Physics at LHCb

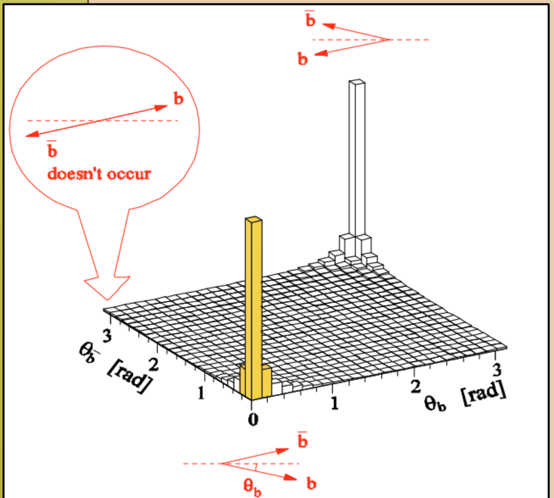
N. Serra on behalf of the LHCb Collaboration

Universität Zürich UZH

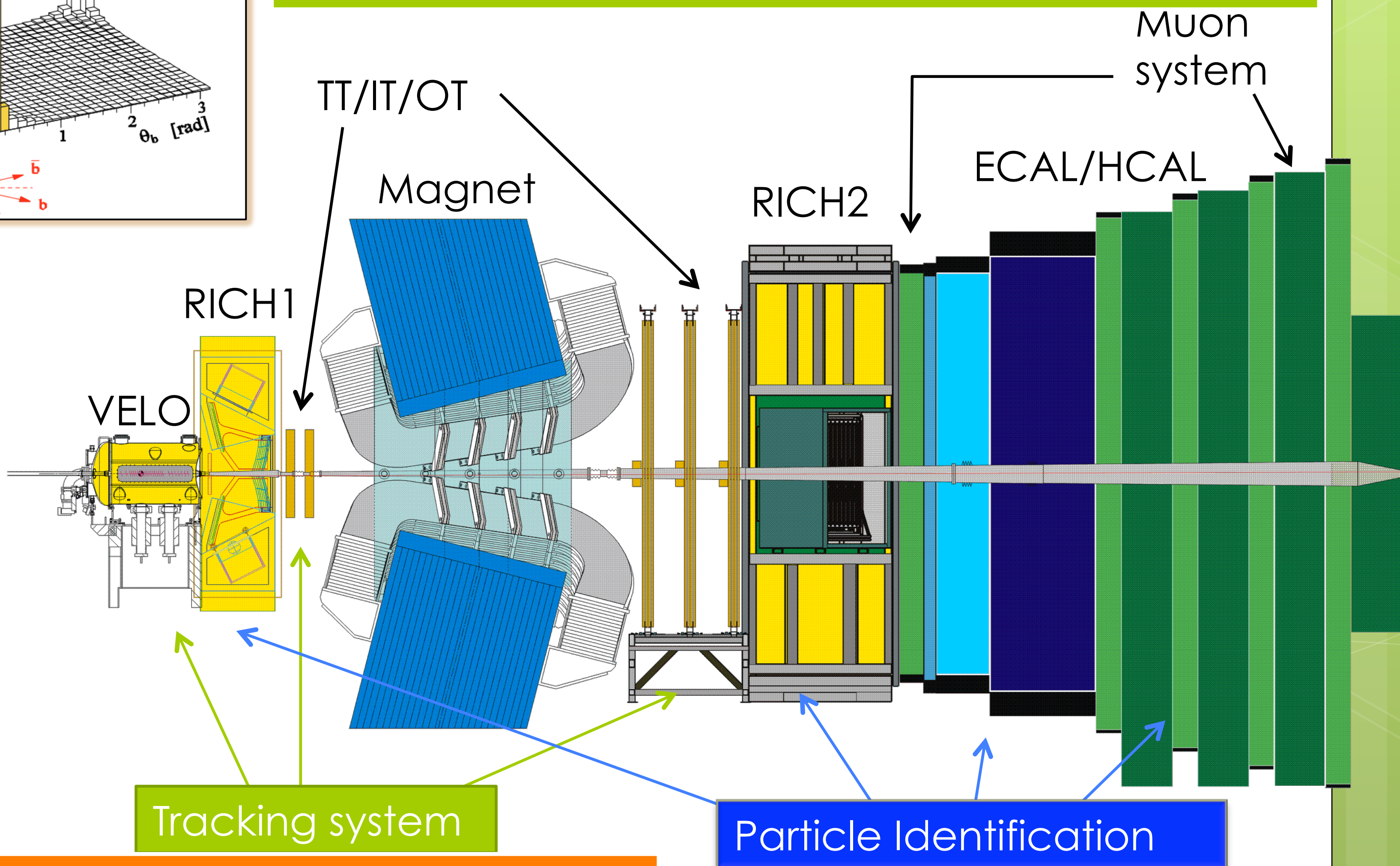
Menu'

- CP Violation in Beauty
- CP violation in Charm
- Some Rare decays

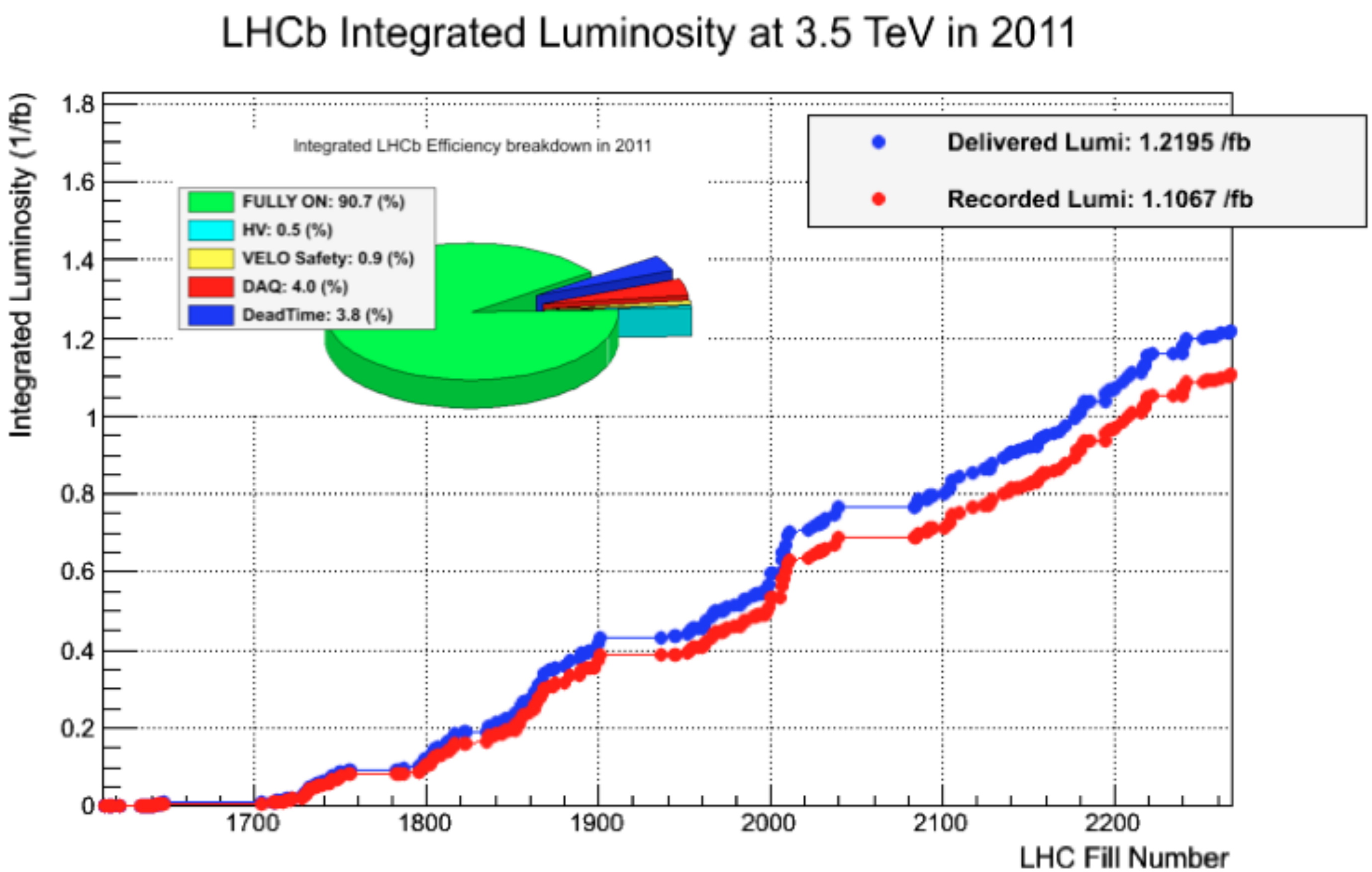
The LHCb experiment



Detector thought for doing b-hadron measuements:
Very good momentum resolution and particle ID.



Also very good for charm physics!


LHCb Integrated Luminosity at 3.5 TeV in 2011
Integrated Luminosity (1/fb)
LHC Fill Number
Integrated LHCb Efficiency breakdown in 2011
FULLY ON: 90.7 (%)
HV: 0.5 (%)
VELO Safety: 0.9 (%)
DAQ: 4.0 (%)
DeadTime: 3.8 (%)
Delivered Lumi: 1.2195 /fb
Recorded Lumi: 1.1067 /fb

2011: 1.1 fb^{-1}

CP Violation in beauty

Unitarity triangles and CPV

$$V^{CKM} = \text{CKM Matrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \quad \text{where} \quad \begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V^{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Unitarity Triangle

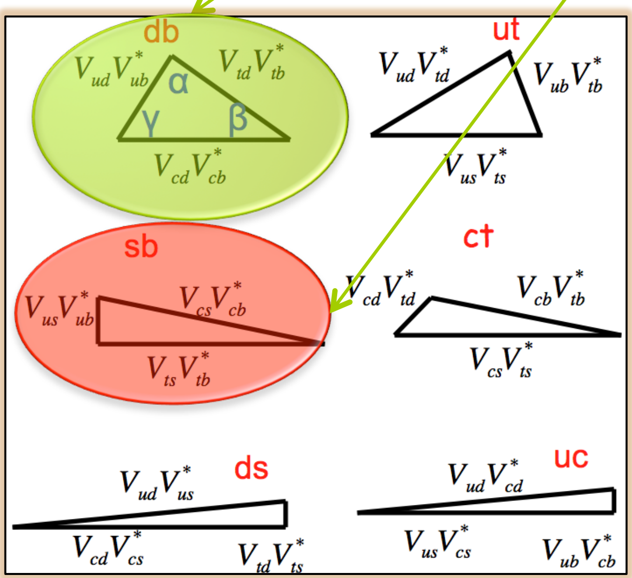
β_s Triangle

Unitarity Triangle Matrix

P. F. Harrison. S. Dallison and W. G. Scott *Phys Lett B 680 209 328*

Imposing Unitarity

$$V^*_{ud}V_{cd} + V^*_{us}V_{cs} + V^*_{ub}V_{cb} = 0$$
$$V^*_{ud}V_{td} + V^*_{us}V_{ts} + V^*_{ub}V_{tb} = 0$$
$$V^*_{cd}V_{td} + V^*_{cs}V_{ts} + V^*_{cb}V_{tb} = 0$$
$$V_{ud}V^*_{us} + V_{cd}V^*_{cs} + V_{td}V^*_{ts} = 0$$
$$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$$
$$V_{us}V^*_{ub} + V_{cs}V^*_{cb} + V_{ts}V^*_{tb} = 0$$



β_s β α

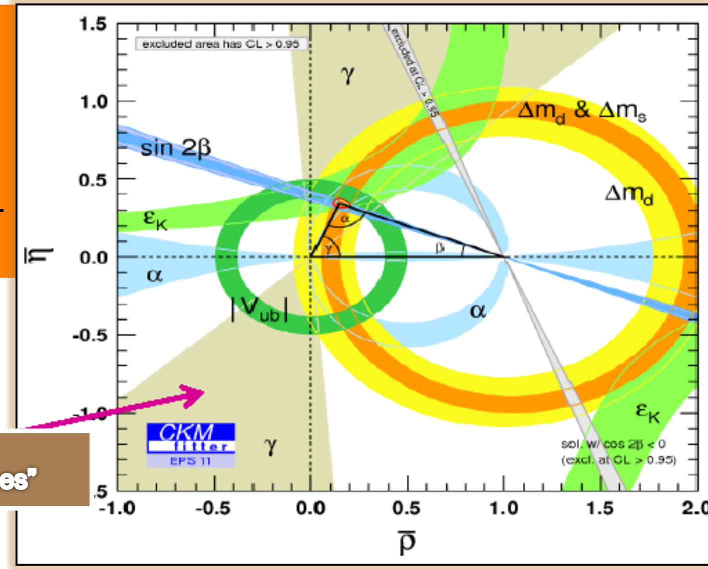
$$\begin{pmatrix} 1^o & 22^o & 157^o \\ 67^o & 90^o & 23^o \\ 112^o & 68^o & \sim 0^o \end{pmatrix}$$

γ $\phi_D/2$

γ with trees

CKM – matrix is measured very precisely.
Great jobs done by B-factories and others,
Less constrained γ-angle :

$\gamma = 68^{+13}_{-14}$ ***V. Niess (CKMFitter) EPS2011***



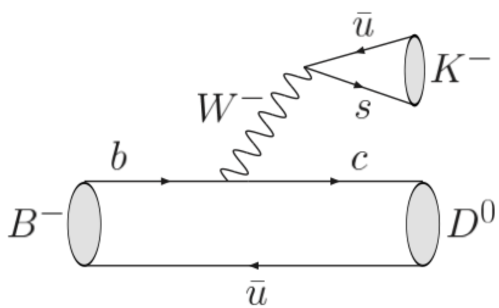
γ "trees"

We can access γ via the interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$,

e.g. with $B \to \bar{D}K$ and $B \to DK$

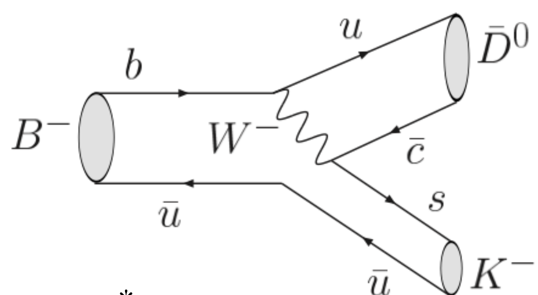
where D and $\bar{D}$ decay to a common final state

γ is the weak phase between V_{cb} and V_{ub}



$V_{cb}V^*_{us}$

Color allowed



$V_{ub}V^*_{cs}$

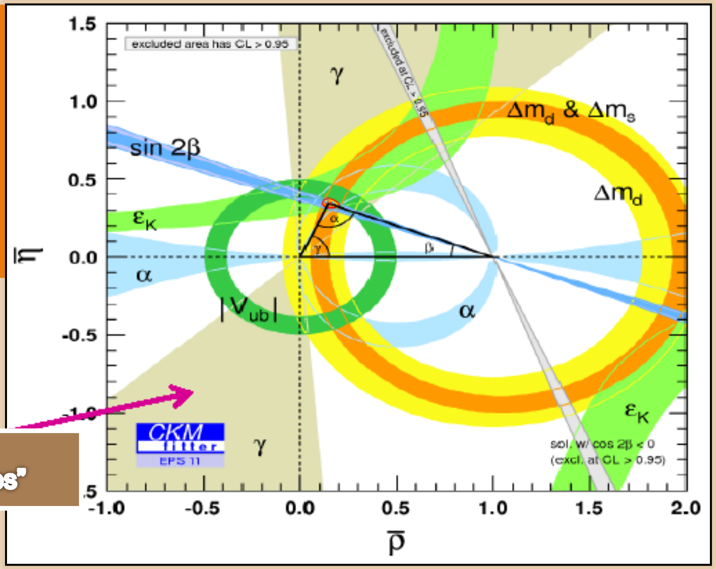
Color suppressed

CKM – matrix is measured very precisely.

Great jobs done by B-factories and others,

Less constrained γ-angle :

$\gamma = 68^{+13}_{-14}$ V. Niess (CKMFitter) EPS2011



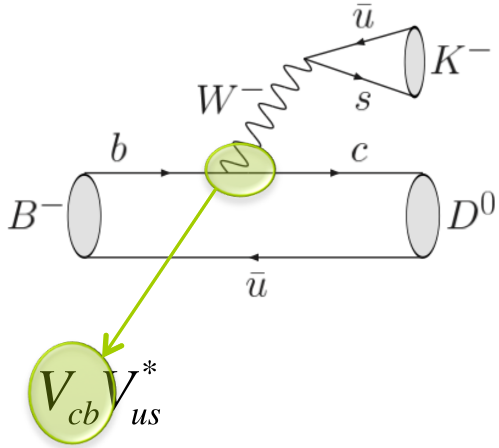
γ "trees"

We can access γ via the interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$,

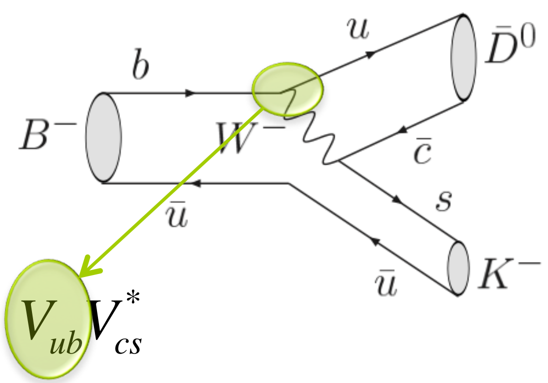
e.g. with $B \to \bar{D}K$ and $B \to DK$

where D and $\bar{D}$ decay to a common final state

γ is the weak phase between V_{cb} and V_{ub}



Color allowed



Color suppressed

GLW/ADS method

M.Gronau,D.London,D.Wyler,PLB253,483(1991);PLB 265,172(1991)

D.Atwood,I.Dunietz,A.Soni,PRL78,3357(1997)

$B^{\pm} \to D^0 K^{\pm}$

CP eigenstate $D^0 \to K^+ K^-$

Cabibbo favoured $D^0 \to K^- \pi^+$

Doubly cabibbo suppressed $D^0 \to K^+ \pi^-$

Time dependent analysis

R. Aleskan, I. Dunietz and B. Kayser, Z. Phys. C 54, 653 (1992)

R. Fleischer, Nucl. Phys. B 671, 459 (2003)

$B_s \to D_s^+ K^-$

$B^0 \to D^{(*)+} \pi^-$

Dalitz analysis

A. Giri, Yu. Grossman, A Soffer and J. Zupan, Phys. Rev. D 68, 054018 (2003)
A. Bondar, Proceedings of BINP Special Analysis Meeting on Dalitz Analysis

$B^{\pm} \to D^0 K^{\pm}$

$D \to K_s^0 \pi\pi$

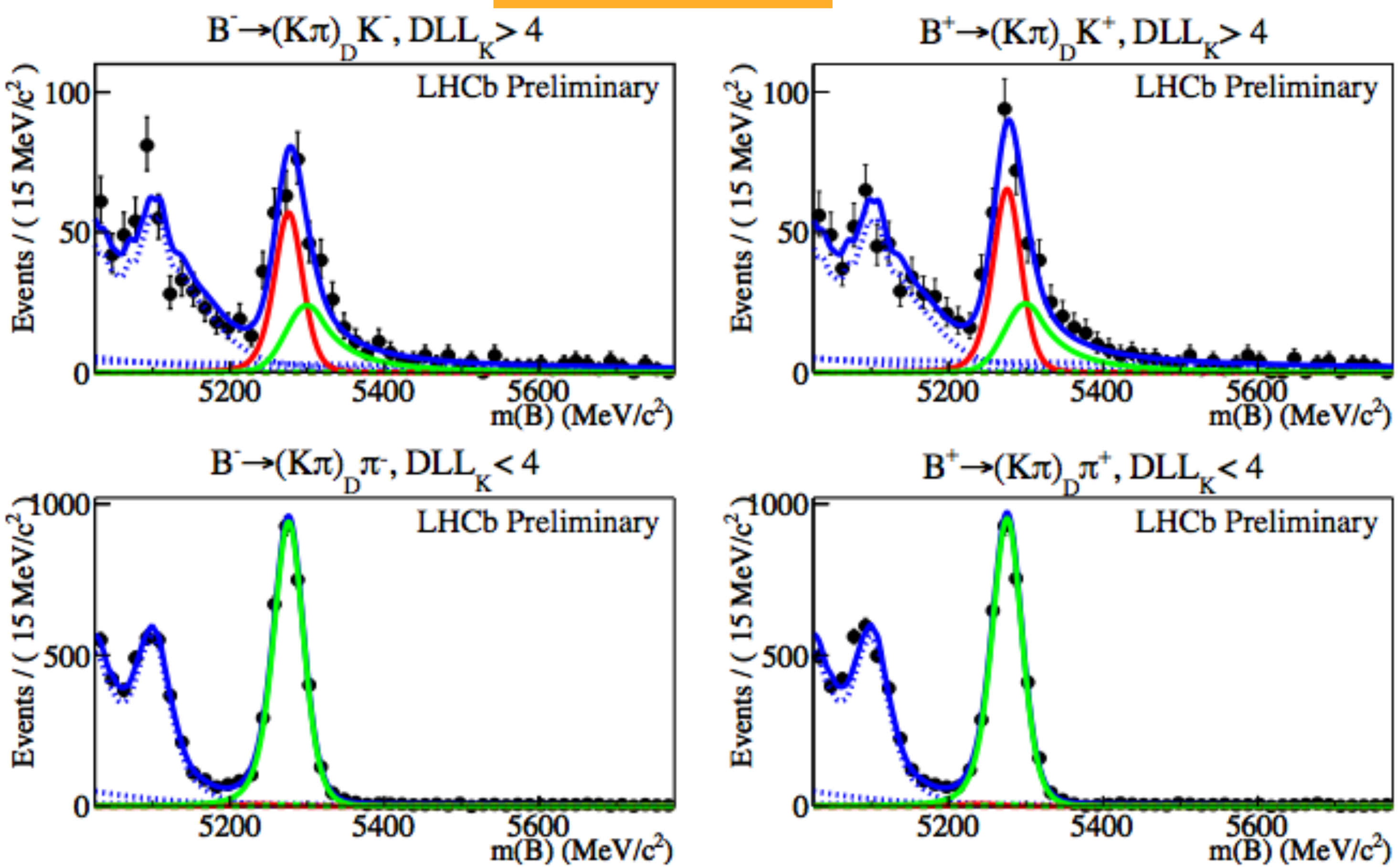
γ with GLW at LHCb

2010 data ($L = 35.5 pb^{-1}$)

Ratio of branching fraction $\frac{BR(B^{\pm} \to DK^{\pm})}{BR(B^{\pm} \to D\pi^{\pm})}$

$R_{CF}^{K/\pi} = (6.30 \pm 0.38 \pm 0.40)\%$

PRELIMINARY



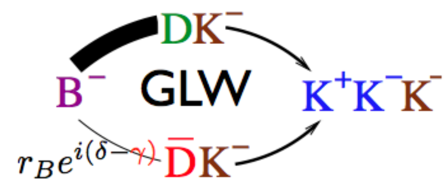
γ with GLW at LHCb

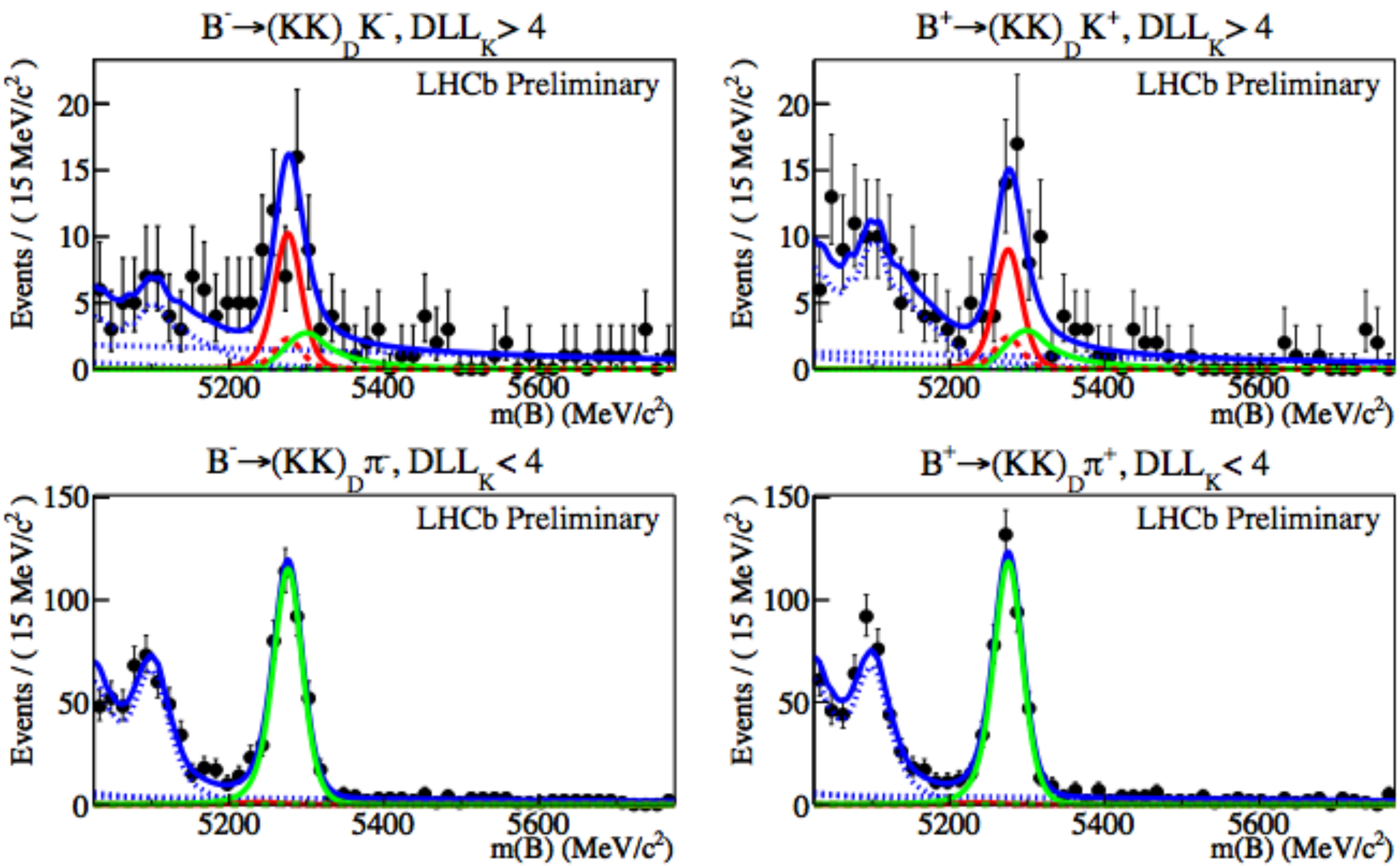
2010 data ($L = 35.5\,pb^{-1}$)

Ratio of branching ratio $\dfrac{BR(B^{\pm} \to DK^{\pm})}{BR(B^{\pm} \to D\pi^{\pm})}$

$R^{k/\pi}_{CP+} = (9.31 \pm 1.89 \pm 0.53)\%$

PRELIMINARY





$$A_{CP\pm} = \frac{\Gamma(B^- \to D^0_{CP\pm}K^-) - \Gamma(B^+ \to D^0_{CP\pm}K^+)}{\Gamma(B^- \to D^0_{CP\pm}K^-) + \Gamma(B^+ \to D^0_{CP\pm}K^+)} = \frac{\pm 2 r_B \sin\delta_B \sin\gamma}{1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma}$$

$$R_{CP\pm} = \frac{\Gamma(B^- \to D^0_{CP\pm}K^-) + \Gamma(B^+ \to D^0_{CP\pm}K^+)}{\Gamma(B^- \to D^0 K^-) + \Gamma(B^+ \to \overline{D}^0 K^+)} = 1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma$$

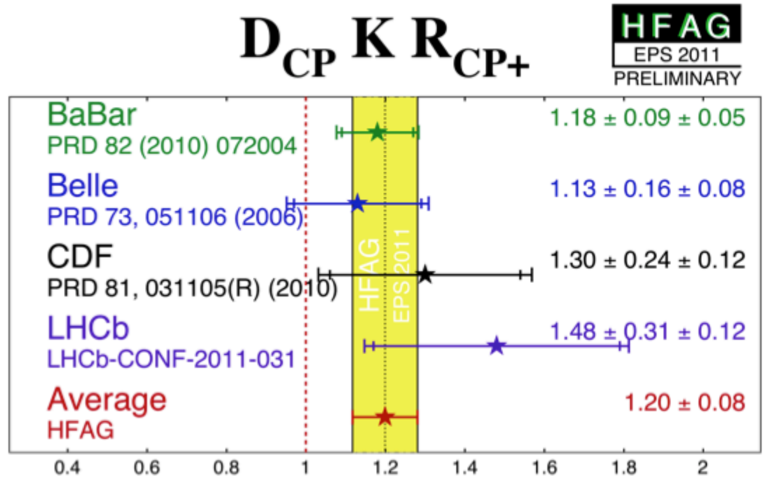
M.Gronau,D.London,D.Wyler,PLB253,483(1991);PLB 265,172(1991)

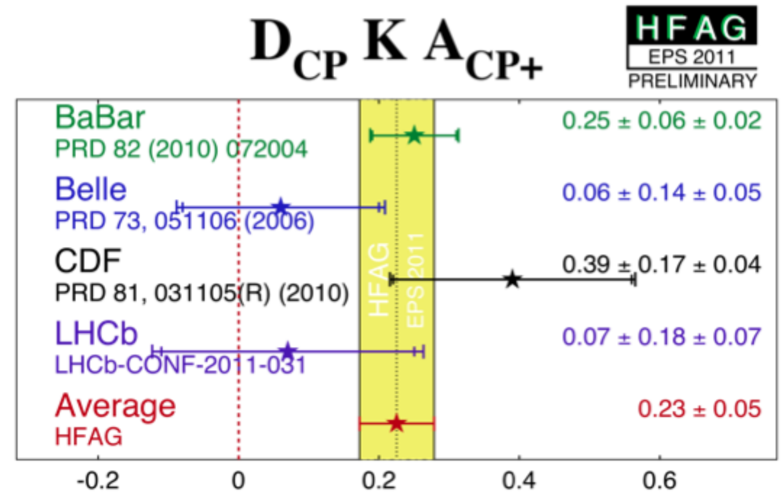
LHCb: PRELIMINARY

$$R_{CP+} = 1.48 \pm 0.31 \pm 0.12$$

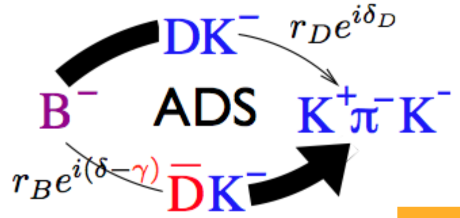
$$A_{CP+} = 0.07 \pm 0.18 \pm 0.07$$

HFAG averages including LHCb results

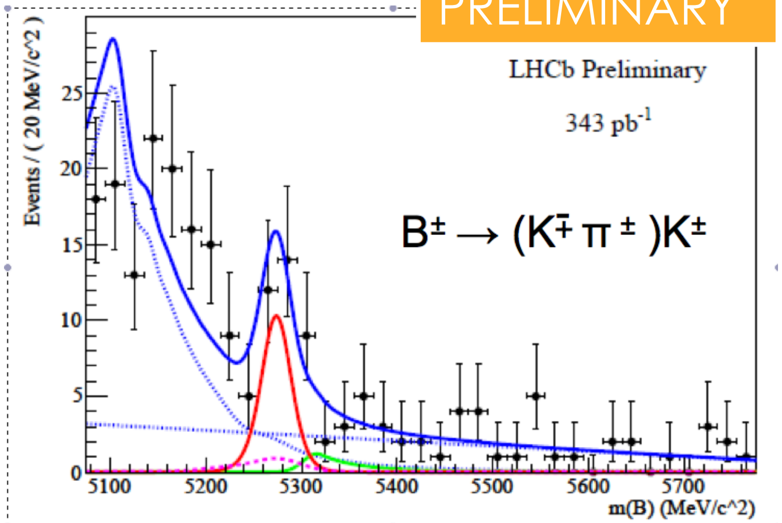




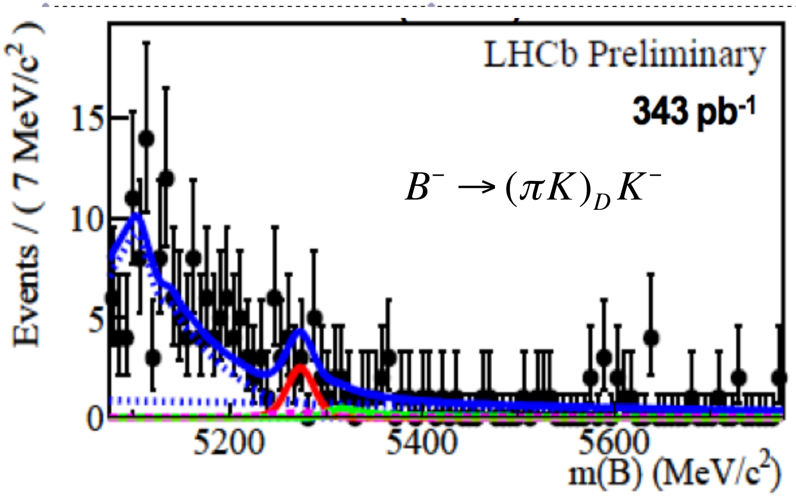
γ with ADS at LHCb

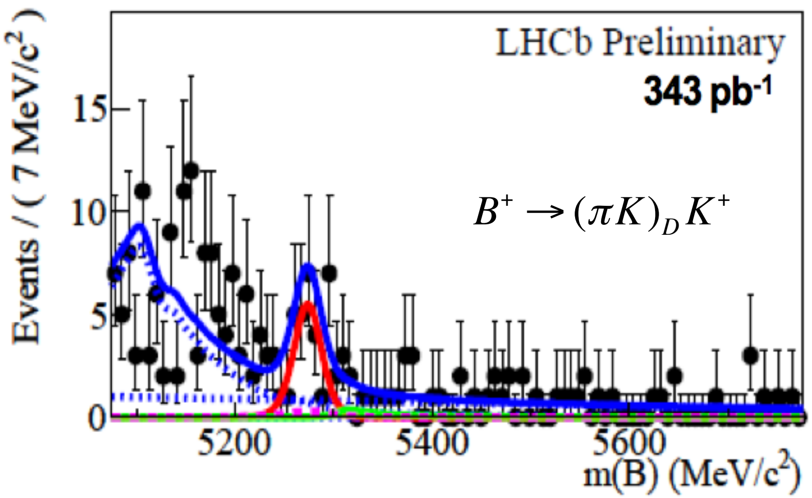


PRELIMINARY



- Significant signal (4σ) for suppressed mode in 343/pb⁻¹.
- Data-driven methods for:
  - PID efficiency
  - Production and detection asymmetry
  - $B^\pm \rightarrow D(K\pi)\pi^\pm$ used as normalisation mode.





$$R_{ADS} = \frac{\Gamma(B^- \to [K^+\pi^-]_D K^-) + \Gamma(B^+ \to [K^-\pi^+]_D K^+)}{\Gamma(B^- \to [K^-\pi^+]_D K^-) + \Gamma(B^+ \to [K^+\pi^-]_D K^+)} = r_B^2 + r_D^2 + 2 r_B r_D \cos\gamma \cos(\delta_B + \delta_D)$$

$$A_{ADS} = \frac{\Gamma(B^- \to [K^+\pi^-]_D K^-) - \Gamma(B^+ \to [K^-\pi^+]_D K^+)}{\Gamma(B^- \to [K^+\pi^-]_D K^-) + \Gamma(B^+ \to [K^-\pi^+]_D K^+)} = 2 r_B r_D \sin\gamma \sin(\delta_B + \delta_D) \Big/ R_{ADS}$$

D.Atwood,I.Dunietz,A.Soni,PRL78,3357(1997)

LHCb : PRELIMINARY

$$R_{ADS}^{DK} = (1.66 \pm 0.39 \pm 0.24) \cdot 10^{-2}$$

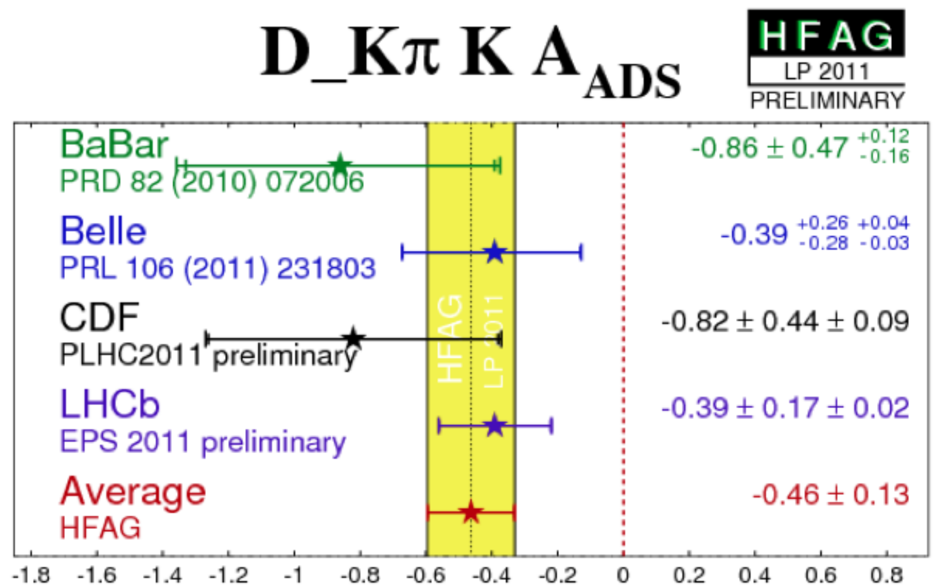
$$A_{ADS}^{DK} = -0.39 \pm 0.17 \pm 0.02$$

World Average (HFAG):

$$R_{ADS}^{DK} = (1.6 \pm 0.3) \cdot 10^{-2}$$

$$A_{ADS}^{DK} = -0.58 \pm 0.21$$

HFAG average including LHCb results



Large CP asymmetry, about 50%!

Measurements of B →DKππ

Other channels which have the similar quark level interference can in principle be added to the measurement of γ.

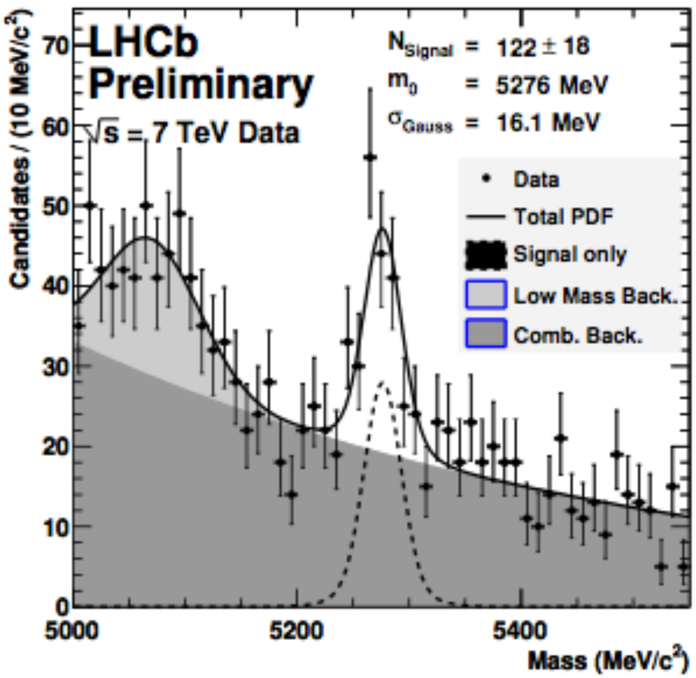
LHCb-CONF-2011-034

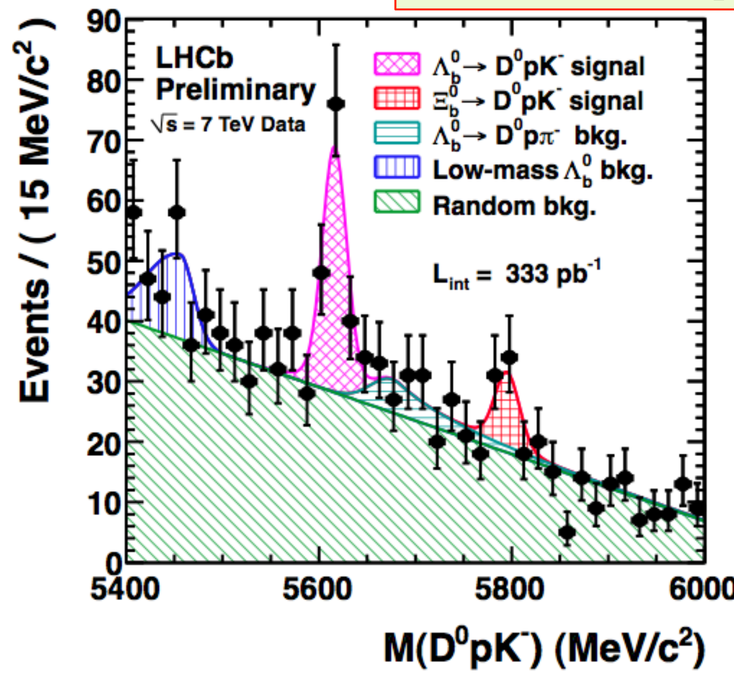
2010 data (L =37pb^{-1})

PRELIMINARY

LHCb-CONF-2011-036

2011 data (L =333pb^{-1})



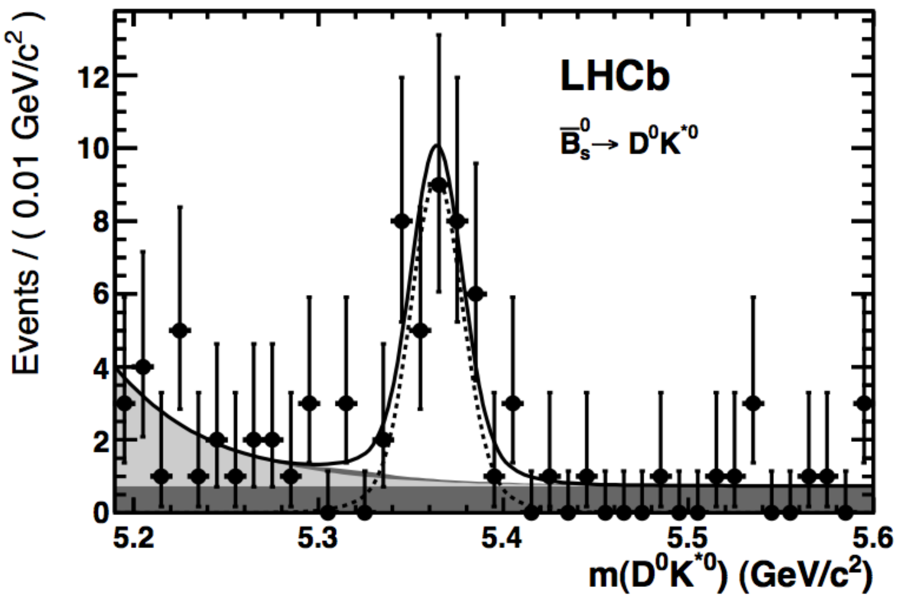


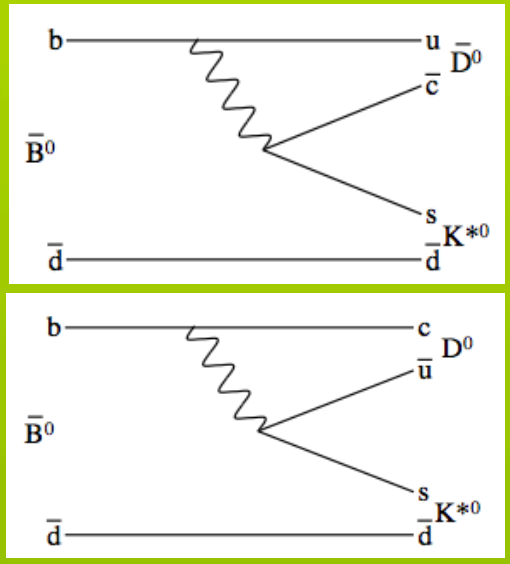
$$\frac{BR(B^- \to D^0 K^- \pi^+ \pi^-)}{BR(B^- \to D^0 \pi^- \pi^+ \pi^-)} = (9.6 \pm 1.5 \pm 0.8) \cdot 10^{-2}$$

$$\frac{BR(\Lambda_b^0 \to D^0 p K^-)}{BR(\Lambda_b^0 \to D^0 p \pi^-)} = 0.112 \pm 0.019^{+0.011}_{-0.014}$$

γ usinig $B^0 \rightarrow D^0 K^{*0}$

- Another promising channel for the measurement of γ are the decays $B^0 \rightarrow DK^{*0}$.
- These modes are both color suppressed therefore it can exhibits an enhanced interference.
- The yet unobserved CF decay $B_s \rightarrow D^0 K^*$ is a potentially dangerous background .





The LHCb Coll. arXiv:1110.3676v3

$$BR(\overline{B}_s^0 \rightarrow D^0 K^{*0}) = (4.72 \pm 1.07(stat) \pm 0.48(syst) \pm 0.37(fs/fd) \pm 0.74(BR)) \cdot 10^{-4}$$

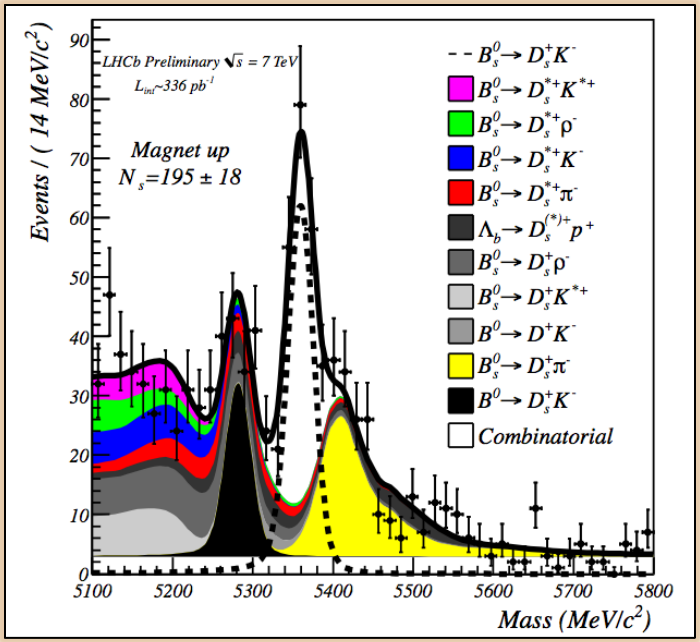
Normalization with $B^0 \rightarrow D^0 \rho^0$

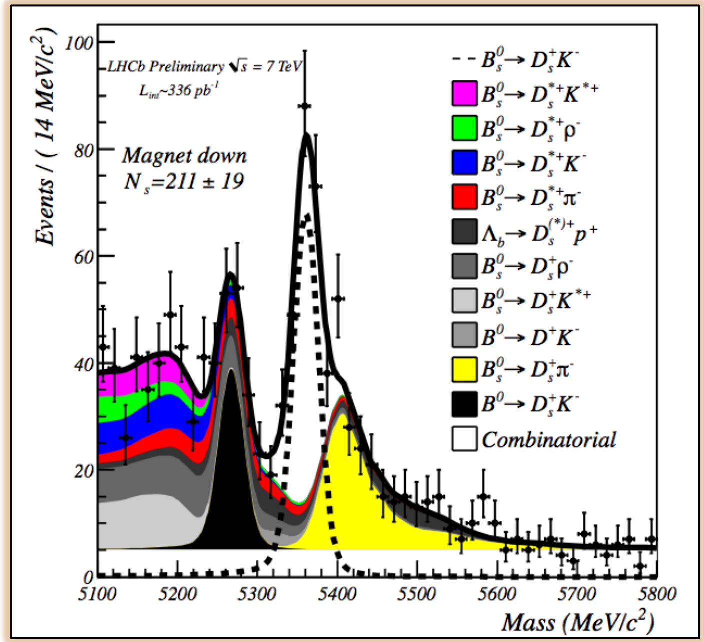
Measured by LHCb, see N. Tuning's talk

γ measurements with $B_s \rightarrow D_s K$

Both *b*→*c* and *b*→*u* diagrams are colour allowed
Time dependent analysis required
The first step is to observe the signal and measure the branching ratio

LHCb-CONF-2011-057





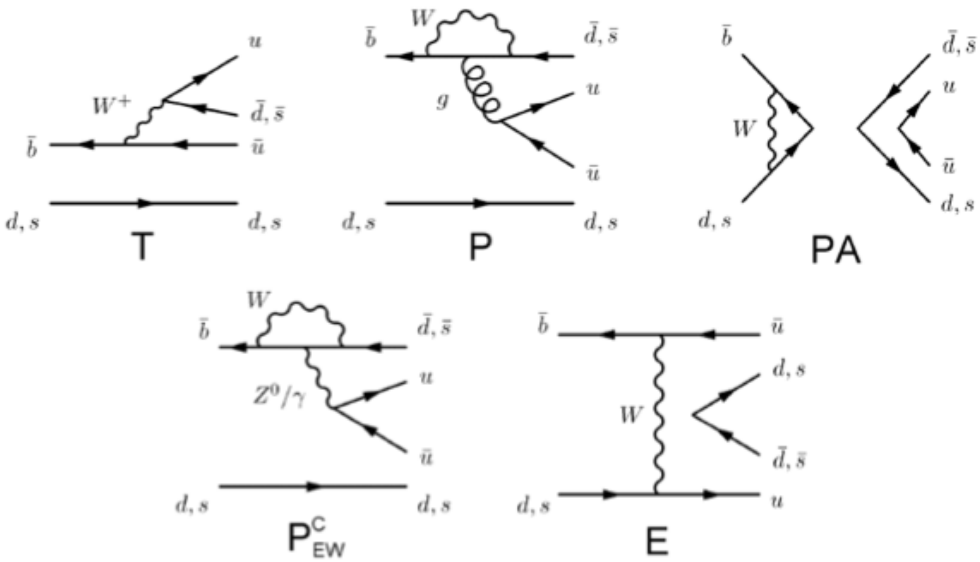
PRELIMINARY

Data sample split for the two magnet polarities.

$$\mathcal{B}(B_s^0 \rightarrow D_s^{\mp} K^{\pm}) = (1.97 \pm 0.18\ (\text{stat.})\ ^{+0.19}_{-0.20}\ (\text{syst.})\ ^{+0.19}_{-0.20}\ (f_s/f_d)) \times 10^{-4}$$

The direct and mixing CP asymmetries in $B_d \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$ are related to the angle γ (need to use U-spin symmetry).

R.Fleischer PLB 459 (1999) 306
R. Fleischer and R. Knegjens EPJ c71 (2011)1532



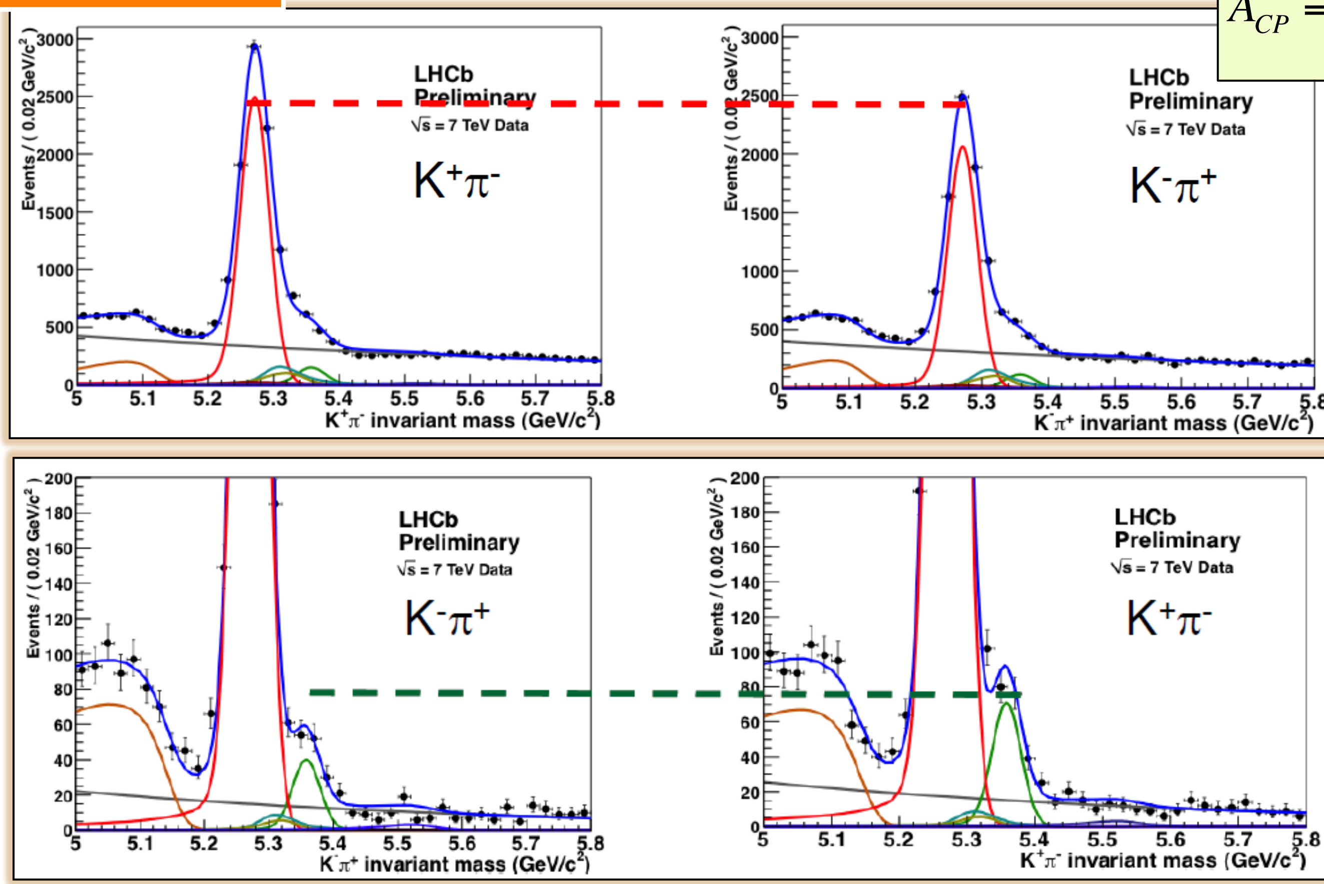
Usng U-spin symmetry and neglecting penguin annihilation and exchange topologies we expect $A_{CP}(B_s^0 \rightarrow \pi K) \sim A_{\pi\pi}^{dir}$

γ measurements with B→hh

- $B^0 \to K\pi$ - the most precise single measurement and first 5σ observation at hadron machine!
- First evidence of CP-violation in $B^0_s \to K\pi$ decay!

LHCb-CONF-2011-042

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



LHCb: PRELIMINARY

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

$$A_{CP}(B^0_s \to K\pi) = 0.27 \pm 0.08 \pm 0.02$$

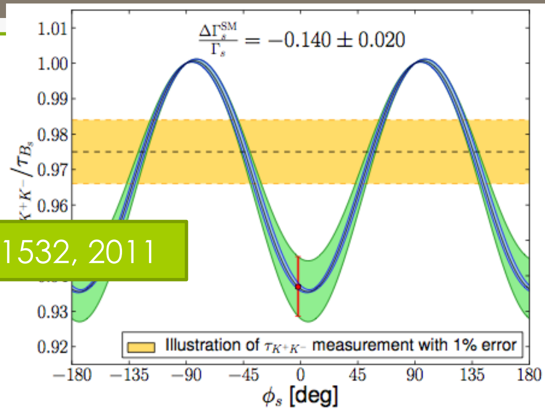
HFAG:

$A_{cp}(B^0 \to K^+\pi) = 0.098^{+0.012}_{-0.011}$

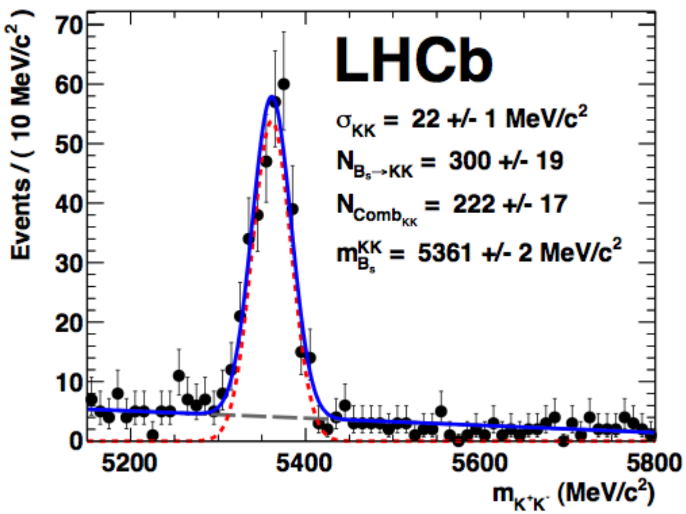
$B_s \to KK$ lifetime measurement

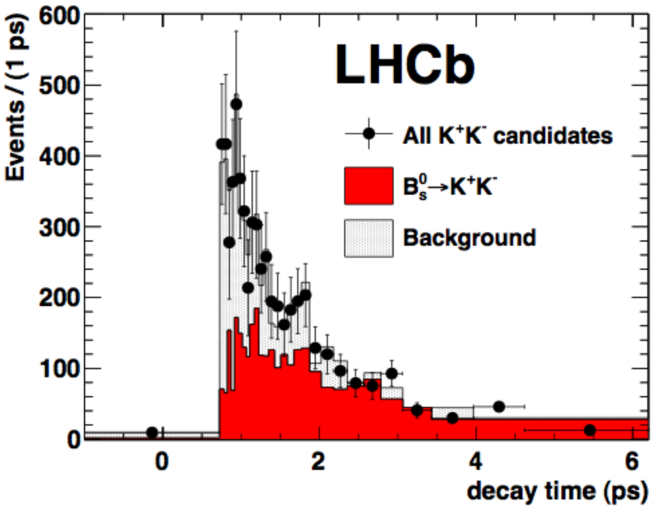
A measurement of the $B_s^0 \to K^+K^-$ lifetime can be used to put constraints on NP to the B_s^0 mixing.

R. Fleischer and R. Knegjens, Eur. Phys. J. C71:1532, 2011



2010 data (L =37pb^{-1})





$$\tau_{LHCb}(B_s^0 \to K^+K^-) = (1.44 \pm 0.10 \pm 0.01)ps$$

The LHCb Coll. arXiv:1111.0521v2

$$\tau_{CDF}(B_s^0 \to K^+K^-) = (1.53 \pm 0.18 \pm 0.02)ps$$

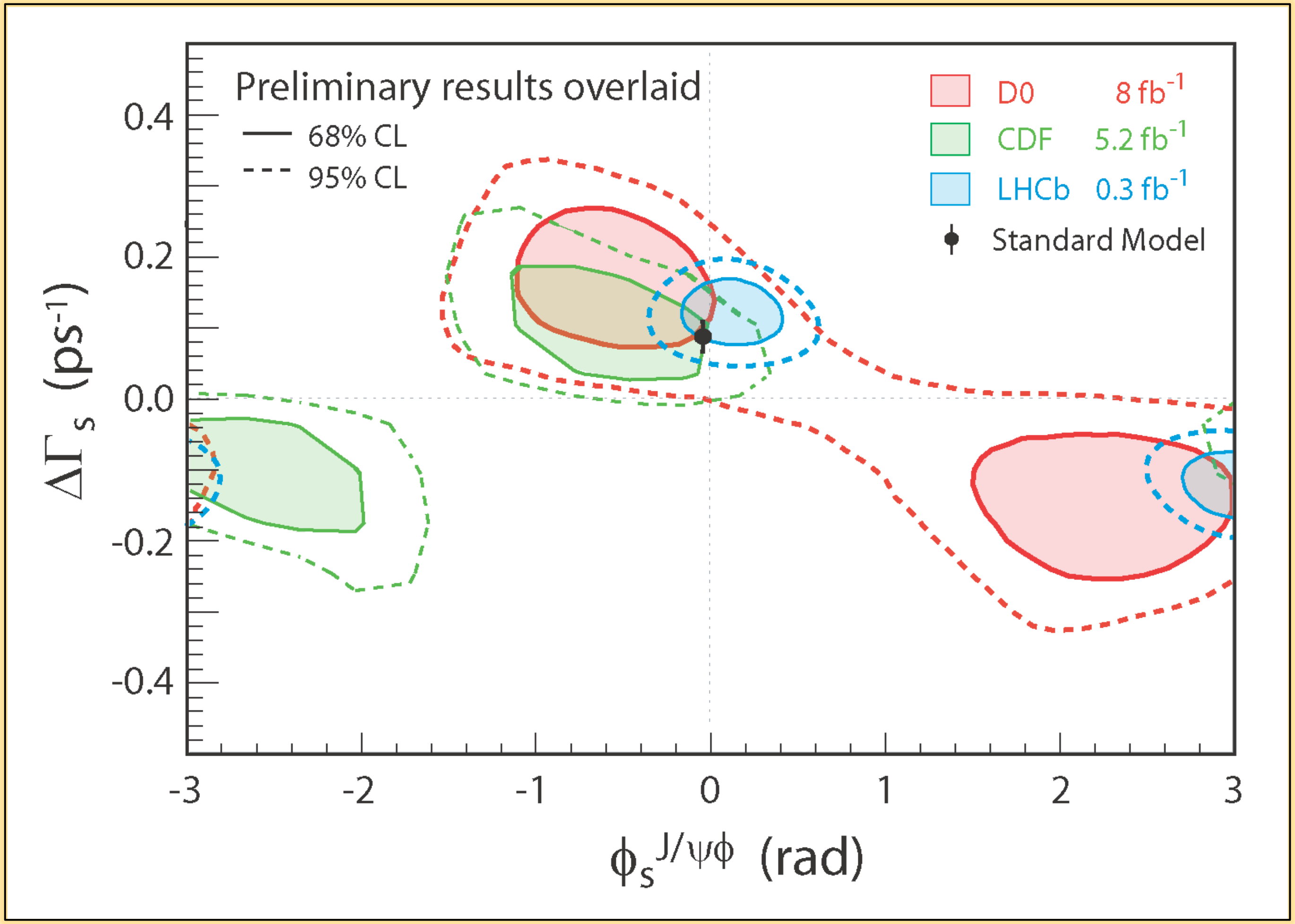
CDF Note 06-01-26

$$\tau_{SM}(B_s^0 \to K^+K^-) = (1.39 \pm 0.032)ps$$

$$\tau_{HFAG}(B_s^0) = (1.48 \pm 0.02)ps$$

R. Fleischer and R. Knegjens, Eur. Phys. J. C71:1532, 2011

CP violation in B_s mixing

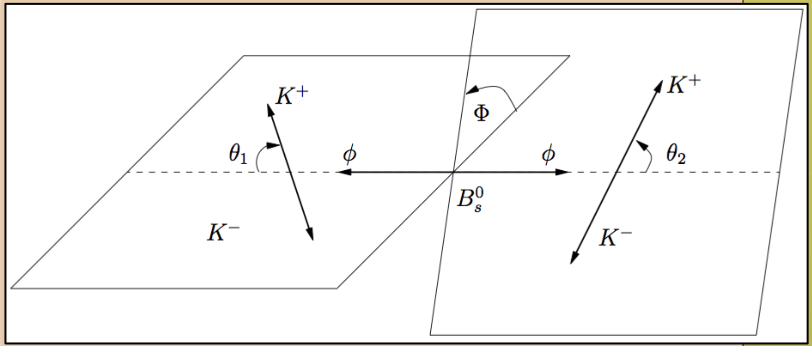


See talk by W. Hulsbergen and talk by N. Tuning

TPA in $B_s \to \phi\phi$

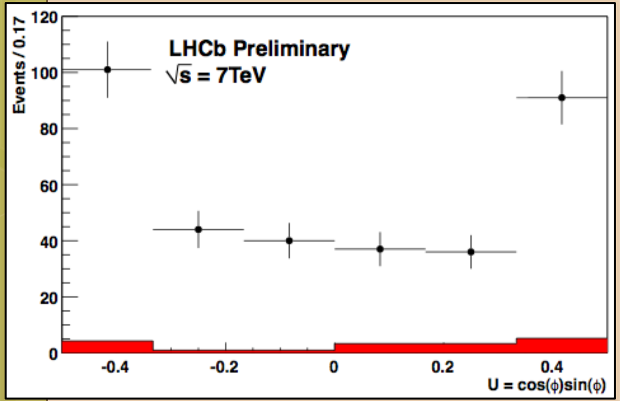
Scalar triple products of momentum or spin vectors are T-odd, a real asymmetry implies CP asymmetry in (under CPT).

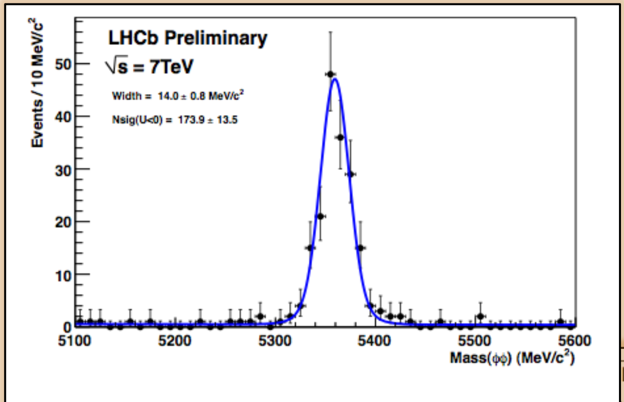
A. Datta, M. Duraisamy, D. London Phys.Lett.B701:357-362,2011
M. Gronau and J.L. Rosner arxiv:1107.1232



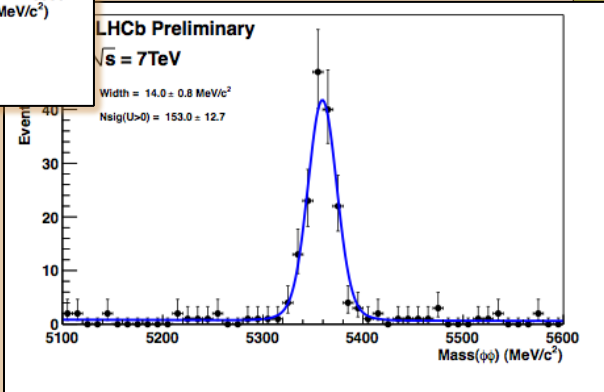
CDF measurement (arXiv:1107.4999)

$$A_u = -0.007 \pm 0.064(stat) \pm 0.018(syst)$$
$$A_v = -0.120 \pm 0.064(stat) \pm 0.016(syst)$$





(b) $U < 0$



(a) $U > 0$

LHCb-CONF-2011-052

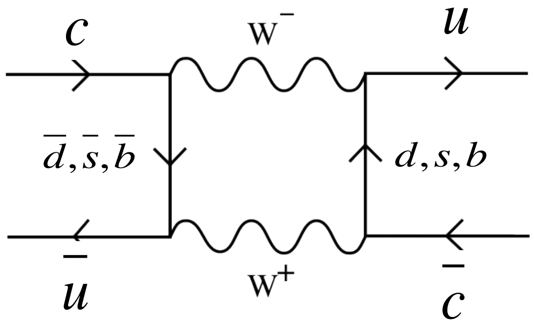
LHCb: PRELIMINARY

$$A_u = -0.064 \pm 0.057(stat) \pm 0.014(syst)$$
$$A_v = -0.070 \pm 0.057(stat) \pm 0.014(syst)$$

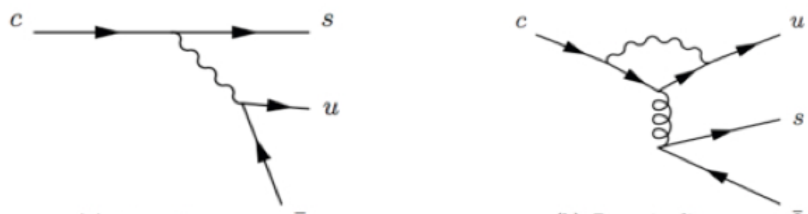
CP Violation in charm

In the SM :

- Indirect CP violation in charm is expected to be small ($<10^{-3}$) and process independent.



- CP violation in the decay (different amplitude for a process and its conjugate) is process dependent:
  - Negligibly small for Cabibbo favoured processes
  - At the level of 10^{-3} possible for Cabibbo suppressed decays



(a) *Tree diagram.* (b) *Penguin diagram.*

New Physics can enhance both direct and indirect!

ΔA_{CP} in charm at LHCb

The CP violation of the decays D→KK and D→pipi is expected to besmall O(10^{-3}) in the SM.

New physics can contribute enhancing this asymmetry (depending on the model)

Lifetime of the sample

CP asymmetry in the mixing

$$A_{CP} = \frac{\Gamma(D^0 \to hh) - \Gamma(\overline{D^0} \to hh)}{\Gamma(D^0 \to hh) + \Gamma(\overline{D^0} \to hh)} \approx a_{CP}^{dir}(hh) + \frac{\langle t \rangle}{\tau} a_{CP}^{ind}$$

Direct CP asymmetry

True D^0 lifetime

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

Using U-spin symmetry $A_{CP}(KK)$ and $A_{CP}(\pi\pi)$ are expected of similar size and opposite sign.

ΔA_{CP} in charm at LHCb

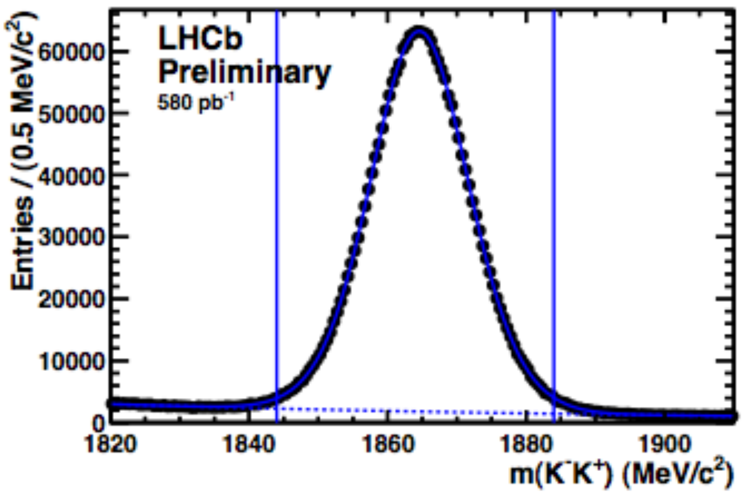
We need to know the flavour of the D^0. We use D^0 coming from $D^{*\pm}$.

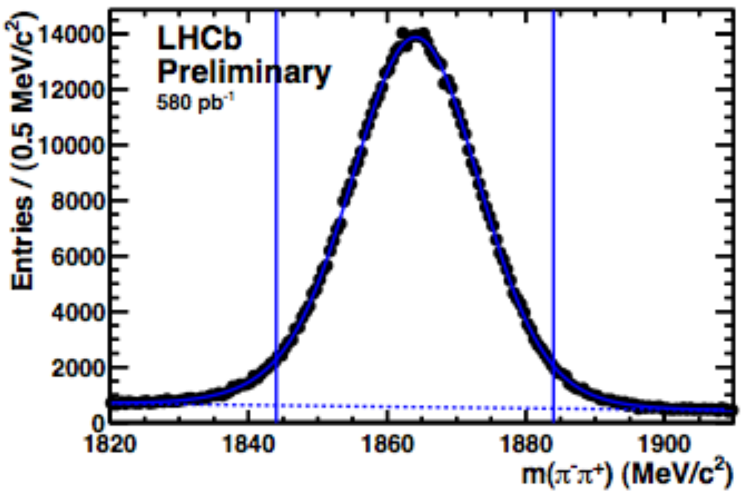
$$A_{raw} = \frac{N(D^{*+} \to D^0(hh)\pi^+) - N(D^{*-} \to \overline{D}^0(hh)\pi^-)}{N(D^{*+} \to D^0(hh)\pi^+) + N(D^{*-} \to \overline{D}^0(hh)\pi^-)} = A_{CP}(hh) + A_D(hh) + A_D(\pi_s) + A_P(D^*)$$

ΔA_{CP} between KK and $\pi\pi$ is very robust:

- For decays in h^+h^- (self-conjugate) of D^0 the term $A_D(hh)=0$
- The production asymmetry cancels out $A_P(D^*)=0$
- At first order also $A_D(\pi_s)$ cancels out

$\Delta A_{CP} \approx A_{RAW}(KK) - A_{RAW}(\pi\pi)$





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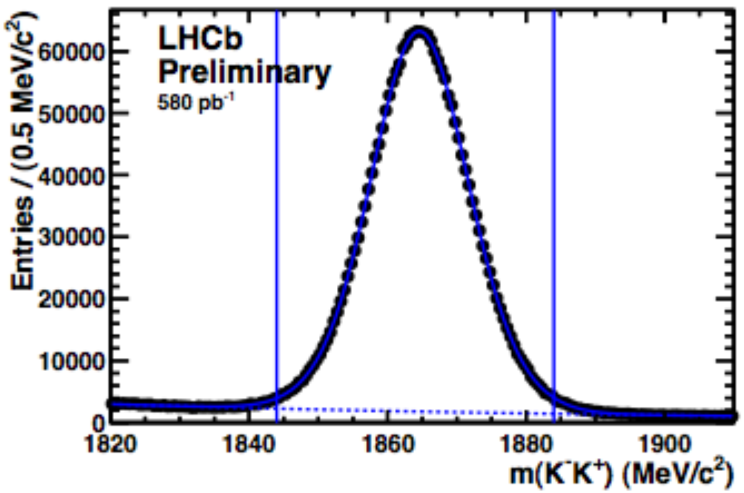

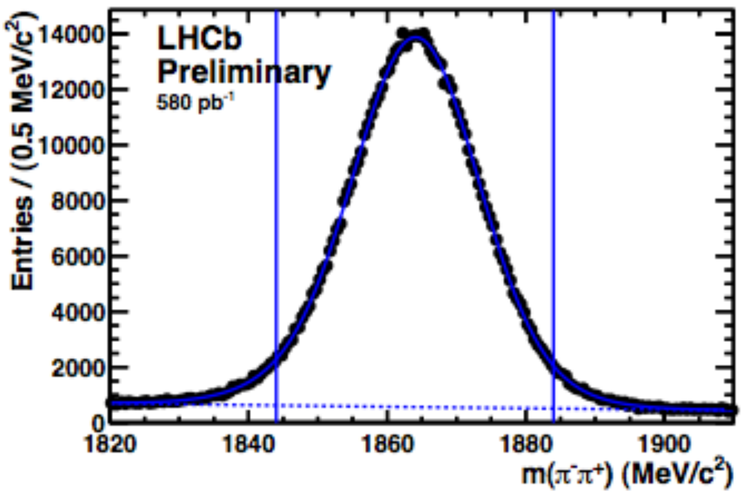

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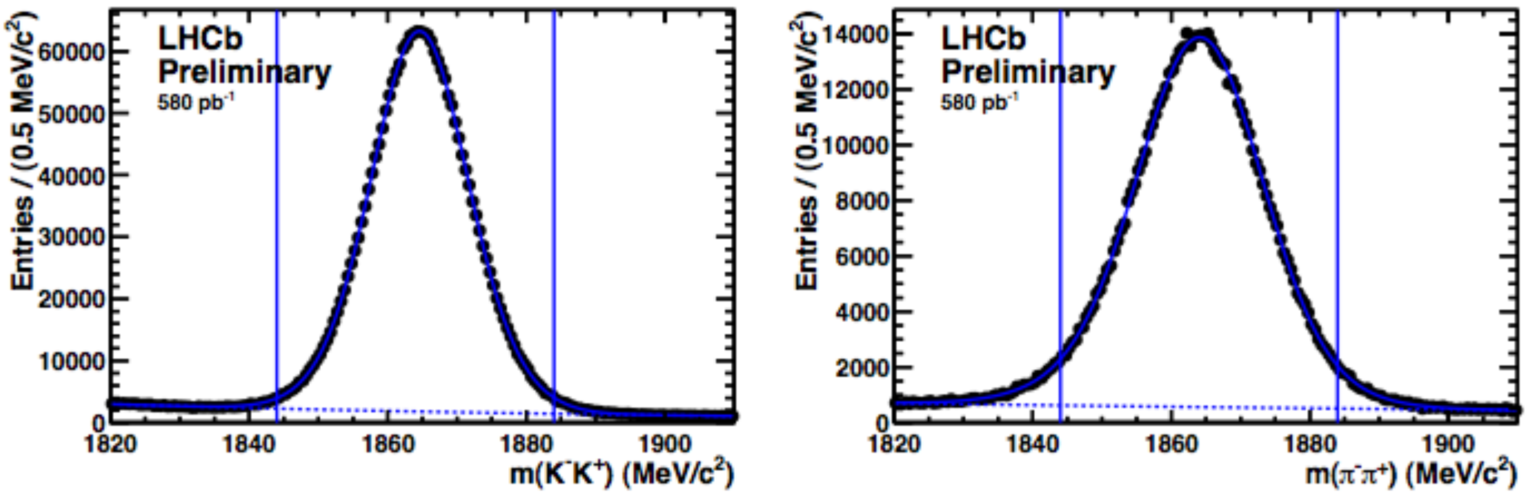
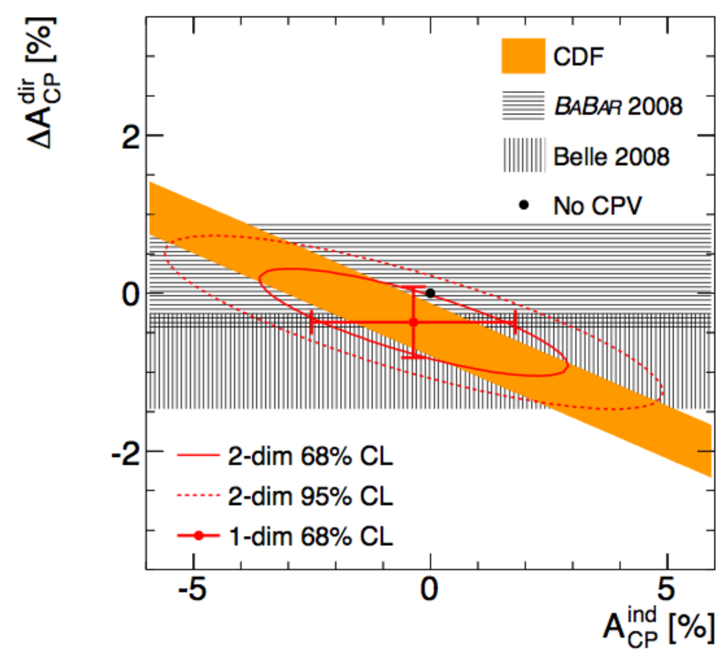


ΔA_{CP} present status

CDF (arXiv:1111.5023v1)

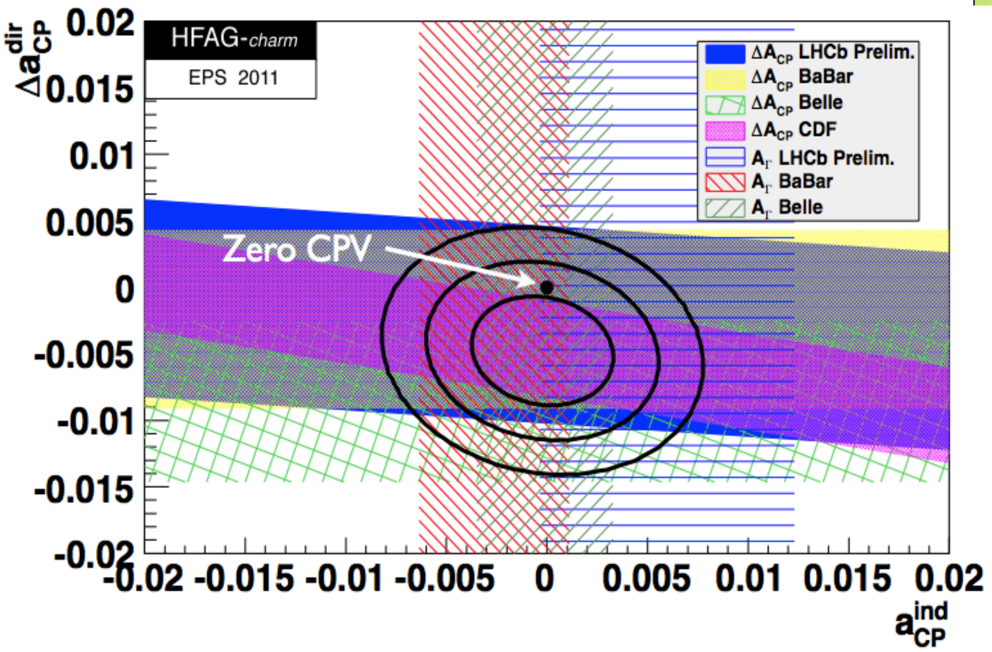


$$a_{CP}(D^0 \to \pi\pi) = (0.22 \pm 0.24 \pm 0.11)\%$$

$$a_{CP}(D^0 \to KK) = (-0.24 \pm 0.22 \pm 0.09)\%$$

$$\Delta a_{CP} = (-0.46 \pm 0.31 \pm 0.12)\%$$

HFAG result which includes the prelimary result by CDF



HFAG world average :

$$a_{CP}^{ind} = (-0.023 \pm 0.232)\%$$

$$\Delta a_{CP}^{dir} = (-0.447 \pm 0.270)\%$$

No evidence of CPV, but world average negative and 1.7 σ form zero

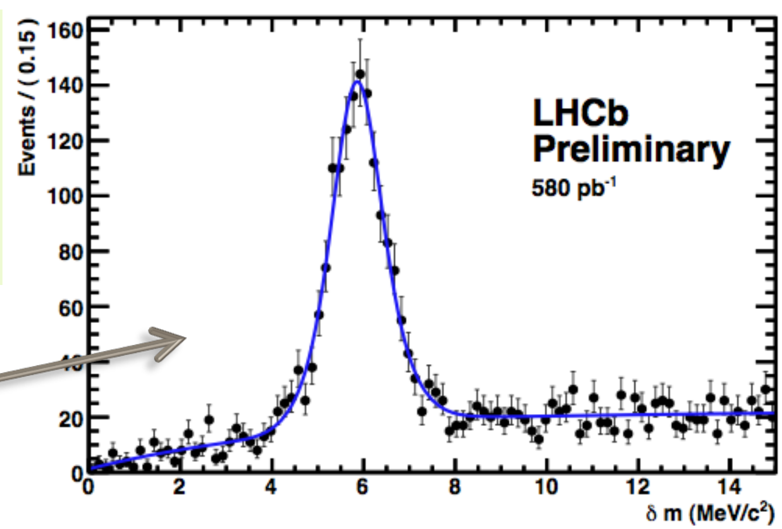
- Divide data into kinematic bins of (pT of D*+, η of D*+, p of soft pion, left/right hemisphere) -- 54 bins
- split by magnet polarity (field pointing up, pointing down)
- split into two run groups (before & after technical stop)
- Fit final states $D0 \rightarrow K+ K-$ and $\pi + \pi -$ separately => 432 independent fits.

Fit to the $\delta m = m(D^0\pi_s) - m(D^0) - m(\pi_s)$ with the model described in (LHCb-PUB-2009-031)

D^{*+} and are allowed to have different resolution

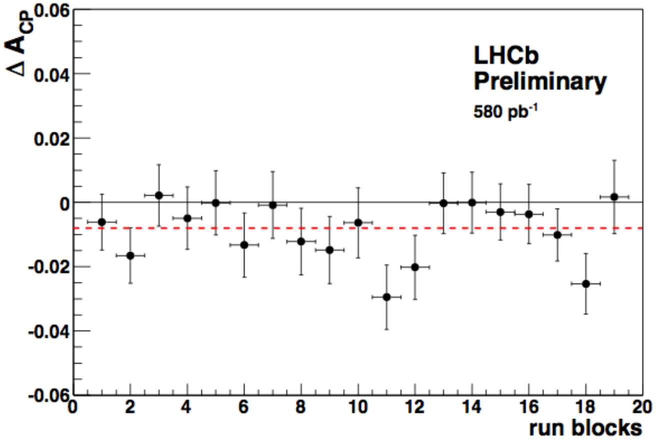
Consistency for Δa_{CP} among individual fits $\chi^2 / nDof = 211/215$

Example of Fit:
$D^0 \rightarrow KK$, First bin, first run block, Magnet Up



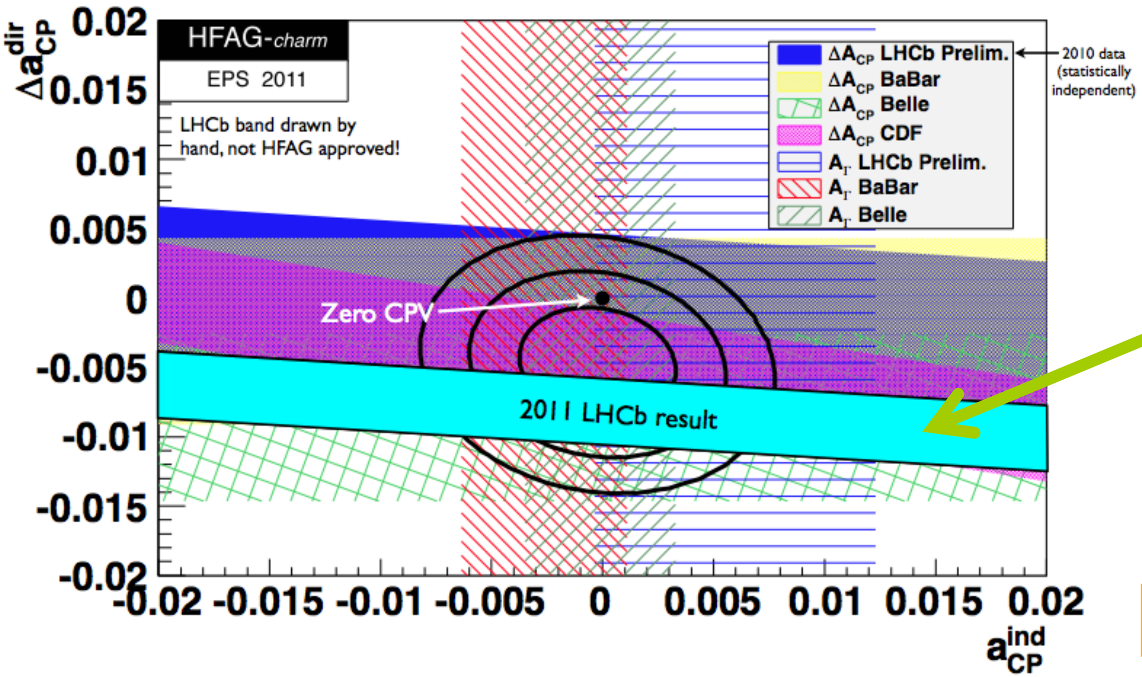
Cross Checks

- Electron and muon vetoes on the soft pion and on the D0 daughters
- Different kinematic binnings
- Stability of result vs time
- Toy MC studies of fit procedure, statistical errors
- Tightening of PID cuts on D0 daughters
- Tightening of kinematic cuts
- Variation with event track multiplicity
- Use of other signal, background lineshapes in the fit
- Use of alternative offline processing (skimming/stripping)
- Internal consistency between subsamples (splitting left/right, magnet up/ down, etc)
- All variation within appropriate statistical/systematic uncertainties.



The result seems pretty stable against systematics!

LHCb result



Band drawn "by hand" not HFAG approved!

PRELIMINARY

ΔA_{CP}=(−0.82 ± 0.21 (stat) ± 0.11 (sys)) %

LHCb-CONF-2011-061

Statistically compatible with world average (and CDF result)!
World First Evidence of CPV in charm (3.5 σ)!
Statistically dominated, eager to analyse more data!

Contribution from CPV suppressed by $\frac{\Delta\langle t\rangle}{\tau} = \frac{\langle t_{KK}\rangle - \langle t_{\pi\pi}\rangle}{\tau} = (9.8 \pm 0.9)\%$

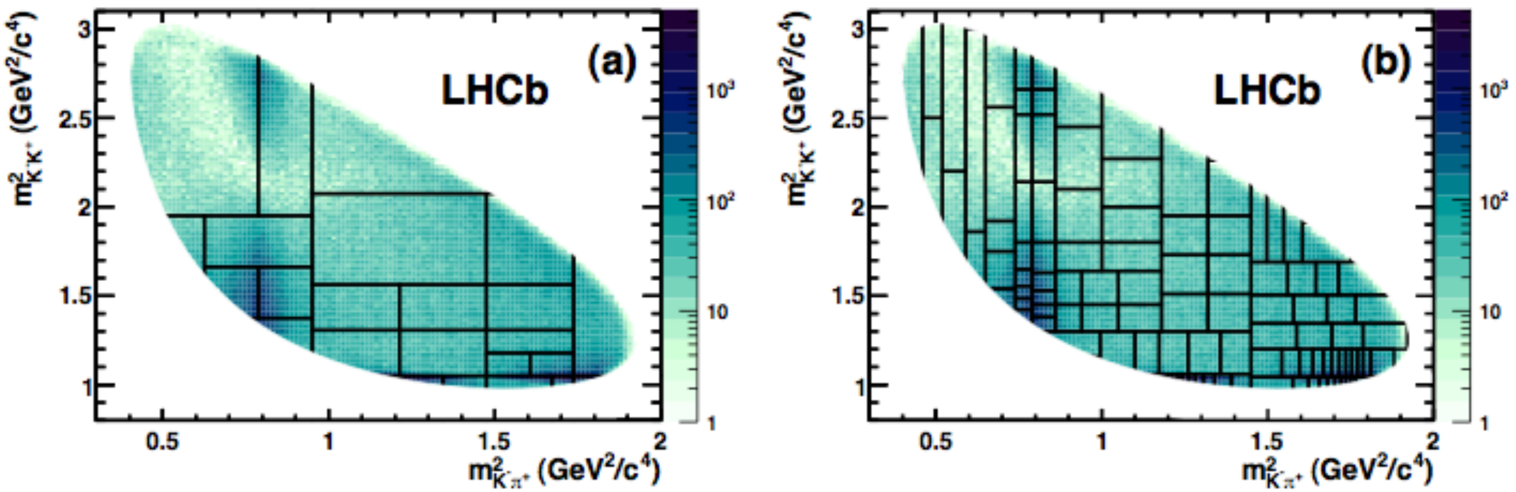
therefore the main contribution is from direct CPV

CPV in $D^+ \rightarrow K^+K^-\pi^-$

One place to look for NP contribution is $D^+ \rightarrow K^+ K^- \pi^+$ .Use of Miranda method for 'spotting' CP asymmetries in the Dalitz plot.

I. Bediaga et al., Phys. Rev. D80 (2009) 096006

LHCb: 2010 dataset of 38 pb^{-1}



The LHCb Coll. arXiv:1110.3970v1 (submitted to Phys. Rev. D)

Measurement very robust against bias:
1) Blind analysis
2) Run with two magnet polarities
3) Validation with 'toy' studies

No evidence of CPV in any binnings!

CPV in charm mixing

An important way to search for anomalous CP violation in charm mixing:

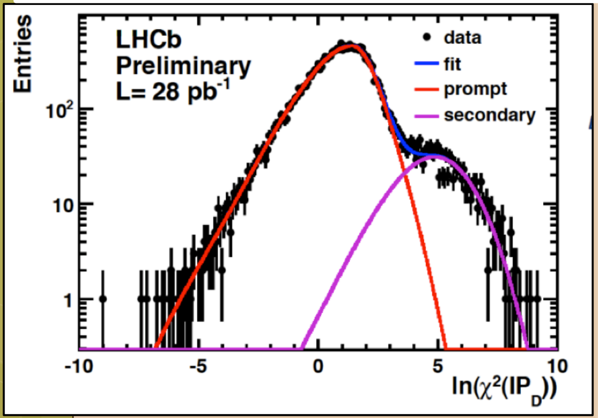
A_Γ measurement (**LHCb-CONF-2011-046**)

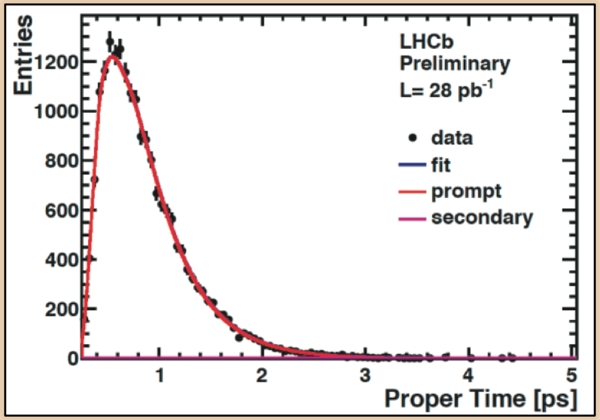
$$A_\Gamma = \frac{\tau(\overline{D^0} \to K^+K^-) - \tau(D^0 \to K^+K^-)}{\tau(\overline{D^0} \to K^+K^-) + \tau(D^0 \to K^+K^-)} \sim (\frac{A_m}{2}) y\cos\phi_D - x\sin\phi_D$$

Y_{CP} measurement (LHCb-CONF-2011-054)

$$y_{CP} = \frac{\Gamma(D^0 \to K^+K^-)}{\Gamma(D^0 \to K^+\pi^-)} - 1 \sim y\cos\phi_D - x\sin\phi_D (\frac{A_m}{2}) \qquad x = \frac{\Delta m}{\Gamma}, y = \frac{\Delta\Gamma}{2\Gamma}$$

- Need to know the flavor of the D^0, we use $D^{*+} \to D^0 \pi_s^+$.
- Need to separate the contribution of charm coming form B





PRELIMINARY

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

$HFAG: (0.12 \pm 0.25)\%$

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

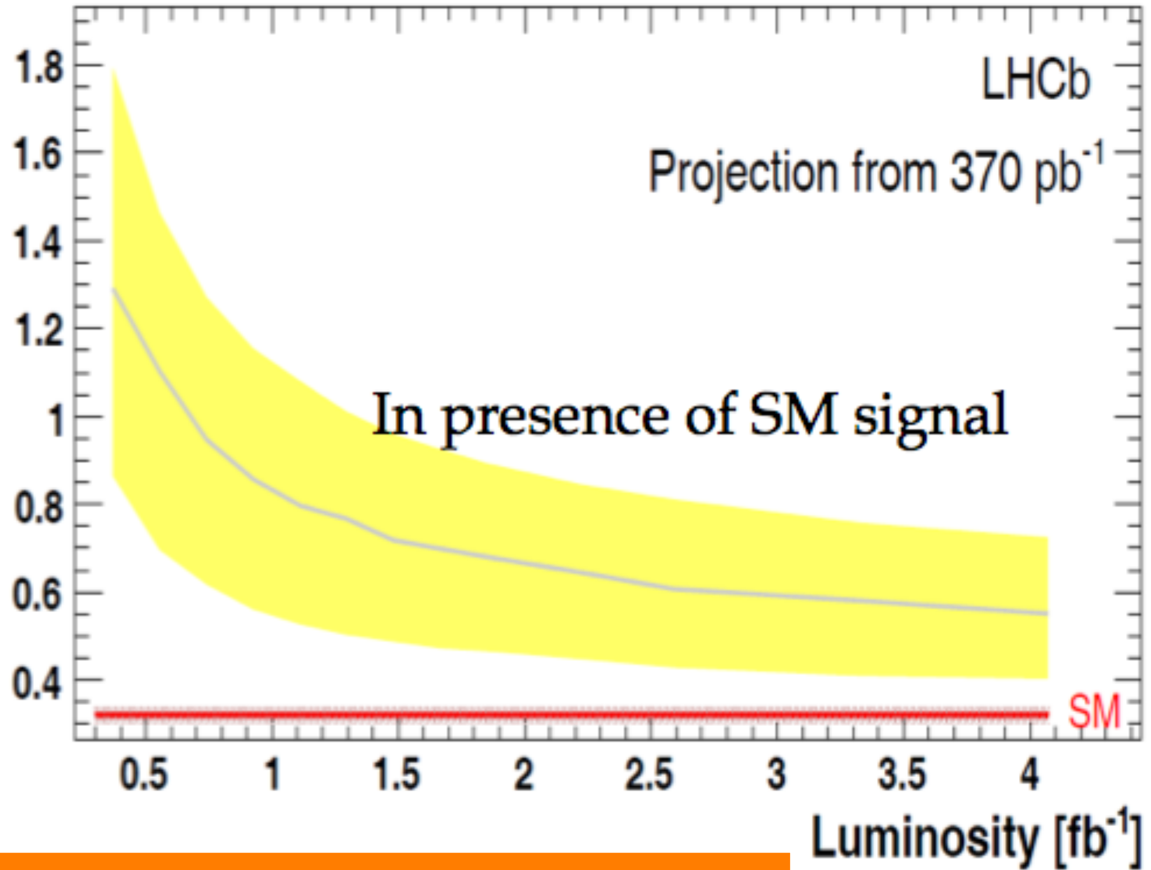
$HFAG: (1.11 \pm 0.22)\%$

Results obtained with a fraction of 2010 data, but LHCb has a large sample!

Rare decays


Found It!!!
Congratulations, it only took you 65298 seconds
www.jolyon.co.uk

$B_s \rightarrow$ mumu at LHCb

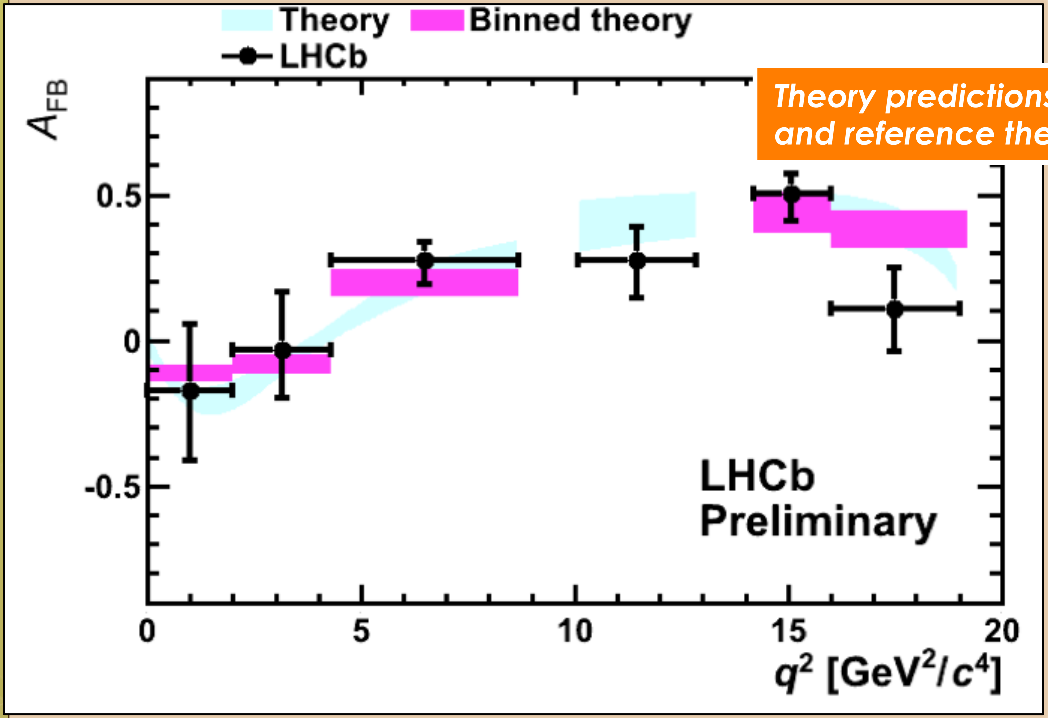


Evidence of $B_s \rightarrow \mu\,\mu$ at LHCb is possible between winter conference and the end of the running period at 7TeV.

For more details see the talk by Niels Tuning.

$B_d \to K^* \mu\mu$ at LHCb

LHCb-CONF-2011-038



Theory predictions from C.Bobeth et al., arXiv:1105.0376v2 and reference therein

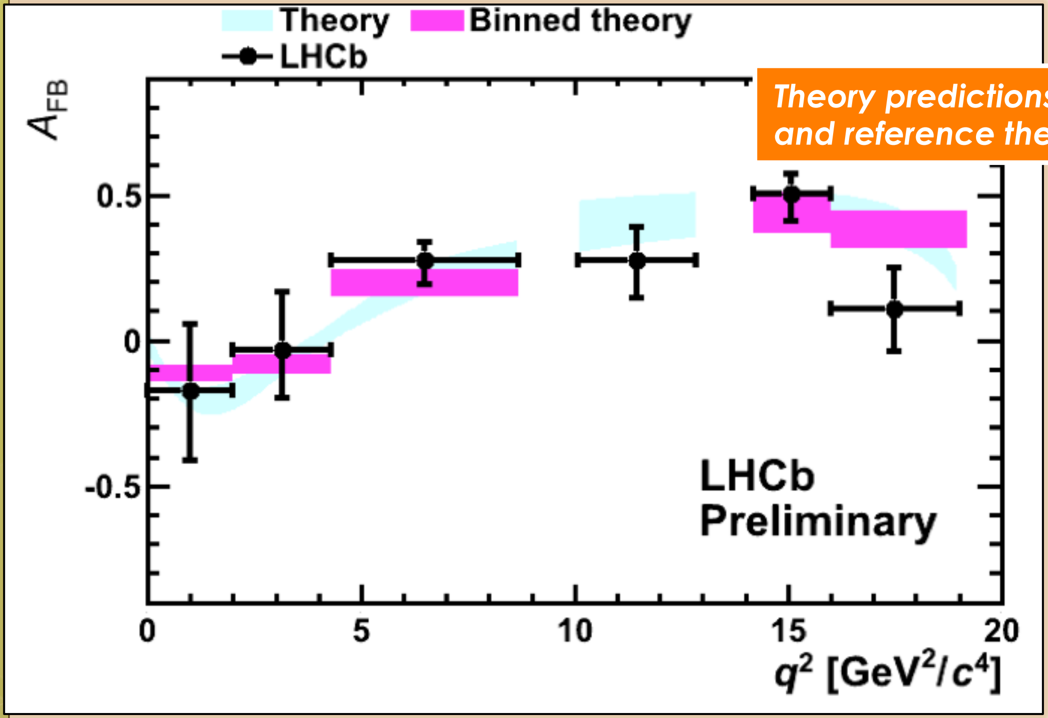
For more details see the talk by Niels Tuning.

Future steps for $B_d \to K^* \mu\, \mu$:

- Measurement of the Zero-crossing of AFB in $B_d \to K^* \mu\, \mu$
- Isospin asymmetry in $B \to K^{(*)} \mu\, \mu$
- **Measurement of A_T^2 in $B_d \to K^* \mu\, \mu$**
- **Measurement of A_T^2 in $B_d \to K^* ee$**
- **Direct CPV in $B_d \to K^* \mu\, \mu$**

$B_d \to K^*\mu\mu$ at LHCb

LHCb-CONF-2011-038



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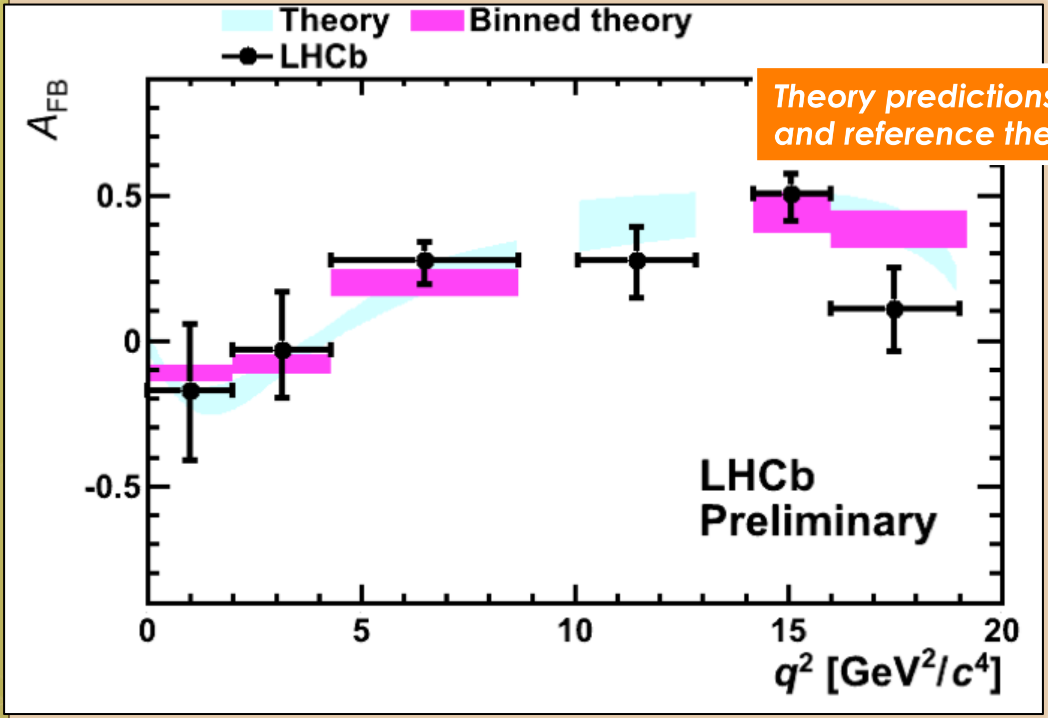
- **Measurement of A_T^2 in $B_d \to K^*ee$**
- **Direct CPV in $B_d \to K^* \mu\ \mu$**

$B_d \to K^*\mu\mu$ at LHCb

LHCb-CONF-2011-038



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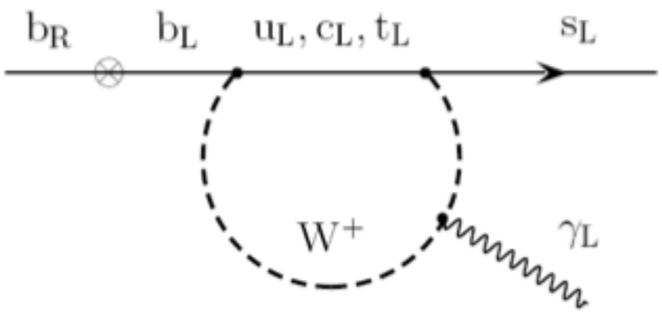
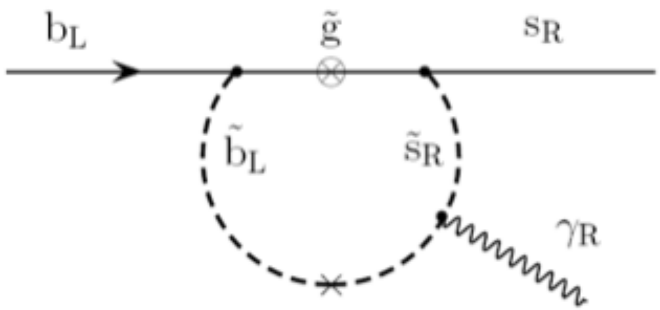
- **Measurement of A_T^2 in $B_d \to K^* ee$**
- **Direct CPV in $B_d \to K^* \mu\ \mu$**

Radiative decays



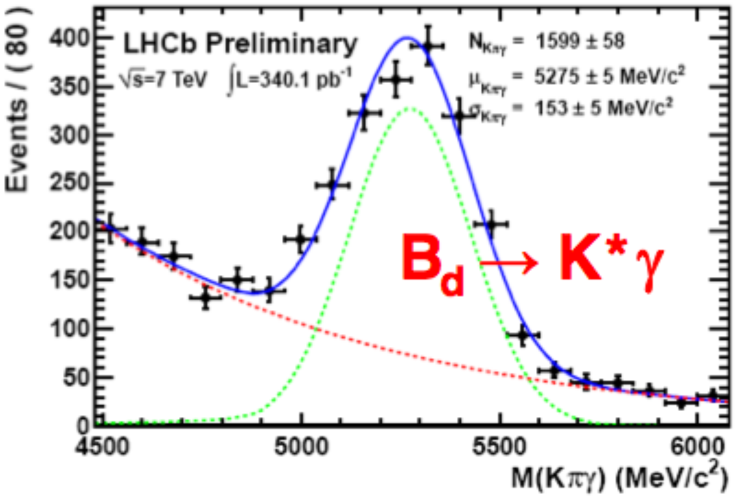


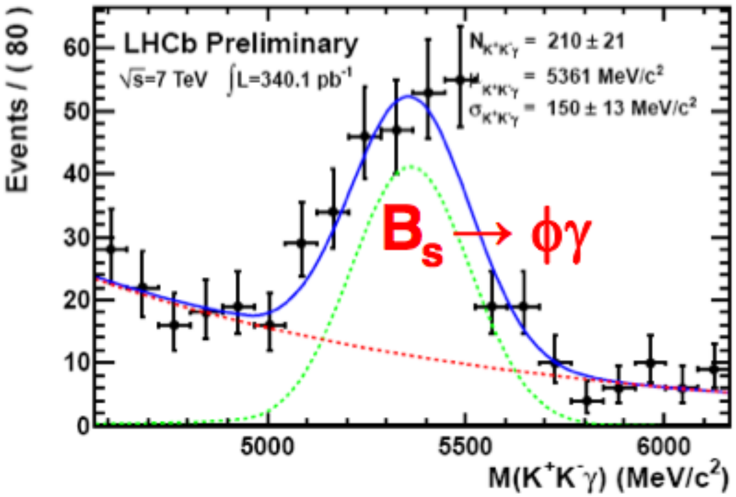
Time evolution for an untagged sample of $B_s^0 \to \Phi\, \gamma$

$$R(t) \propto e^{-\Gamma_s t}\{\cosh(\Delta\Gamma_s t/2) + A_D \sinh(\Delta\Gamma_s t/2)\}$$

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

- In the SM photons are emitted almost completely left-handed polarized
- A_D is sensitive to fraction of right-handed photons (even for small Φ_s) ($A_D \sim 0$ in SM)
- Can be enhanced by NP with large Right-Handed currents.





LHCb-CONF-2011-055

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

SM expectation 1.0±0.2 A. Ali, B. D. Pecjak, and C. Greub, Eur. Phys. J. C55 (2008) 577–595

Future steps: Direct CPV in $B_d \to K^* \gamma$, Measurement of baryon radiative decays, Photon Polarization in $B_s \to \phi \gamma$.

What I did not cover in this talk

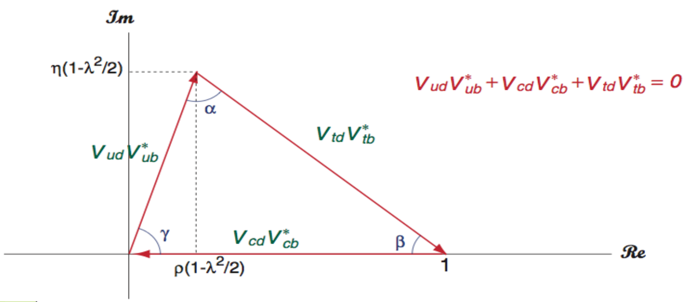
- Measurement of the BR($B_s \rightarrow K^* K^*$)
- Limits to LFV $B^+ \rightarrow h^- \mu^+ \mu^+$
- Measurement of mass of B resonances
- Measurement of excited B states
- Measurement on XYZ states
- Measurement on B_c decays
- B production measurement
- Electroweak Physics
- … and many more

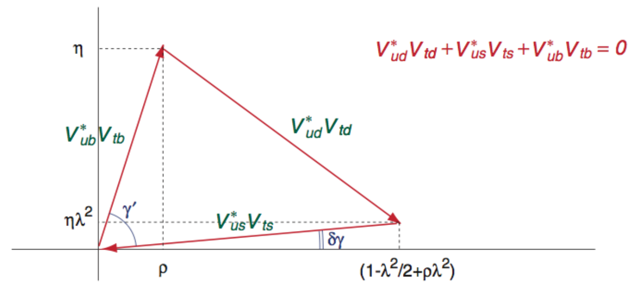
Conclusions

- LHCb is over taking other experiments in several B-physics measurements
- World largest sample of exclusive B-decays
- Many propaedeutical measurements towards γ (with Tree and Penguin) have been done
- LHCbeauty is also a nice "LHCcharm":
  - We search in several decays for direct CPV
  - We also look for mixing induced CPV in D^0
  - **We have the world first evidence of CPV in charm in $\Delta A_{CP} = A_{CP}(KK) - A_{CP}(\pi\pi)$**
- We have many measurements in rare decays that already severely constraint NP :
  - $BR(B_s \to \mu\mu)$
  - AFB in $Bd \to K^* \mu\mu$
- We are also studying radiative decays (e.g. $B_s \to \phi\gamma$)
- **MUCH MORE WILL BE COMING SOON, STAY TUNED!**

Backup slides

Unitarity Triangle





Sides:

V_{ud}	β-decay	$(A,Z) \to (A,Z+1) + e^- + \bar{\nu}_e$	$\cos\vartheta_C$
V_{us}	K-decay	$K^+ \to \pi^0 + \ell^+ + \nu_\ell$	$\sin\vartheta_C$
		$K^0 \to \pi^- + \ell^+ + \nu_\ell$	
V_{cd}	ν-production of c's	$\nu_\ell + d \to \ell^- + c$	$\cos\vartheta_C$
V_{cs}		$D^\pm \to K^0 + \ell^\pm + \nu_\ell$	$\sin\vartheta_C$
V_{ub}	B-decay	$b \to u + \ell^- + \bar{\nu}_\ell$	
V_{cb}		$b \to c + \ell^- + \bar{\nu}_\ell$	
V_{td}	Δm in B^0-$\bar{B}^0$		

Measurement of the angles:

$$\alpha \Rightarrow \quad B \to \pi\pi, \quad B \to \rho\rho, \quad B \to \rho\pi$$

$$\beta \Rightarrow \quad B \to J/\psi K_s, \quad B \to \phi K_s, \quad B \to D^{(*)}D^{(*)}$$

$$\gamma \Rightarrow \quad B \to D^{(*)}\pi, \quad B \to DK$$

Wolfstein parameterization

$$V^{CKM} = \text{CKM Matrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \Rightarrow \text{Standard rapresentation: } s_i = \sin\vartheta_i \quad c_i = \cos\vartheta_i$$

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} =$$

$$\begin{pmatrix} c_{12}c_{13} & s_{12}c_{23} & s_{13}e^{i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & s_{23}c_{13} \end{pmatrix}$$

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

$V^*_{ud}V_{td} + V^*_{us}V_{ts} + V^*_{ub}V_{tb} = 0 \qquad \lambda^3, \lambda^3, \lambda^3$

$V^*_{cd}V_{td} + V^*_{cs}V_{ts} + V^*_{cb}V_{tb} = 0 \qquad \lambda^4, \lambda^2, \lambda^2$

$V_{ud}V^*_{us} + V_{cd}V^*_{cs} + V_{td}V^*_{ts} = 0 \qquad \lambda, \lambda, \lambda^5$

$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0 \qquad \lambda^3, \lambda^3, \lambda^3$

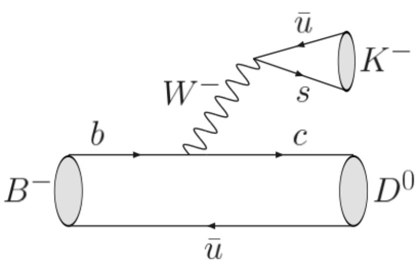
$V_{us}V^*_{ub} + V_{cs}V^*_{cb} + V_{ts}V^*_{tb} = 0 \qquad \lambda^4, \lambda^2, \lambda^2$

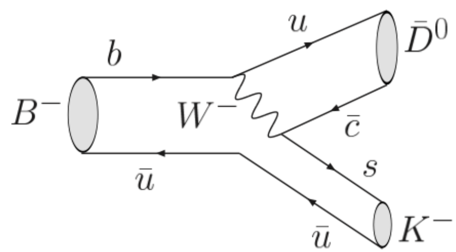
Expanding as a function of the sin of Cabibbo angle:

$$s_{12} = \lambda, \quad s_{13}\sin\delta_{13} = A\lambda^3\eta, \quad s_{23} = A\lambda^2, \quad s_{13}\cos\delta_{13} = A\lambda^3\rho$$

$$\begin{pmatrix} 1-\frac{\lambda^2}{2}-\frac{\lambda^4}{8} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda - A^2\lambda^5(\rho + i\eta - \frac{1}{2}) & 1-\frac{\lambda^2}{2}-(\frac{1}{8}+\frac{A}{2})\lambda^4 & A\lambda^2 \\ A\lambda^3[1-(\rho+i\eta)(1-\frac{\lambda^2}{2})] & -A\lambda^2 - A\lambda^4(\rho + i\eta - \frac{1}{2}) & 1-\frac{1}{2}A^2\lambda^4 \end{pmatrix} + \mathcal{O}(\lambda^6)$$

Gamma with Trees





$A(B^- \to D^0 K^-) = A_c e^{i\delta_c}, \quad A(B^- \to \overline{D}^0 K^-) = A_u e^{i(\delta_u - \gamma)}$

$A(D^0 \to f) = A_f e^{i\delta_f}$ and $A(\overline{D}^0 \to f) = A_{\bar{f}} e^{i\delta_{\bar{f}}}$ $\;f$ being a generic final state of D-meson.

The δs are strong phases and γ is the week phase, while A are real and positive

$$A(B^- \to (f)_D K^-) = A_C A_f e^{i(\delta_c + \delta_f)} + A_u A_{\bar{f}} e^{i(\delta_u + \delta_{\bar{f}} - \gamma)}$$

$$\Gamma(B^- \to (f)_D K^-) = A_C^2 A_{\bar{f}}^2 \left(A_f^2 / A_{\bar{f}}^2 + r_B^2 + 2 r_B \, A_f / A_{\bar{f}} \, \mathrm{Re}(e^{i(\delta_B + \delta_D - \gamma)}) \right)$$

where $\quad r_B = A_u / A_C, \quad \delta_B = \delta_u - \delta_C, \quad \delta_D = \delta_{\bar{f}} - \delta_f$

GLW method

In the GLW method the D meson is reconstructed when it decays into a CP eigenstate (e.g. K K), therefore the $A_f / A_{\bar{f}} = 1$, $\delta_D = 0, \pi$ and CP=+1,-1 $\Rightarrow$

$$\Rightarrow \quad \Gamma(B^- \to [f_{CP\pm}]_D K^-) = A_C^2 A_{f_{CP\pm}}^2 (1 + r_B^2 \pm 2 r_B \cos(\delta_B - \gamma))$$

We have:

$$A_{CP\pm} = \frac{\Gamma(B^- \to D^0_{CP\pm} K^-) - \Gamma(B^+ \to D^0_{CP\pm} K^+)}{\Gamma(B^- \to D^0_{CP\pm} K^-) + \Gamma(B^+ \to D^0_{CP\pm} K^+)} = \frac{\pm 2 r_B \sin\delta_B \sin\gamma}{1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma}$$

$$R_{CP\pm} = \frac{\Gamma(B^- \to D^0_{CP\pm} K^-) + \Gamma(B^+ \to D^0_{CP\pm} K^+)}{2\Gamma(B^- \to D^0 K^-)} = 1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma$$

ADS method

In the ADS method it used the interference of

$B^- \to D^0 K^-$ followed by doubly Cabibbo-suppressed $D^0 \to K^+\pi^-$

and the suppressed $B^- \to \overline{D}^0 K^-$ followed by the Cabibbo-allowed $\overline{D}^0 \to K^+\pi^-$.

$$r_D = A/A = \frac{\left\| A(D^0 \to K^+\pi^-) \right\|}{\left\| A(D^0 \to K^-\pi^+) \right\|}$$

Since $r_D \sim 5\%$ and r~10% the interference can be quite large!

$$R_{ADS} = \frac{\Gamma(B^- \to [K^+\pi^-]_D K^-) + \Gamma(B^+ \to [K^-\pi^+]_D K^+)}{\Gamma(B^- \to [K^-\pi^+]_D K^-) + \Gamma(B^+ \to [K^+\pi^-]_D K^+)} = r_B^2 + r_D^2 + 2 r_B r_D \cos\gamma \cos(\delta_B + \delta_D)$$

$$A_{ADS} = \frac{\Gamma(B^- \to [K^+\pi^-]_D K^-) - \Gamma(B^+ \to [K^-\pi^+]_D K^+)}{\Gamma(B^- \to [K^+\pi^-]_D K^-) + \Gamma(B^+ \to [K^-\pi^+]_D K^+)} = 2 r_B r_D \sin\gamma \sin(\delta_B + \delta_D) / R_{ADS}$$

Other ways of extracting ϒ

GGSZ:

In this method the D^0 is reconstructed when it decays in 3bodies (e.g. $K_s^0 \pi \pi$).

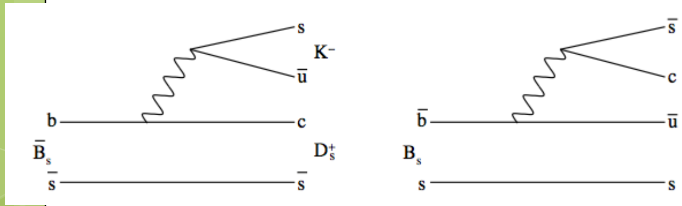
$$A_f e^{i\delta_f} = f(m_-^2, m_+^2)$$

$$A_{\bar f} e^{i\delta_{\bar f}} = f(m_+^2, m_-^2)$$

$$\Gamma(B^\mp \to [K_s^0 \pi\pi]_D K^\mp) \propto \left\| f(m_\mp^2, m_\pm^2) \right\|^2 + r_B^2 \left\| f(m_\pm^2, m_\mp^2) \right\|^2 + 2 r_B \left\| f(m_\mp^2, m_\pm^2) \right\| \left\| f(m_\pm^2, m_\mp^2) \right\| \cos(\delta_B + \delta_D(m_\mp^2, m_\pm^2) \mp \gamma)$$

Bs→DsK (Time dependent CP asymmetry):

The interference between the direct decay and the decay after mixing allows to access ϒ. The non-zero $\Delta \Gamma_s$ allows to include non tagged events in the analysis.

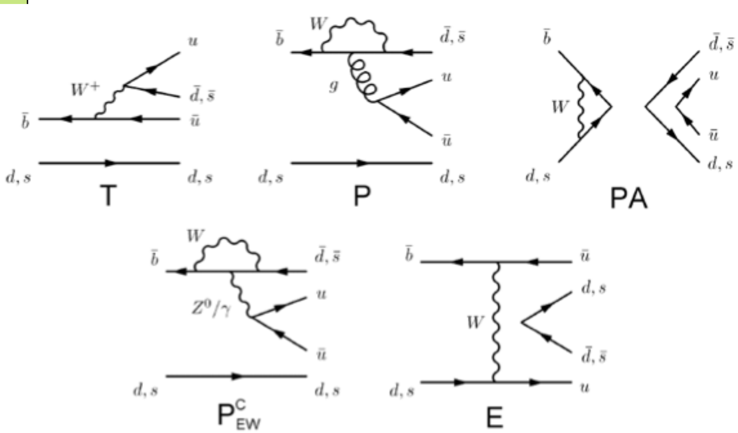


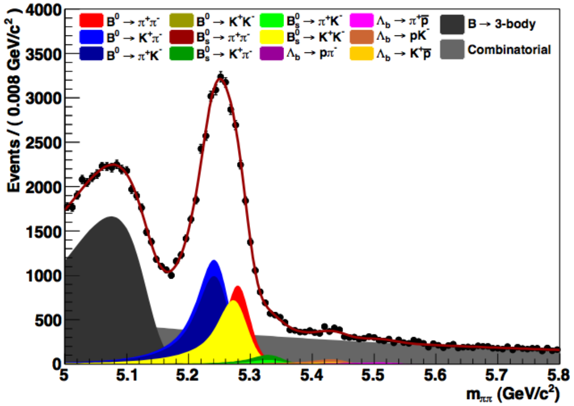
$$\Gamma_{B_s^0/\bar B_s^0 \to f}(t) = 2 \cdot |A_f|^2 (1 + |\lambda_f|^2) \frac{e^{-\Gamma_s t}}{2} \cdot \left(\cosh \frac{\Delta\Gamma_s t}{2} + D_f \sinh \frac{\Delta\Gamma_s t}{2} \right)$$

$$\Gamma_{B_s^0/\bar B_s^0 \to \bar f}(t) = 2 \cdot |\bar A_{\bar f}|^2 (1 + |\bar\lambda_{\bar f}|^2) \frac{e^{-\Gamma_s t}}{2} \cdot \left(\cosh \frac{\Delta\Gamma_s t}{2} + D_{\bar f} \sinh \frac{\Delta\Gamma_s t}{2} \right)$$

$$\gamma + \phi_s = \frac{1}{2}[arg(\bar\lambda_{\bar f}) - arg(\lambda_f)]$$

ϒ with penguin





Decay mode	Contributing diagrams
$B^0 \to \pi^+\pi^-$	$T,\ P,\ PA,\ P^C_{EW},\ E$
$B^0 \to K^+\pi^-$	$T,\ P,\ P^C_{EW}$
$B^0_s \to \pi^+K^-$	$T,\ P,\ P^C_{EW}$
$B^0_s \to K^+K^-$	$T,\ P,\ PA,\ P^C_{EW},\ E$
$B^0 \to K^+K^-$	$PA,\ E$
$B^0_s \to \pi^+\pi^-$	$PA,\ E$

$$\mathcal{A}^{dir}_{K^+K^-} = -\frac{2\tilde{d}'\sin(\vartheta')\sin(\gamma)}{1+2\tilde{d}'\cos(\vartheta')\cos(\gamma)+\tilde{d}'^2}$$

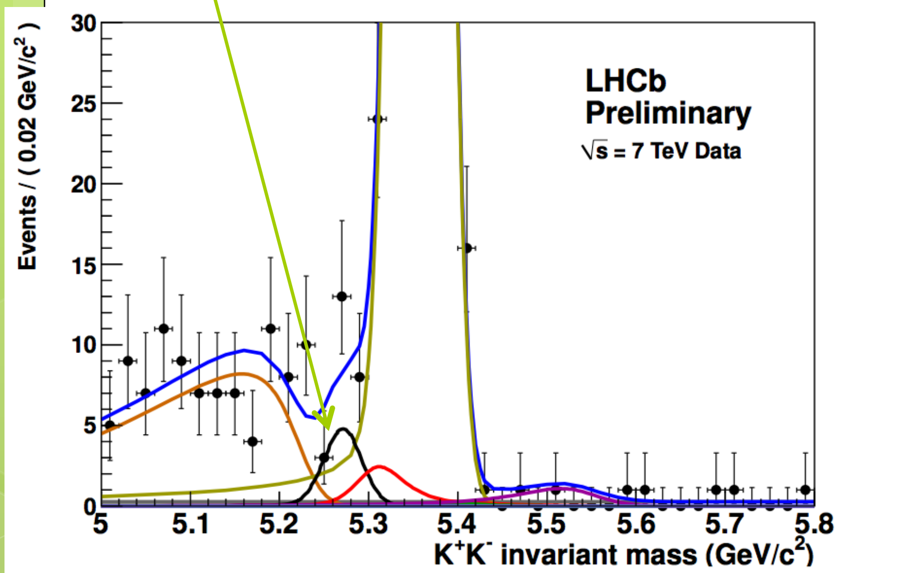
$$\mathcal{A}^{dir}_{\pi^+\pi^-} = \frac{2d\sin(\vartheta)\sin(\gamma)}{1-2d\cos(\vartheta)\cos(\gamma)+d^2}$$

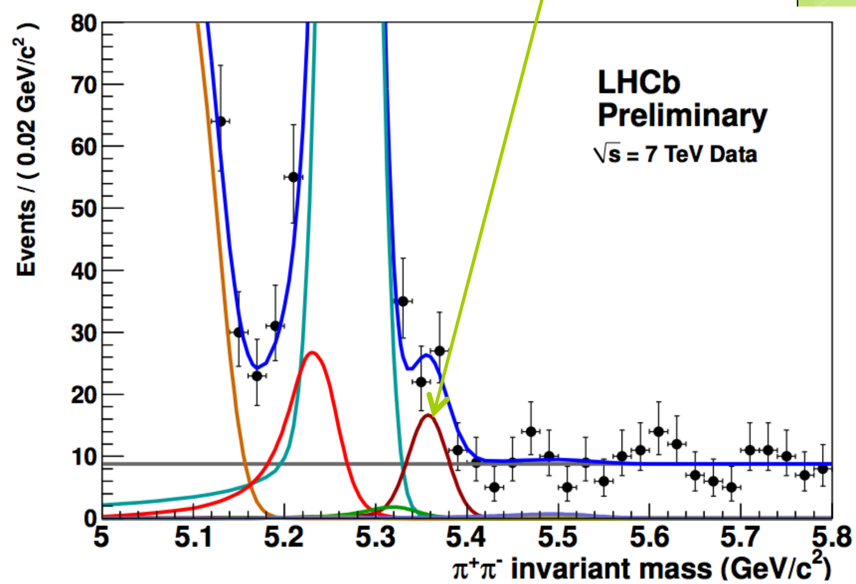
$$\mathcal{A}^{mix}_{\pi^+\pi^-} = -\frac{\sin(\phi_d+2\gamma)-2d\cos(\vartheta)\sin(\phi_d+\gamma)+d^2\sin(\phi_d)}{1-2d\cos(\vartheta)\cos(\gamma)+d^2}$$

$$\mathcal{A}^{mix}_{K^+K^-} = -\frac{\sin(\phi_s+2\gamma)+2\tilde{d}'\cos(\vartheta')\sin(\phi_s+\gamma)+\tilde{d}'^2\sin(\phi_s)}{1+2\tilde{d}'\cos(\vartheta')\cos(\gamma)+\tilde{d}'^2}$$

BR measurements :

$B^0 \to K^+K^-$ **LHCb: 2011 data, L=320pb^{-1}** $B_s \to \pi^+\pi^-$





$$BR(B^0 \to K^+K^-) = (0.13^{+0.06}_{-0.05}(stat) \pm 0.07(syst)) \cdot 10^{-6}$$

$$BR(B_s \to \pi^+\pi^-) = (0.98^{+0.23}_{-0.19}(stat) \pm 0.11(syst)) \cdot 10^{-6}$$

Using new LHCb reasult (LHCb-CONF-2011-34)

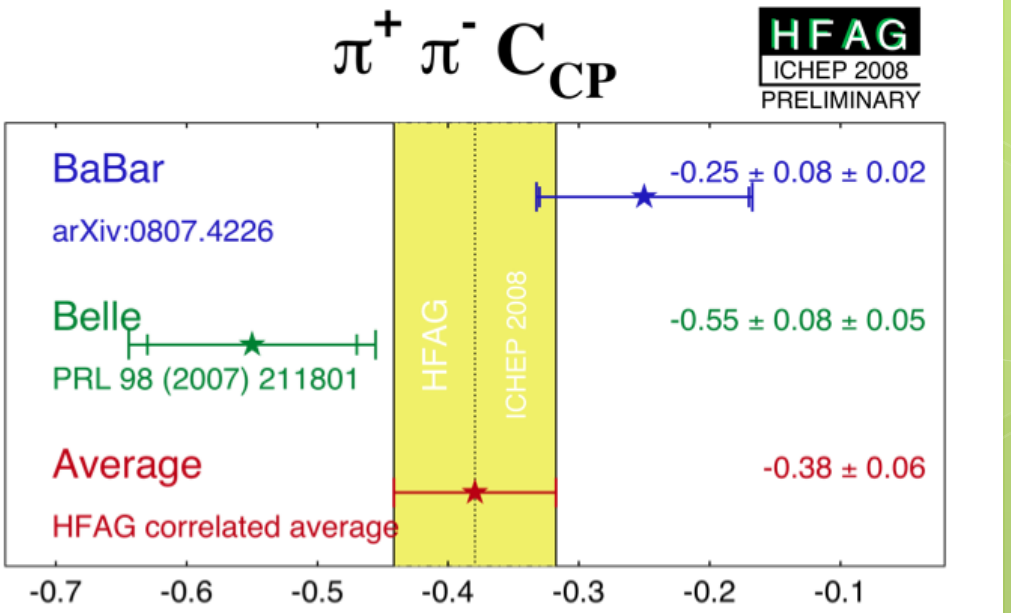
$$fs/fd = 0.267^{+0.21}_{-0.20}$$

U-spin assumption

Usng U-spin symmetry and neglecting penguin annihilation and exchange topologies we expect:

$$C_{CP} = -A^{dir}_{\pi\pi}$$

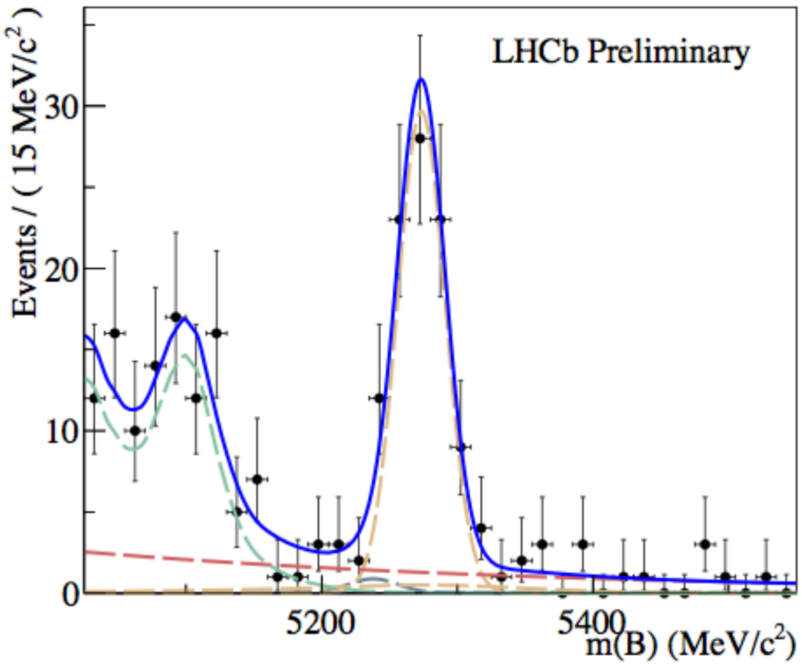
$$A_{CP}(B^0_s \to \pi^+ K^-) \approx A^{dir}_{\pi^+\pi^-}$$

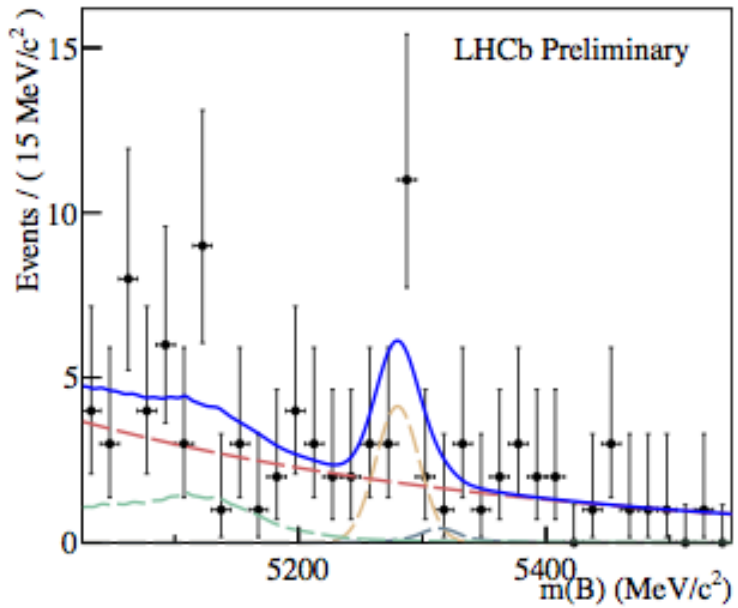


$A_{CP}(B^0 \to K\pi) = A_{Raw} - A_{\Delta} = -0.088 \pm 0.011(stat) \pm 0.008(syst)$

World Average: $-0.098^{+0.012}_{-0.011}$

2010 data ($L = 35.5 pb^{-1}$)





PRELIMINARY

Ratio of branching fraction $\dfrac{BR(B^{\pm} \to DK^{\pm})}{BR(B^{\pm} \to D\pi^{\pm})}$

$$R^{K/\pi}_{K_s^0\pi\pi} = (12.0^{+6.0}_{-5.0} \pm 1.0)\%$$