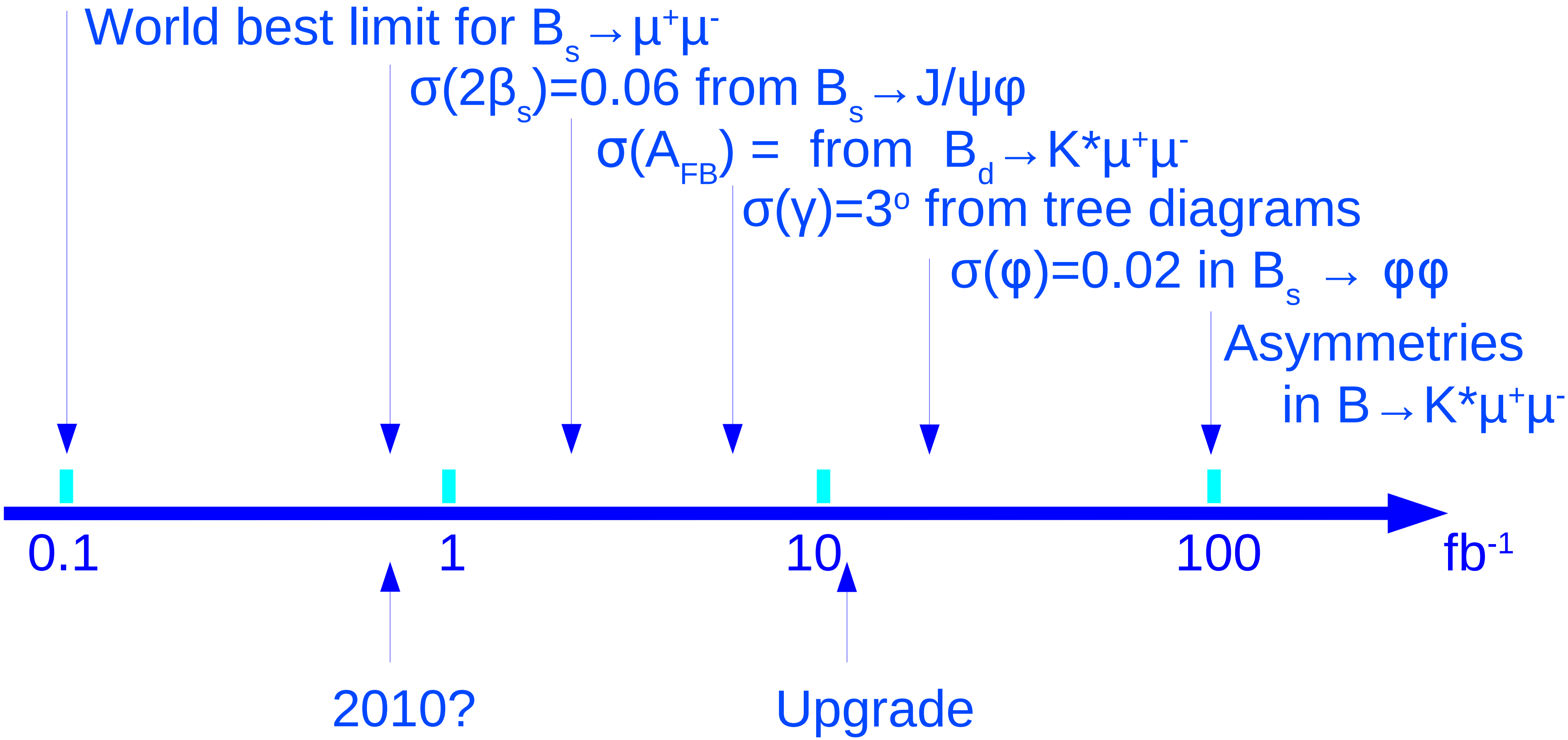
Verification of large $2\beta_s$ hint from Tevatron

Still consistent with B_d box

Would expect significant effects in $B_d \to K^{*0}\mu^+\mu^-$ as well

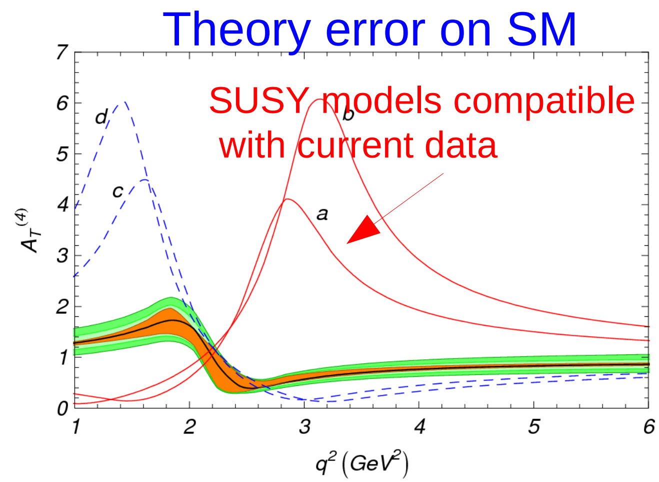
Physics with LHCb

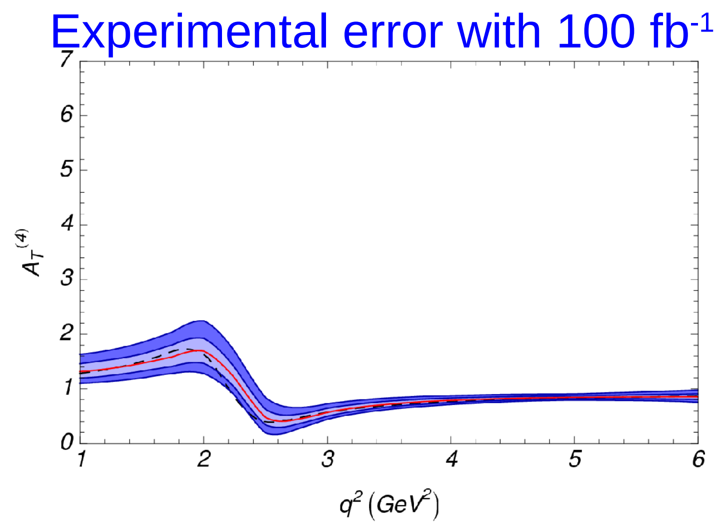
There is interesting physics for LHC*b* across a very wide range of integrated luminosities



Why do we need an upgrade?

- For many observables 10 fb^{-1} will not make us reach theoretical limits
- Excellent opportunities to study the nature of New Physics discovered during first phase of LHC
- Comparison of CP violation in $b \rightarrow s$ box and penguin processes
  - $B_s \rightarrow \phi\phi$ possible with high precision (~0.01) with 100 fb^{-1}
  - Compare with further studies of $B_s \rightarrow J/\psi\,\phi$
- Angular observables in $B_d \rightarrow K^{*0}\mu^+\mu^-$





Conclusion

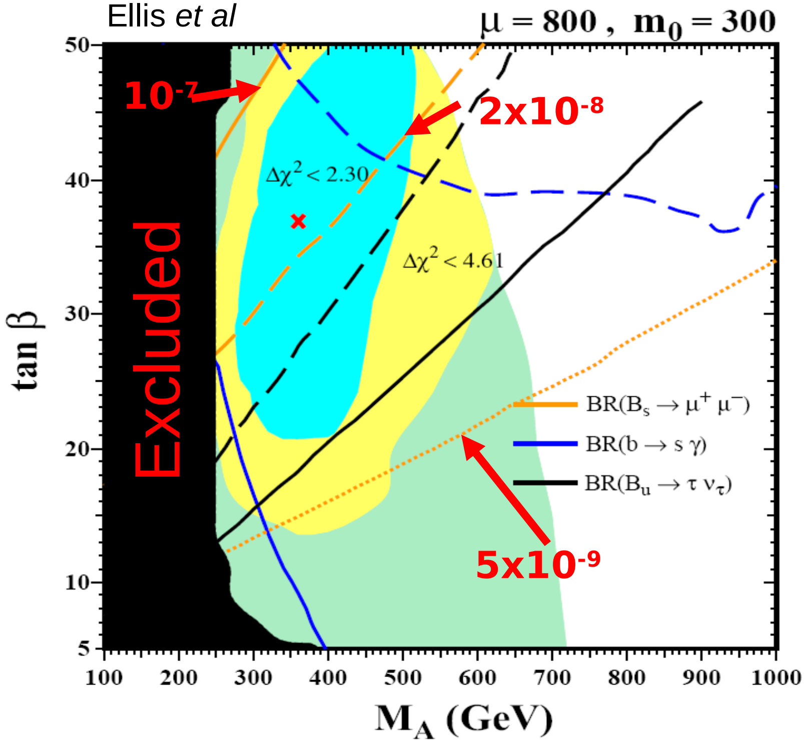
- Flavour physics at the LHC will play a central role in the understanding of any new physics signals
- Several New Ideas presented today but also open questions in the interpretation.
- LHC*b* has a physics programme extending through the full range of integrated luminosity achievable
- Many channels available even if only subset shown here
  - CP violation in $B_s \to \varphi\gamma$, CP angle α, D^0 mixing and *CP* violation, B meson and baryon spectroscopy, $B_s \to \varphi\, \mu^+\mu^-$
- An upgrade is essential to reach ultimate precision in channels with small theoretical errors
- Exclusive channels have much to offer in flavour physics

Backup

$B_s \rightarrow \mu^+\mu^-$

- This very rare decay has a SM branching ratio of 3.5 10^{-9}
- Any pseudoscalar Higgs can modify BR by large amount
  - Can thus set severe constraints on NP

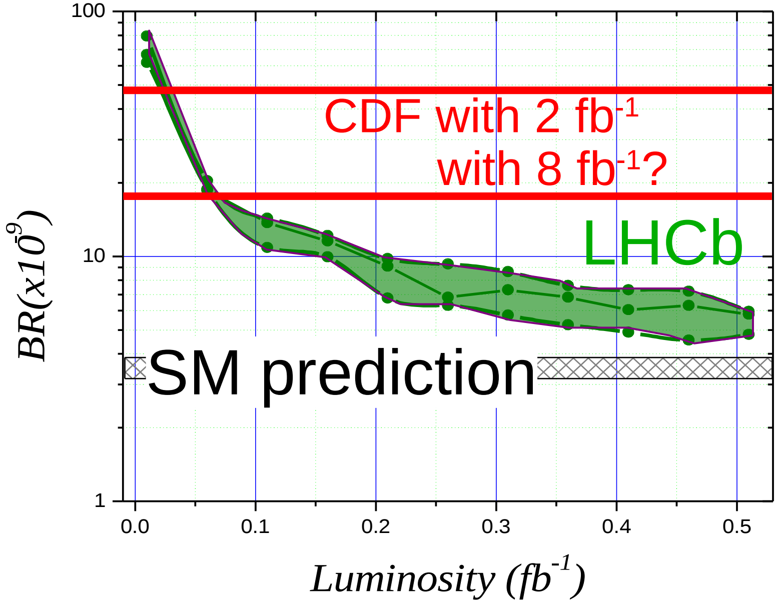
JHEP 0710:092,2007
Ellis *et al*



Limits in m_A versus tan β within MSSM

$B_s \rightarrow \mu^+\mu^-$

- 8 SM signal and 12 background events in $2fb^{-1}$ in most sensitive region
  - Background estimated from sidebands
  - Normalisation from $B_d \rightarrow J/\psi K^+$ decay
- With just 0.1 fb^{-1} of data it will be world leading measurement.

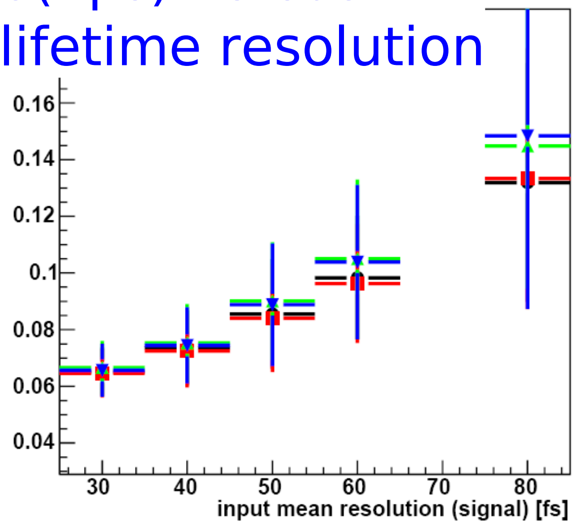


90% Confidence limit with no signal observed

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

- The box diagram for B_s oscillations is beginning to be understood
  - Oscillation period well measured by Tevatron
  - Phase $2\beta_s$ is 2.2σ away from SM prediction
    - SM prediction 0.04, central experimental value 0.77.
- LHCb will be able to improve results dramatically

$\sigma(2\beta s)$ versus lifetime resolution



  - Lifetime resolution of 39 fs
  - Flavour tag efficiency of 6%
- In 2 fb^{-1} of data:
  - 100k signal events
  - 50k background events
  - $\sigma(2\beta_s) = 0.03$

CP angle γ

Results shown as function of δ_{B^0}, least well known parameter. Sensitivity of $B^0 \rightarrow D^0 K^{*0}$ improves by factor of two in going from δ_{B^0} = 45→180º . Residual dependence remains in global fit, but diluted due to other measurements.

δ_{B^0} (°)	0	45	90	135	180
σ_γ for 0.5 fb^{-1} (°)	8.1	10.1	9.3	9.5	7.8
σ_γ for 2 fb^{-1} (°)	4.1	5.1	4.8	5.1	3.9
σ_γ for 10 fb^{-1} (°)	2.0	2.7	2.4	2.6	1.9

Weight (in %) of each contributing analysis with 2 fb^{-1} for two values of δ_{B^0}:

Analysis	$\delta_{B^0} = 0°$	$\delta_{B^0} = 45°$
$B^- \rightarrow D^0(hh)K^-$, $B^- \rightarrow D^0(K^+\pi^\mp\pi^+\pi^-)K^-$	25	38
$B^- \rightarrow D^0(K^0_S\pi^+\pi^-)K^-$	12	25
$B^0 \rightarrow D^0(hh)K^{*0}$	44	8
$B_s \rightarrow D_s^\mp K^\pm$	16	24
$B^0 \rightarrow D^\mp\pi^+$	3	5

Vector mesons dominance.

From PDG :

$BR(B^0 \to K^* \gamma) = 4.0\ 10^{-5}$

$BR(B^0 \to K^* \rho) = 5.6\ 10^{-6}$

$BR(B^0 \to K^* \omega) < 4.2\ 10^{-6}$

$BR(B^0 \to K^* \Phi) = 9.5\ 10^{-6}$

The leptonic BR of the vector mesons are :

$BR(\Phi \to ee) = 3.0\ 10^{-4}$

$BR(\rho \to ee) = 7.2\ 10^{-5}$

$BR(\omega \to ee) < 4.7\ 10^{-5}$

From Grossman and Pirjoj BR(BR($B^0 \to K^* ee$) = 215 10^{-9} with 30 MeV <M(ee)<1 GeV

$BR(B^0 \to K^* \rho) \Rightarrow BR(B^0 \to K^* ee) = .26\ 10^{-9}$

$BR(B^0 \to K^* \omega) \Rightarrow BR(B^0 \to K^* ee) < .30\ 10^{-9}$

$BR(B^0 \to K^* \Phi) \Rightarrow BR(B^0 \to K^* ee) = 2.8\ 10^{-9}$

Extremely small for ρ and ω ⇒ even with interference the effect will be quite small

In the ρ range (600-900 MeV) the direct amplitude comtibutes 24.6 10^{-9} ⇒ interference effect < 20 %

In the Φ range (1015-1025) : effect larger but outside our window.