Experimental Status and Perspectives of Flavour Physics

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INFN-Bologna

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Before the start

The current experimental status in flavour physics is quite hard to cover in 35 minutes.
More than 100 different measurements in the last year!

Some of important results not included into the current presentation may be found in the backup slides.

Some history:

CP violation originally observed in the kaon system in the1960s, but ~40 years passed without new discoveries of *CP* violation in other systems.

Till 2001, when newly constructed B-factories, BaBar and Belle, have discovered the *CP* violation in the *B* system.

CP violation closely connected with the CKM matrix, originally proposed by Nicola Cabibbo in 1963 and later extended by Kobayashi and Maskawa in 1973.

N. Cabibbo, Phys. Rev. Lett. 10 (1963) 531
M. Kabayashi, T Maskawa Prog.Theor.Phys. 49 (1973) 652

In 2008 Kobayashi and Maskawa were awarded Nobel prize (with Y. Nambu).

In the mass basis the Lagrangian for the weak gauge interaction is:

$$L_W = \frac{g}{3}\bar{q}'_{Li}\gamma^{\mu}(V_L^{q'}V_L^{q+})q_{Lj}W_{\mu}^{a} + \text{h.c.}$$

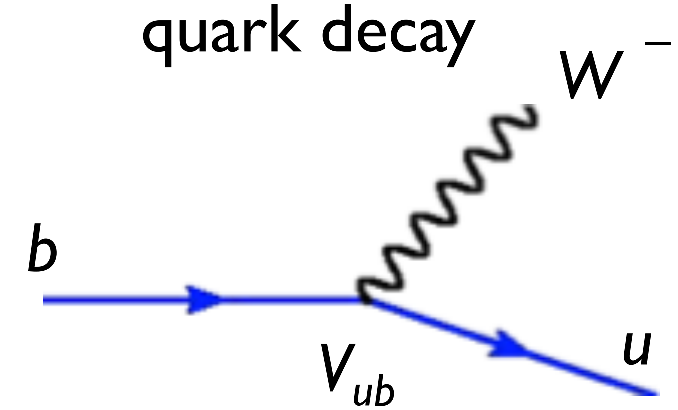
where: $q_{Lj} = (V_L^q)_{ji}\, q_{L_i}^{Int.}$

$$V_{\text{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

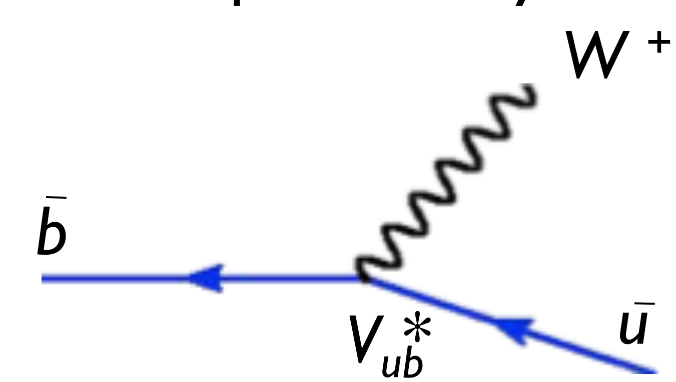
The V_{CKM} must be unitary

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

quark decay



anti-quark decay



CP violation can be explained by only one complex phase. Amplitude interference is different for quark vs anti-quark decay.

In the mass basis the Lagrangian for the weak gauge interaction is:

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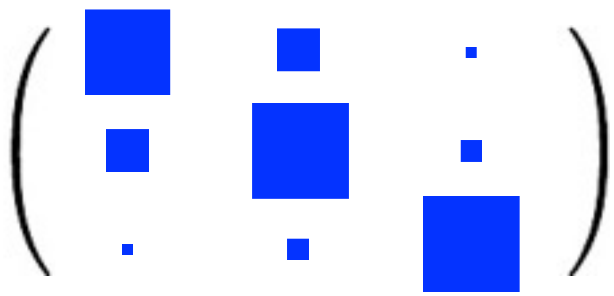
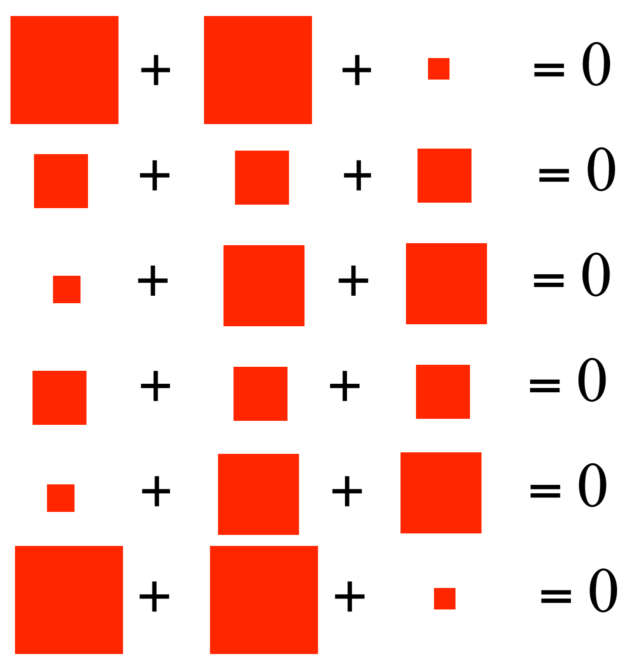
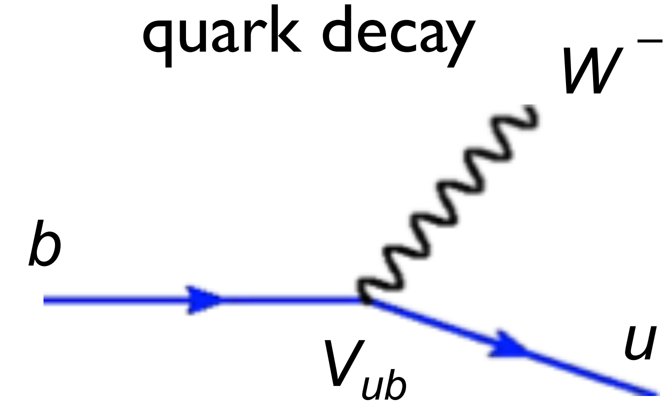
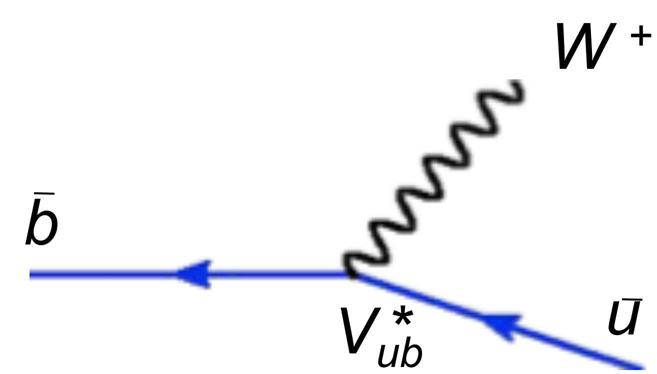
$V_{\text{CKM}} =$ 

The V_{CKM} must be unitary



quark decay





CP violation can be explained by only one complex phase. Amplitude interference is different for quark vs anti-quark decay.

L. Wolfenstein, Phys. Rev. Lett. 51 (1983) 1945

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ \lambda & 1-\lambda^2 2 & A\lambda^2 \\ \lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

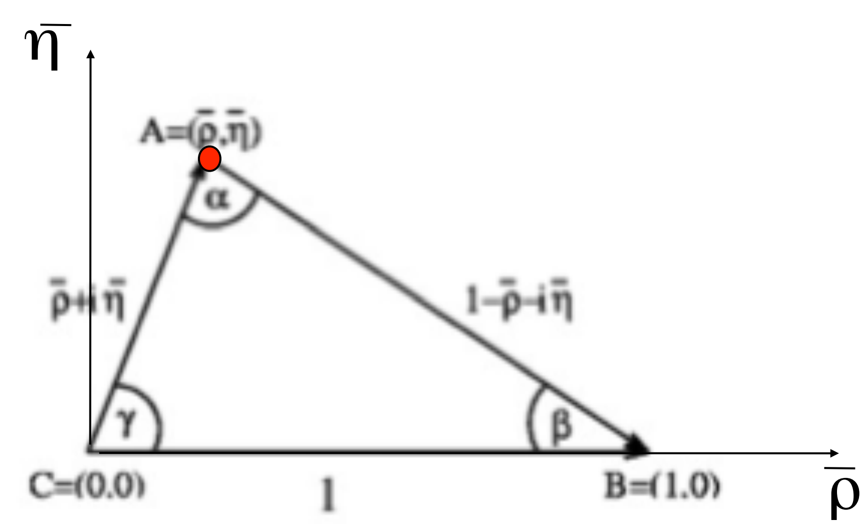
Wolfenstein parameterization

$\lambda \sim 0.22$	$A \sim 0.8$
$\rho \sim 0.16$	$\eta \sim 0.34$

The most representative triangle is constructed from this equation:

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

Different measurements can be used to constrain the vertex of the triangle.



Experimental Setups

proton-(anti)proton colliders:

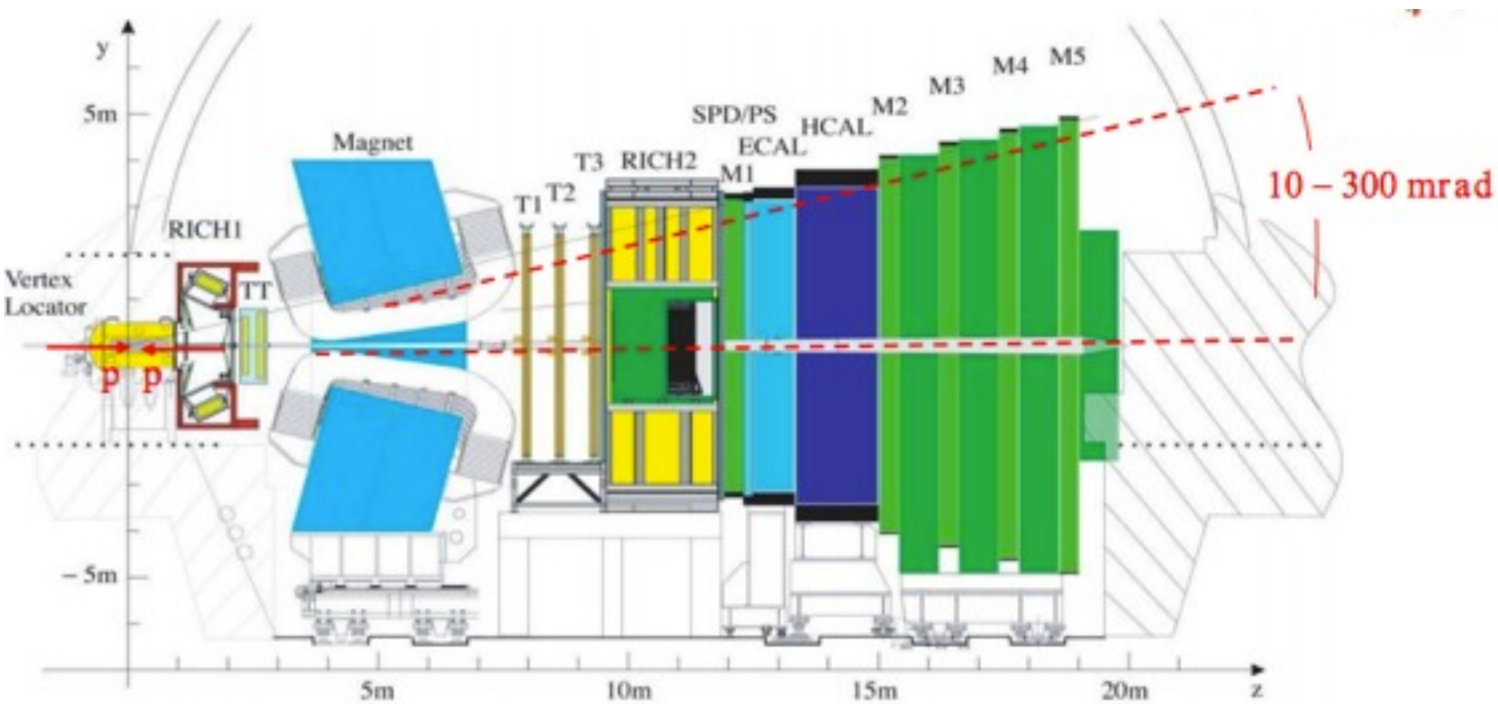
- high statistics;
- better access to B_s and B_c mesons;
- high backgrounds (trigger tuning needed);
- bad access to neutrals

General purpose experiments:

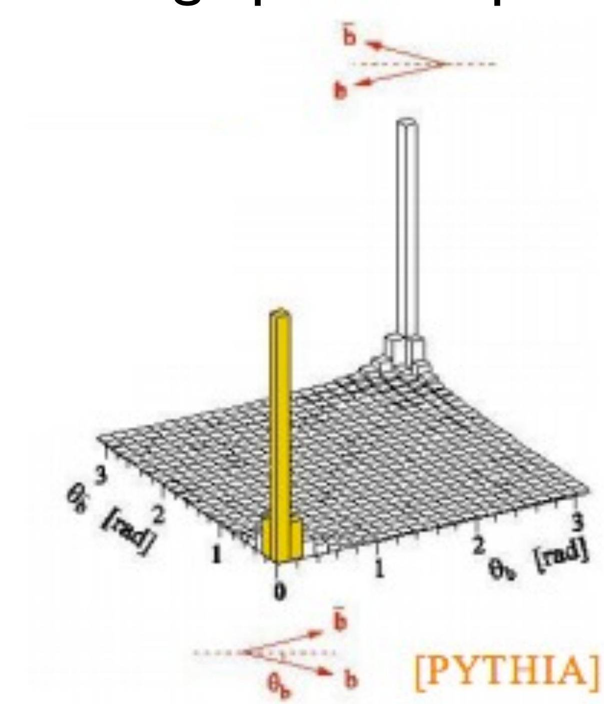
LHC:

Tevatron:

Dedicated experiment:



bb pairs are mostly produced in the region with high pseudorapidities



Experimental Setups

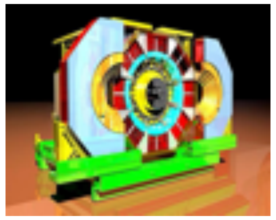
electron-positron beam colliders:

- smaller amount of background;
- better flavour tagging;
- known amount of collision energy;
- small statistics;
- Bc mesons are almost not accessible;

B-factories:

BaBar Belle

Charm-factories:



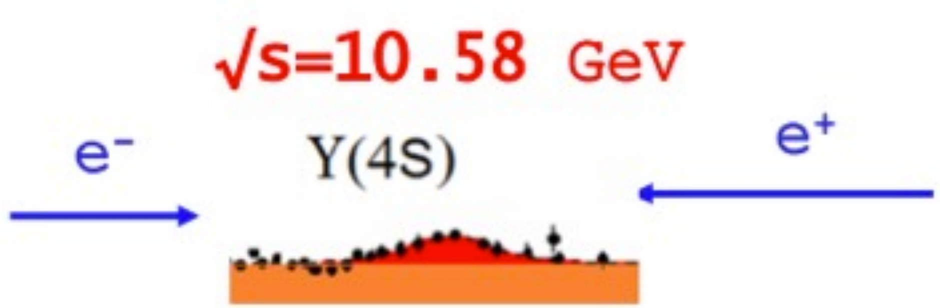
CLEO BES III

K-physics experiment

KLOE

Dedicated Kaon beam:

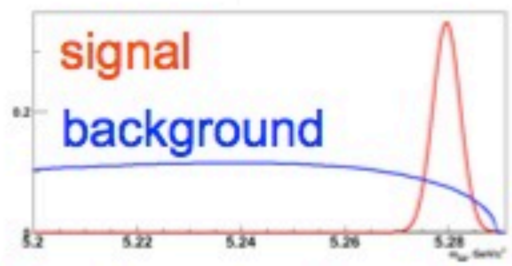
The boost helps to perform the time-dependent analysis and perform better particle identification (PID).



BaBar	$9\ \mathrm{GeV}/c^2$	$3.1\ \mathrm{GeV}/c^2$
Belle	$8\ \mathrm{Gev}/c^2$	$3.5\ \mathrm{Gev}/c^2$

Energy substituted mass

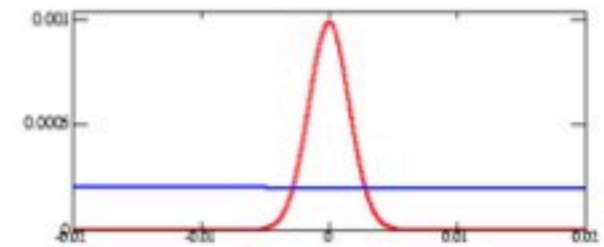
$$m_{ES} = \sqrt{E^2_{\mathrm{beam}} - p^2_B}$$



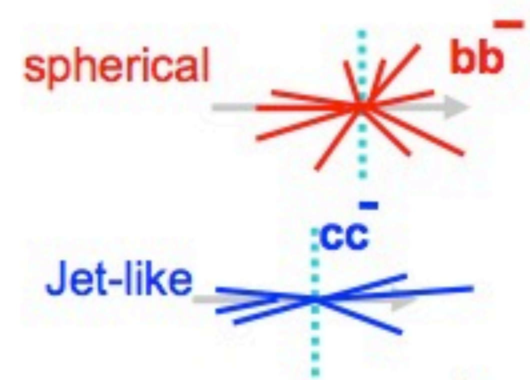
Typical experimental resolution ~2.6 MeV/c²

Beam-energy difference

$$\Delta E = E_B - E_{\mathrm{beam}}$$



Typical experimental resolution [15-20] MeV



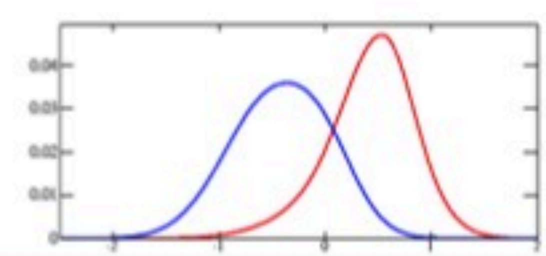
event shape moments

angles of thrust axes

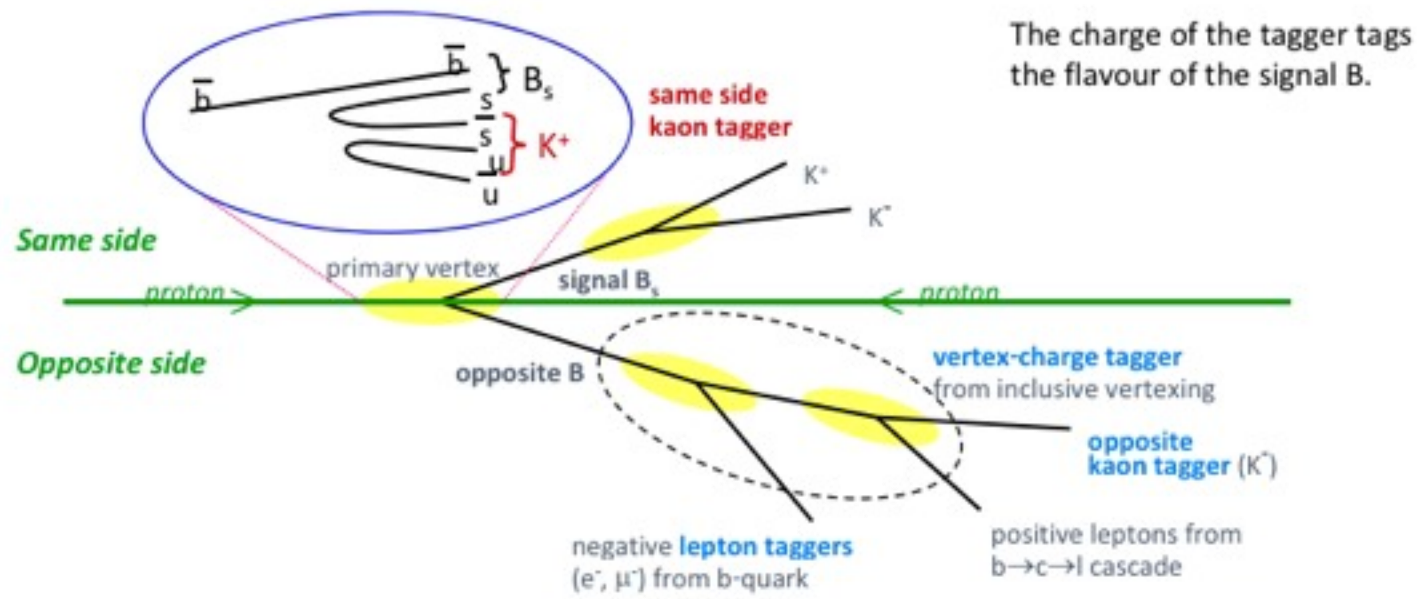
proper time interval

non-signal B variables

Information is usually combined into Fisher discriminant or Neural Net



LHCb Tagging



Tagging can be same side and opposite side.

opposite side taggers:
Exploit the decay products of the other b hadron: lepton (e or μ); kaon; overall charge of secondary vertex.

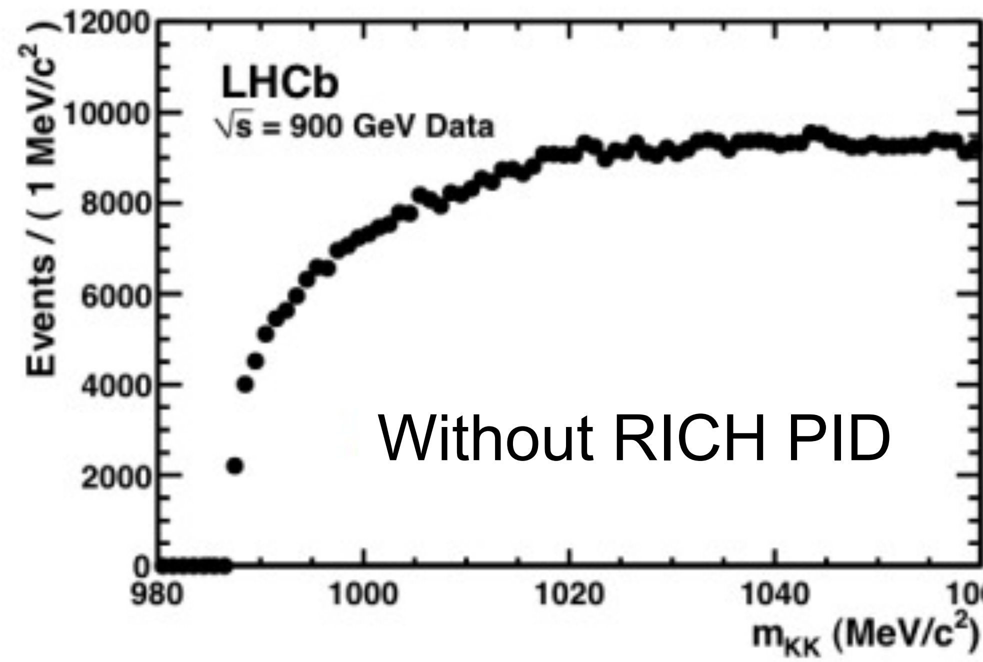
same side taggers:
π (for B_d or B_u) or K (for B_s) produced at the fragmentation process of the signal *B* (only at hadron machines)

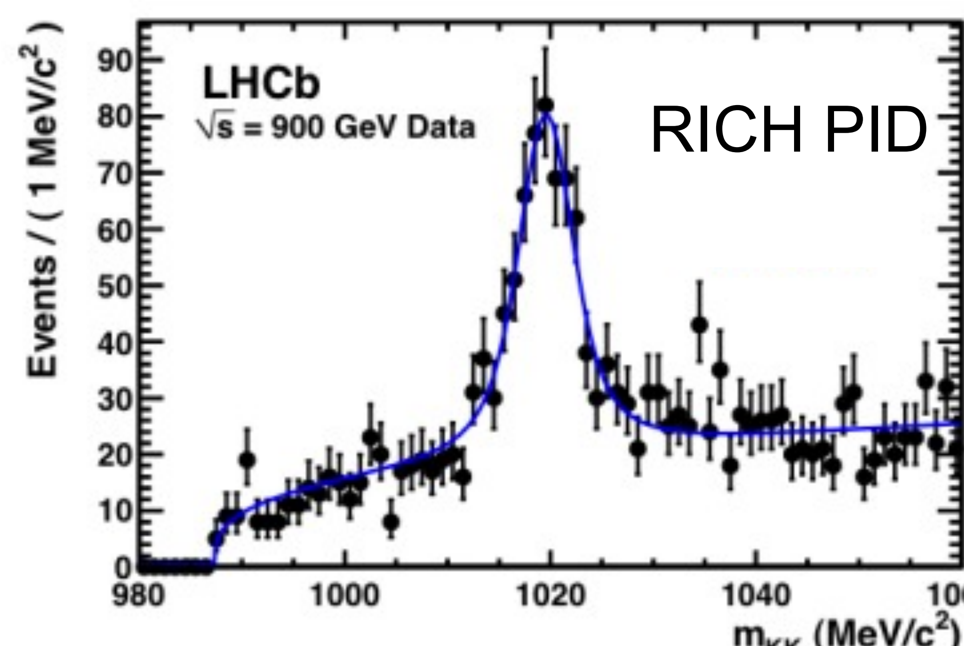
Eur. Phys. J. 72 (2012), 2022.

Also can be performed for the *D* mesons

LHCb PID

Allows strong suppression of combinatorial background





arXiv:1211.6759

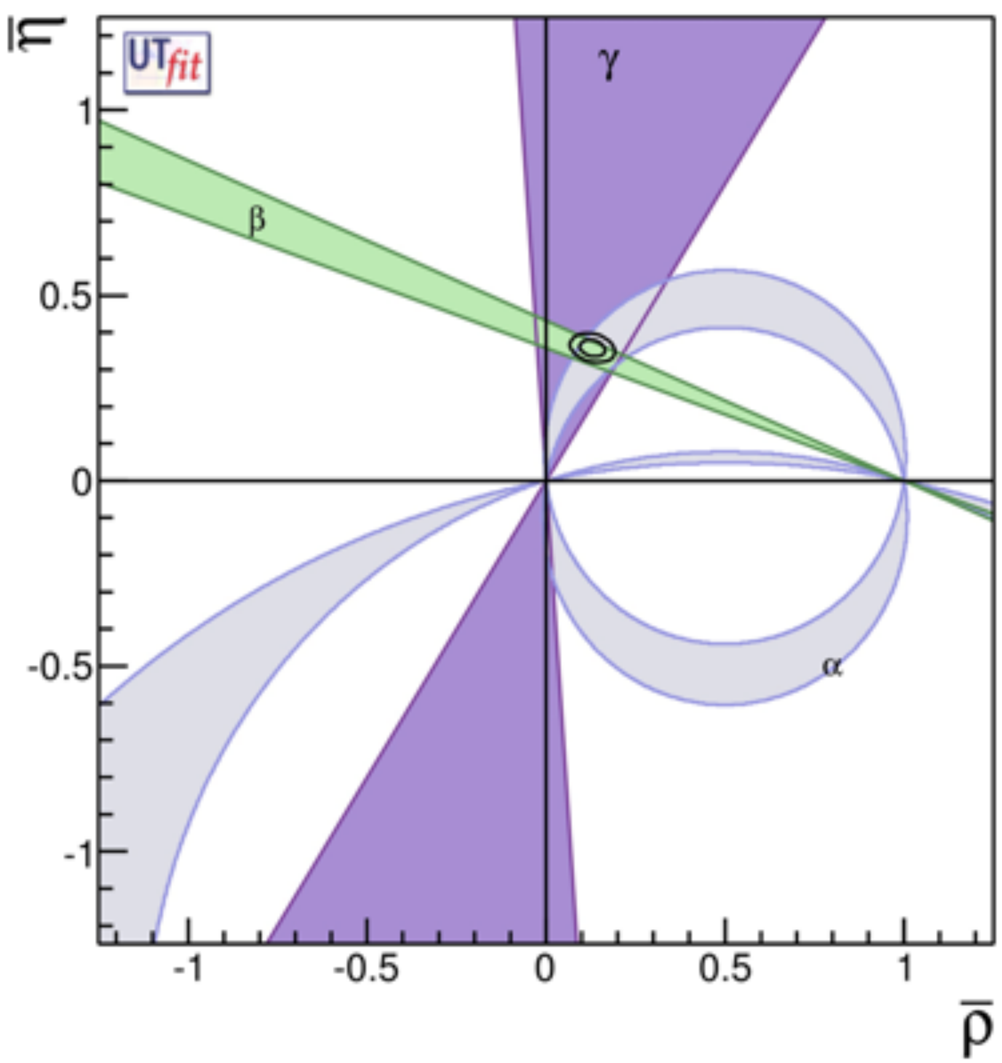
Angles

Angles measurements bring the basic and most evident information about the triangle.
In the selected triangle we have the following angles:

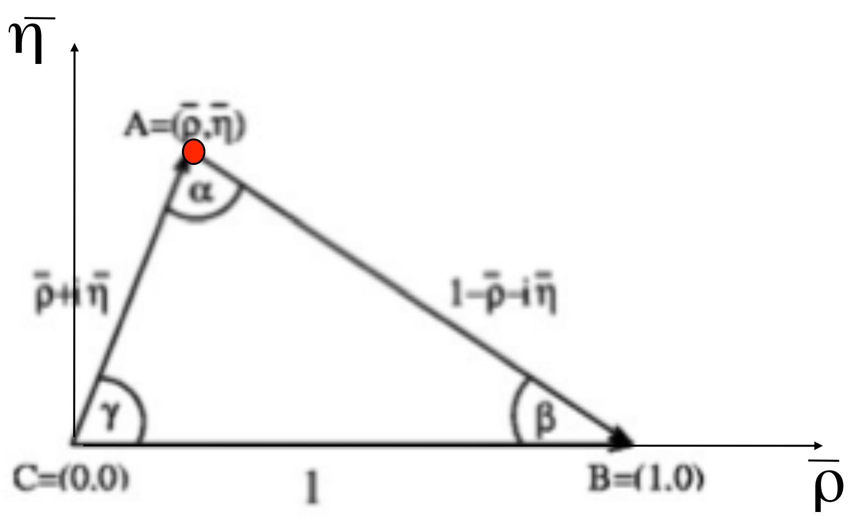
$$\alpha \equiv \varphi_2 \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

$$\beta \equiv \varphi_1 \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

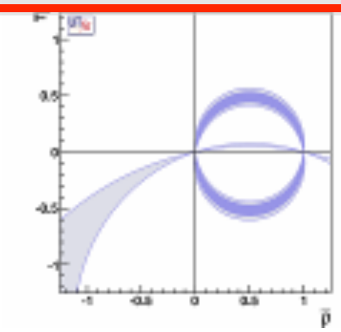
$$\gamma \equiv \varphi_3 \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$



Constraints (angles)

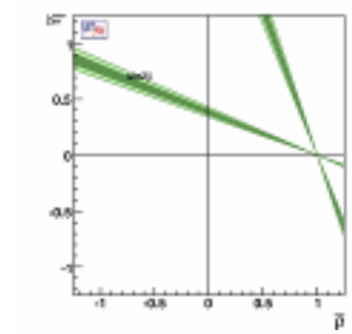


α



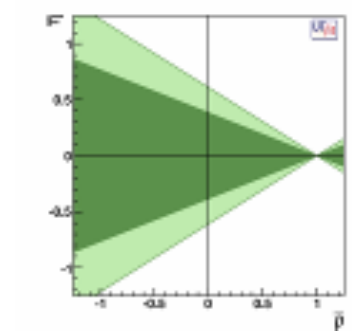
$B \to \pi\pi$, $B \to \rho\rho$, $B \to \rho\pi$

$\sin(2\beta)$



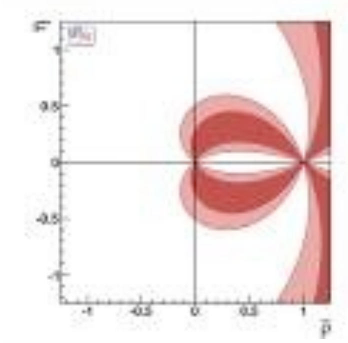
$B \to J/\Psi K$

$\cos(2\beta)$



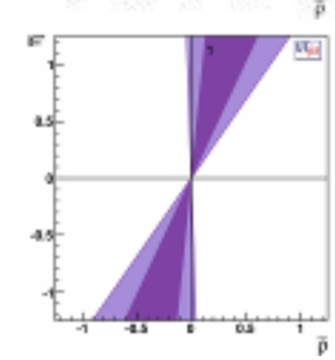
$B \to DK$, $B \to D\pi$

$2\beta+\gamma$

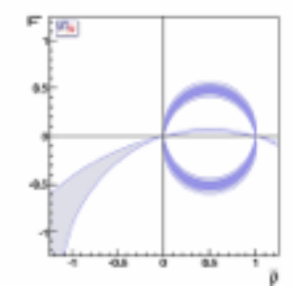


$B \to DK$, $B \to D\pi$

γ

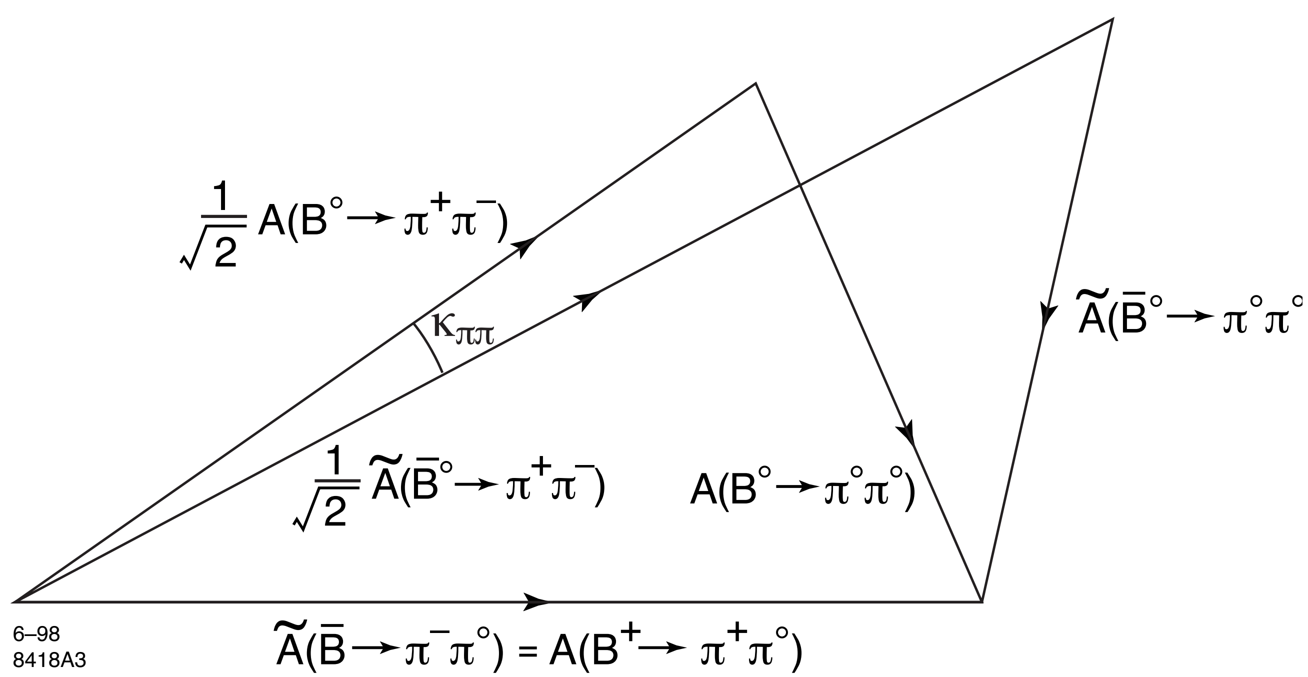


$B \to DK$, $B \to D\pi$



Alpha from B→ππ

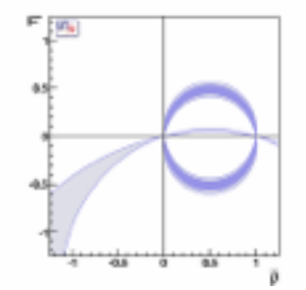
B→$\pi^+\pi^-$, B→$\pi^0\pi^0$, B→$\pi^+\pi^0$ decays are connected from isospin relations. ππ states can have I = 2 or I = 0
the gluonic penguins contribute only to the I = 0 state (ΔI=1/2)
$\pi^+\pi^0$ is a pure I = 2 state (ΔI = 3/2) and it gets contribution only from the tree diagram
triangular relations allow for the determination of the phase difference induced on α



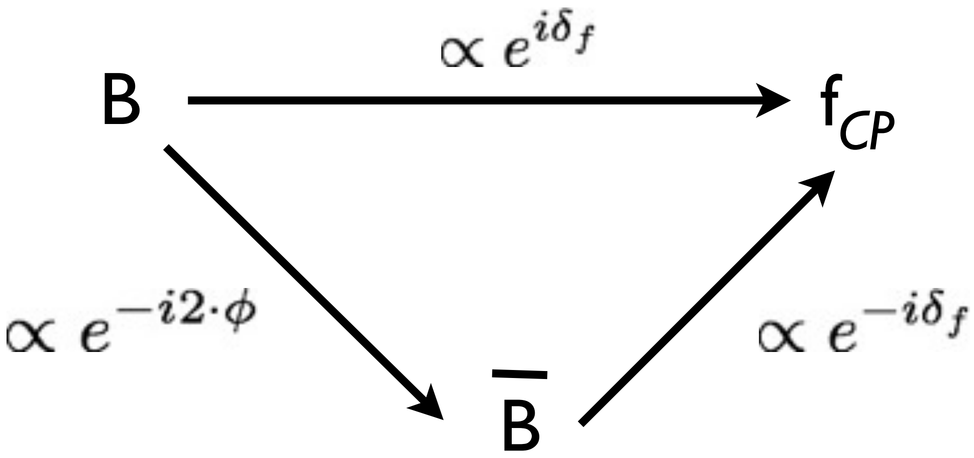
$$
\begin{aligned}
A^{+-} &= -Te^{-i\alpha} + Pe^{i\delta_P} \\
A^{+0} &= -\frac{1}{\sqrt{2}}\left[e^{-i\alpha}(T + T_c\, e^{i\delta_{T_c}})\right] \\
A^{00} &= -\frac{1}{\sqrt{2}}\left[e^{-i\alpha}T_c\, e^{i\delta_{T_c}} + P\, e^{i\delta_P}\right],
\end{aligned}
$$

We can construct the observables, like *CP* asymmetries and branching fractions from amplitudes and solve the equation on α

 M. Gronau and D. London, Phys. Rev. Lett. 65 (1990) 3381

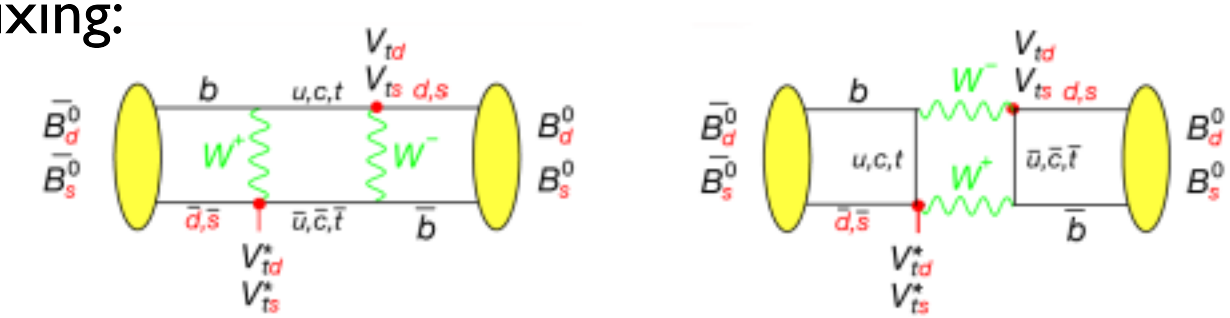


$B_d \rightarrow \pi^+\pi^-$

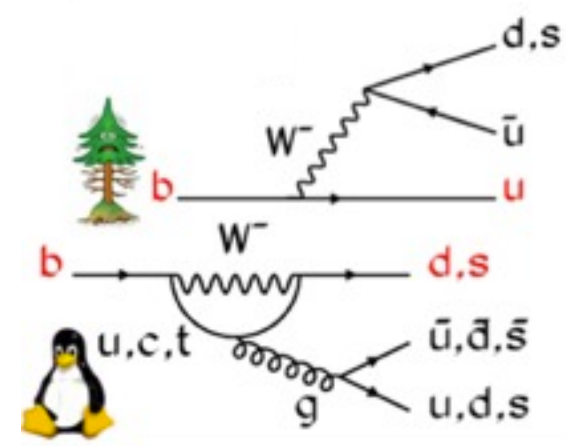


Two diagrams types are involved:

Mixing:



Decay:



The time-dependent asymmetry is defined as:

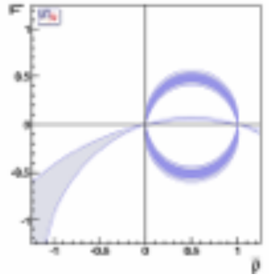
$$A_{CP}(t) = \frac{\Gamma(\bar{B} \rightarrow f_{CP}) - \Gamma(B \rightarrow f_{CP})}{\Gamma(\bar{B} \rightarrow f_{CP}) + \Gamma(B \rightarrow f_{CP})}$$

For the B_d mesons:

$\mathcal{A}_{CP}(\Delta t) \propto \mathcal{S}_{CP} \sin(\Delta m_d \Delta t) - \mathcal{C}_{CP} \cos(\Delta m_d \Delta t)$, Δm is a mass difference between B mass eigenstates

With:

$$\mathcal{S}_{CP} = \frac{\mathrm{Im}(A^{+-}\bar{A}^{+-*})}{|A^{+-}|^2 + |\bar{A}^{+-}|^2} \qquad \mathcal{C}_{CP} = \frac{|A^{+-}|^2 - |\bar{A}^{+-}|^2}{|A^{+-}|^2 + |\bar{A}^{+-}|^2}$$



Belle have recently performed the update of the $B_d \to \pi^+\pi^-$ analysis to the full data sample.

Simultaneous fit including $B_d \to \pi^+\pi^-$, $K^+\pi^-$, K^+K^-.

N_{sig}~2k

6D fitter: ΔE, $M_{\rm bc}$, $\mathcal{L}^+_{K\pi}$, $\mathcal{L}^-_{K\pi}$, $\mathcal{F}_{s/b}$, and Δt

$\mathcal{L}^{\pm}_{K\pi}$ is a likelihood of the track to K for a π hypothesis

$\mathcal{F}_{s/b}$ is an event shape dependent variable

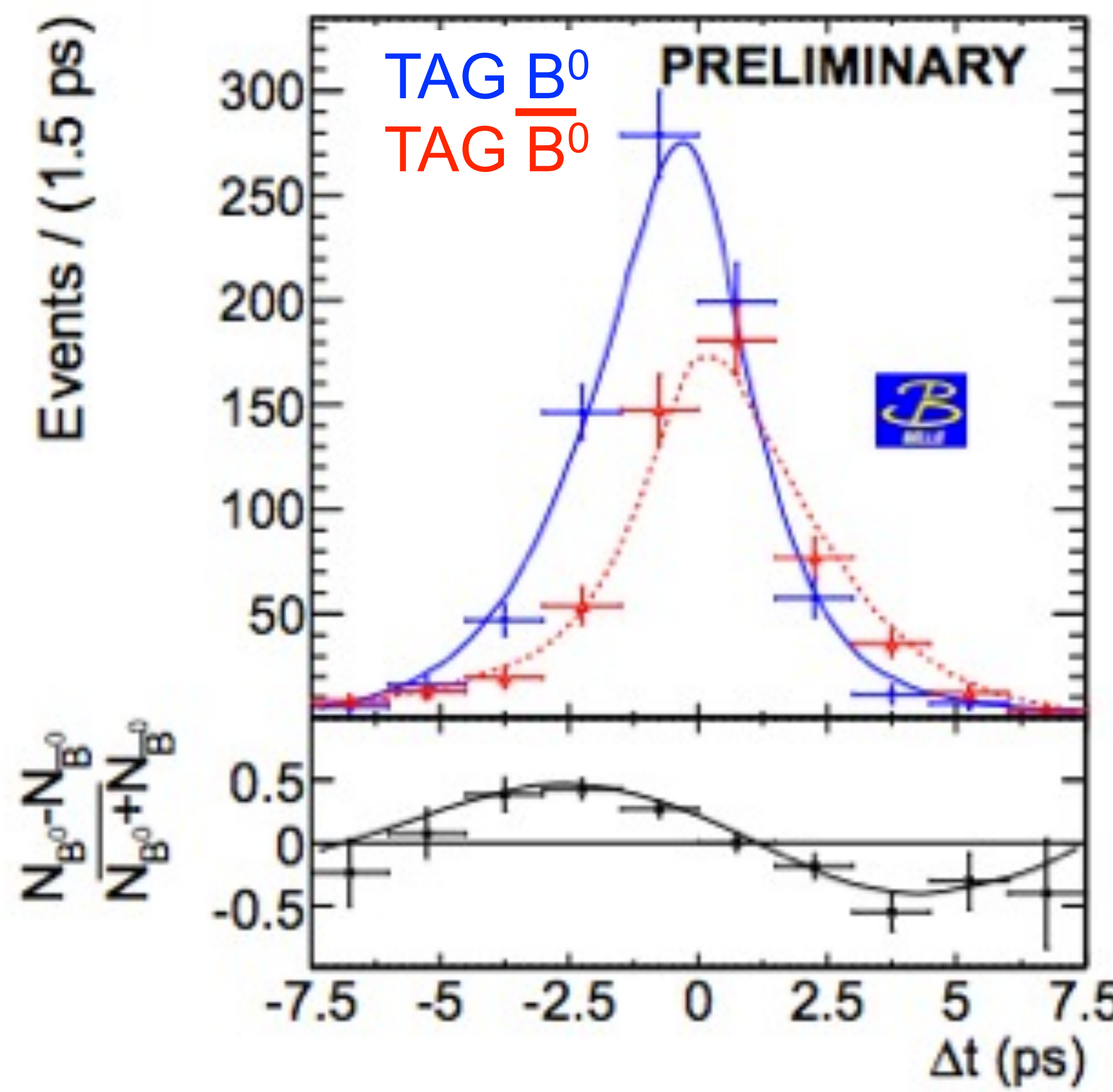
Δt decay time difference between tag B and signal

The fit is performed simultaneously to branching ratios and CP asymmetries:

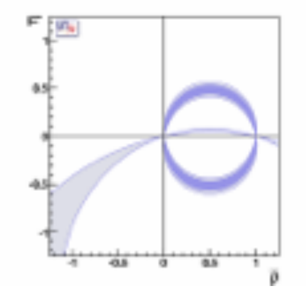
$$\mathcal{A}_{CP}(\Delta t) \propto \mathcal{S}_{CP}\sin(\Delta m_d \Delta t) - \mathcal{C}_{CP}\cos(\Delta m_d \Delta t)$$

$\mathcal{C}_{CP}$ direct *CP* violation

$\mathcal{S}_{CP}$ mixing induced *CP* violation



$$\mathcal{C}_{CP} = -0.328 \pm 0.061 \pm 0.027$$
$$\mathcal{S}_{CP} = -0.636 \pm 0.082 \pm 0.027$$



LHCb $B_d \rightarrow \pi^+\pi^-$ analysis

LHCb-CONF-2012-007

N_{sig}~5.4k events (~60% of 2011 dataset)

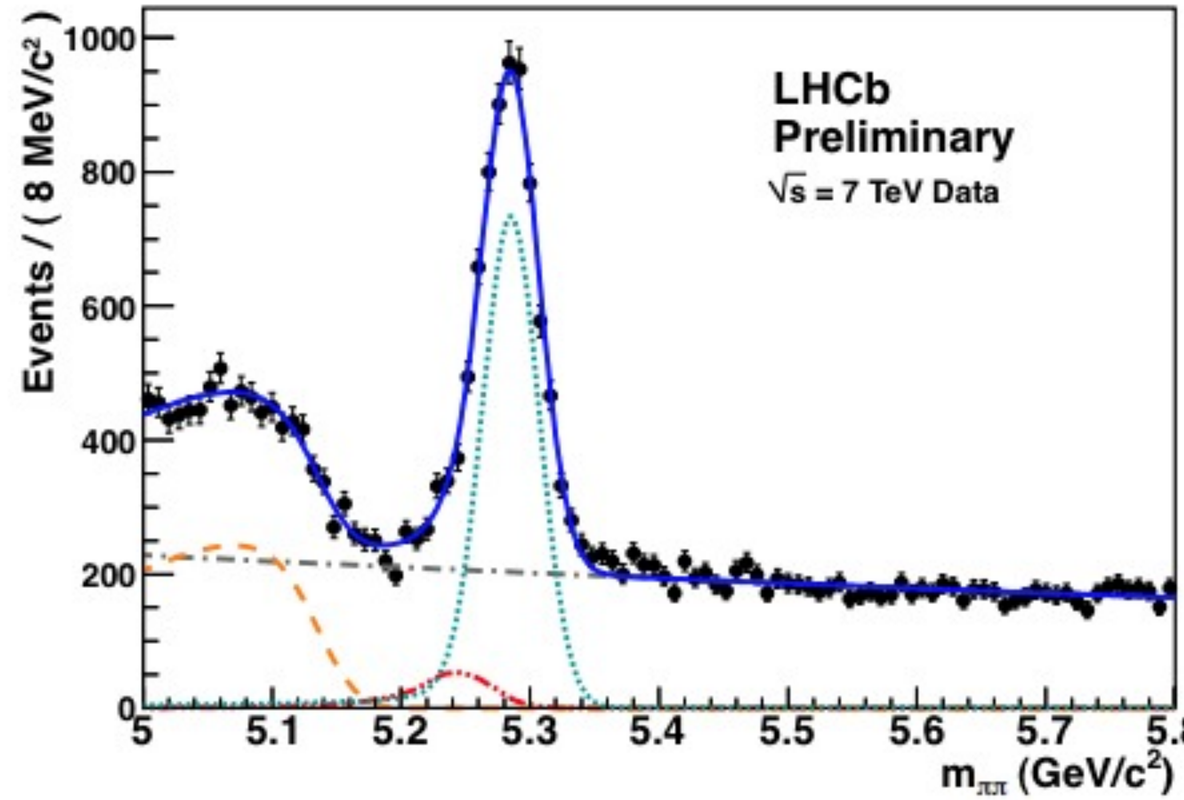
2D ML fit to mass and time

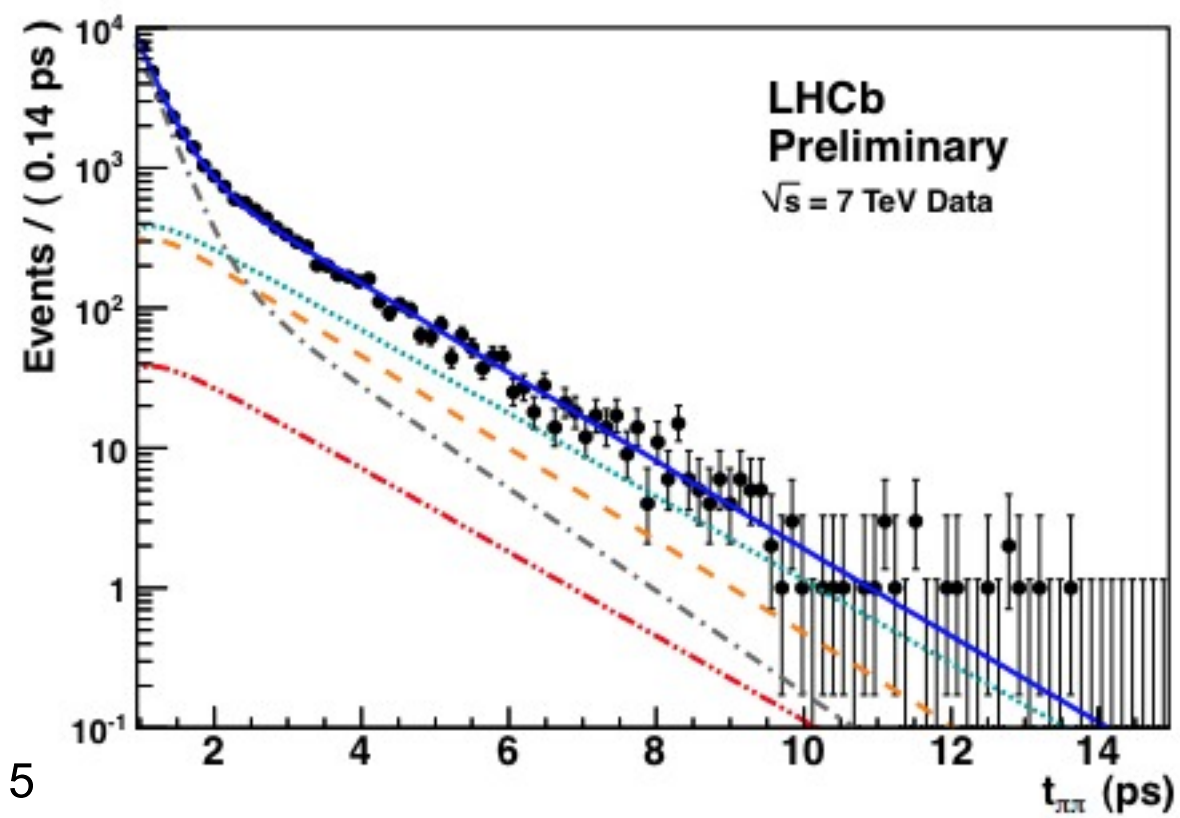
ω_{mistag} likelihood is taken from the $B_d \rightarrow K\pi$ channel

Results:

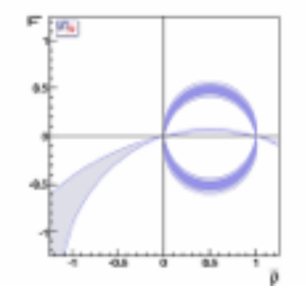
$$\mathcal{C}_{CP} = -0.11 \pm 0.21 \pm 0.03$$
$$\mathcal{A}_{CP} = -0.56 \pm 0.17 \pm 0.03$$
$$\rho\left(C_{CP}, A_{CP}\right) = -0.34$$

The first evidence of mixing induced CP violation at an hadron collider(3.2σ)





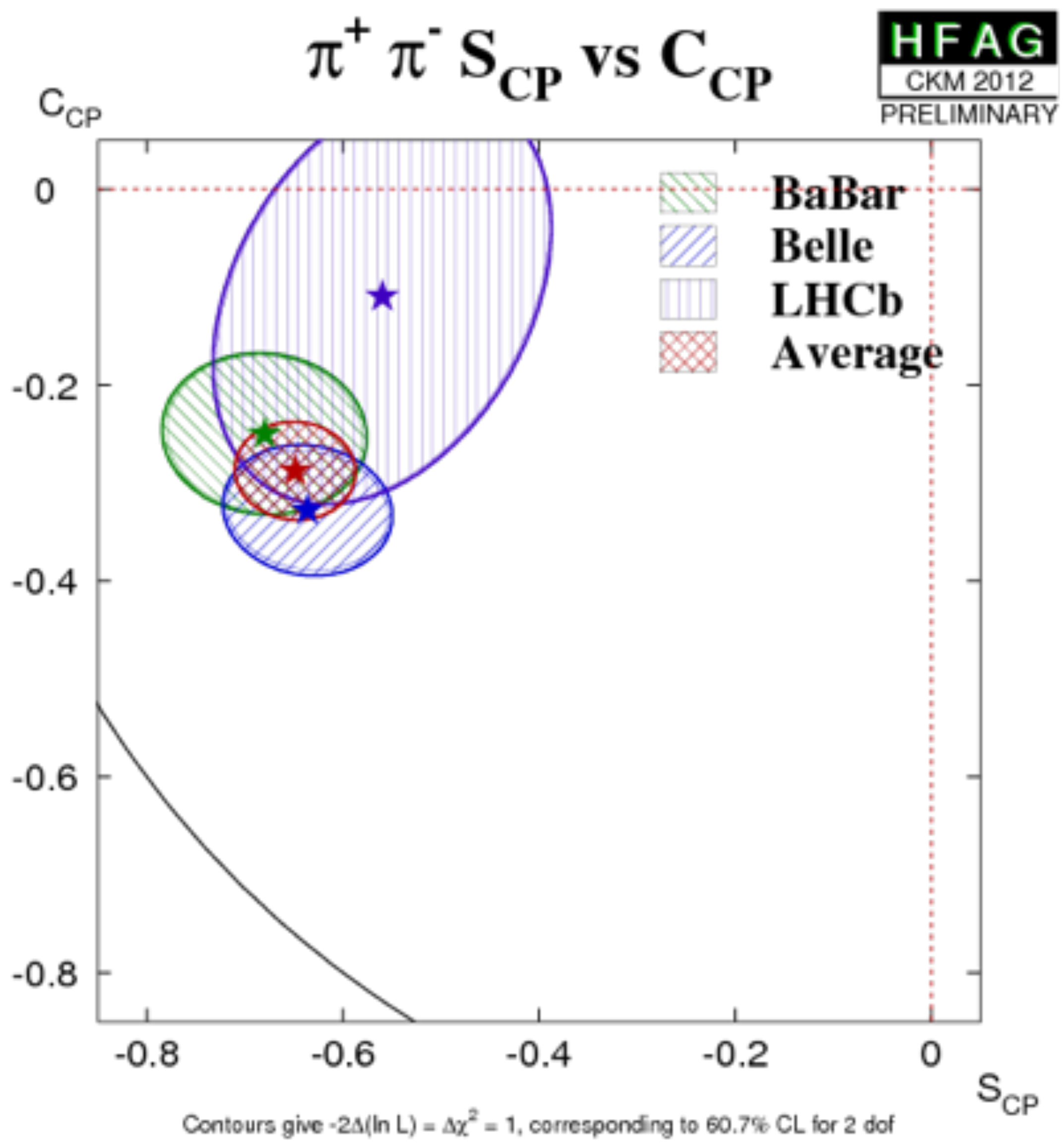
- Full fit
- $B_d \rightarrow \pi\pi$ signal
- $B \rightarrow 3h$ bkg
- $B_d \rightarrow K\pi$ bkg
- comb bkg



Alpha combination

UTFIT

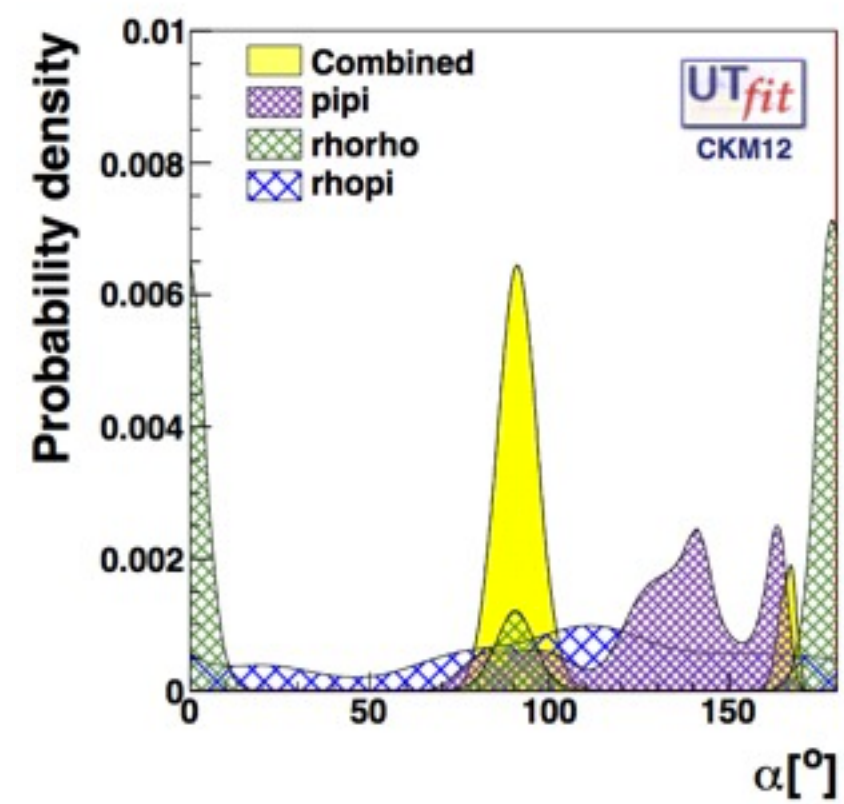
Although LHCb have got higher statistics, the overall tagging efficiency is smaller then in B-factories.



LHCb will be competitive with the B-factories results after ~2012 run.

HFAG

The B→ρπ analysis is a completely different analysis:
The time-dependent Dalitz plot analysis of the decays of the neutral *B* allows one to infer the value of α without any dependence on the hadronic parameter.

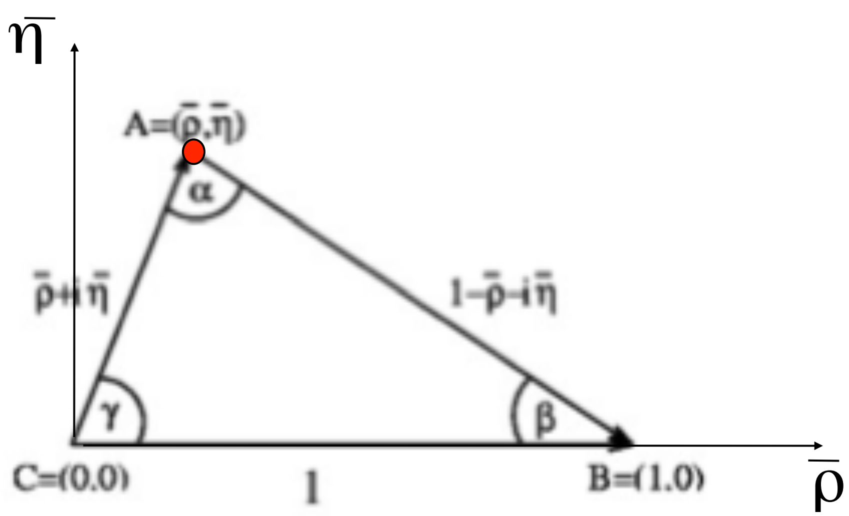


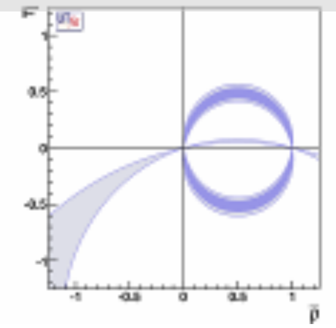
$$\alpha = (90.6 \pm 6.6)^{\circ}$$

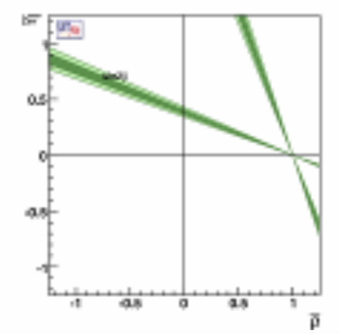
SM prediction: $(87.8 \pm 3.7)^{\circ}$

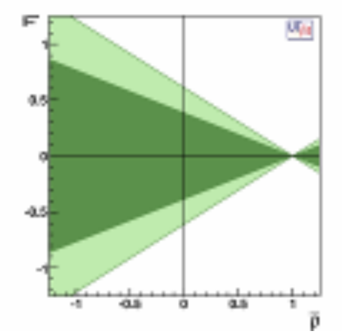
UTFIT

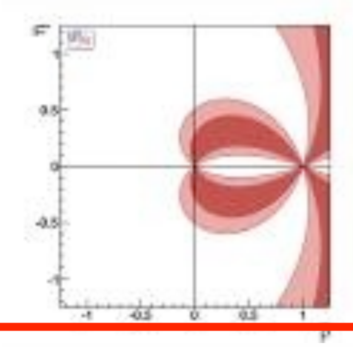
Constraints (angles)

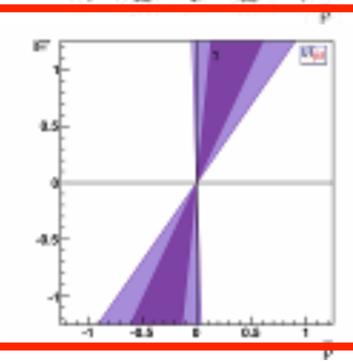


α  B→ππ, B→ρρ, B→ρπ

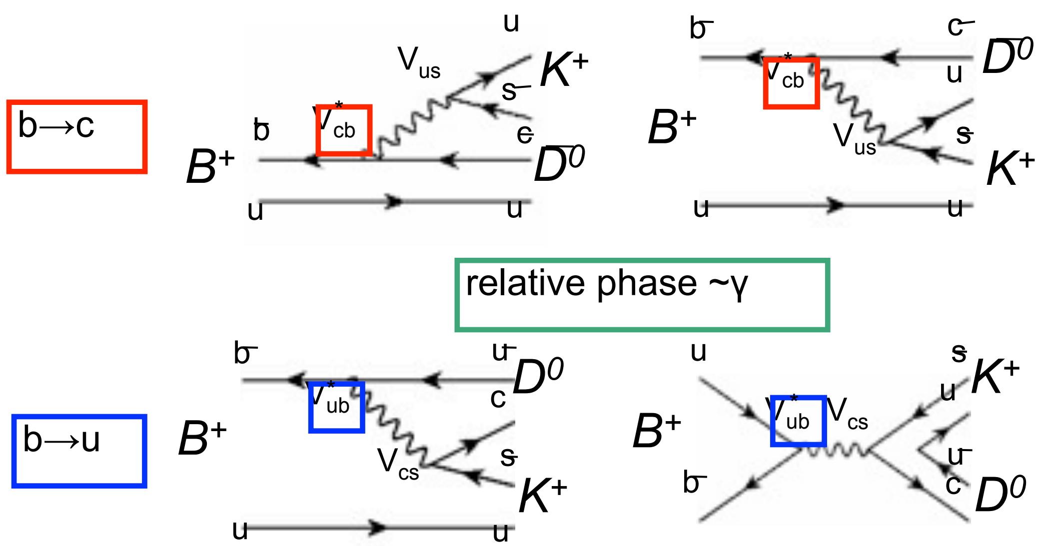
sin(2β)  B→J/ΨK

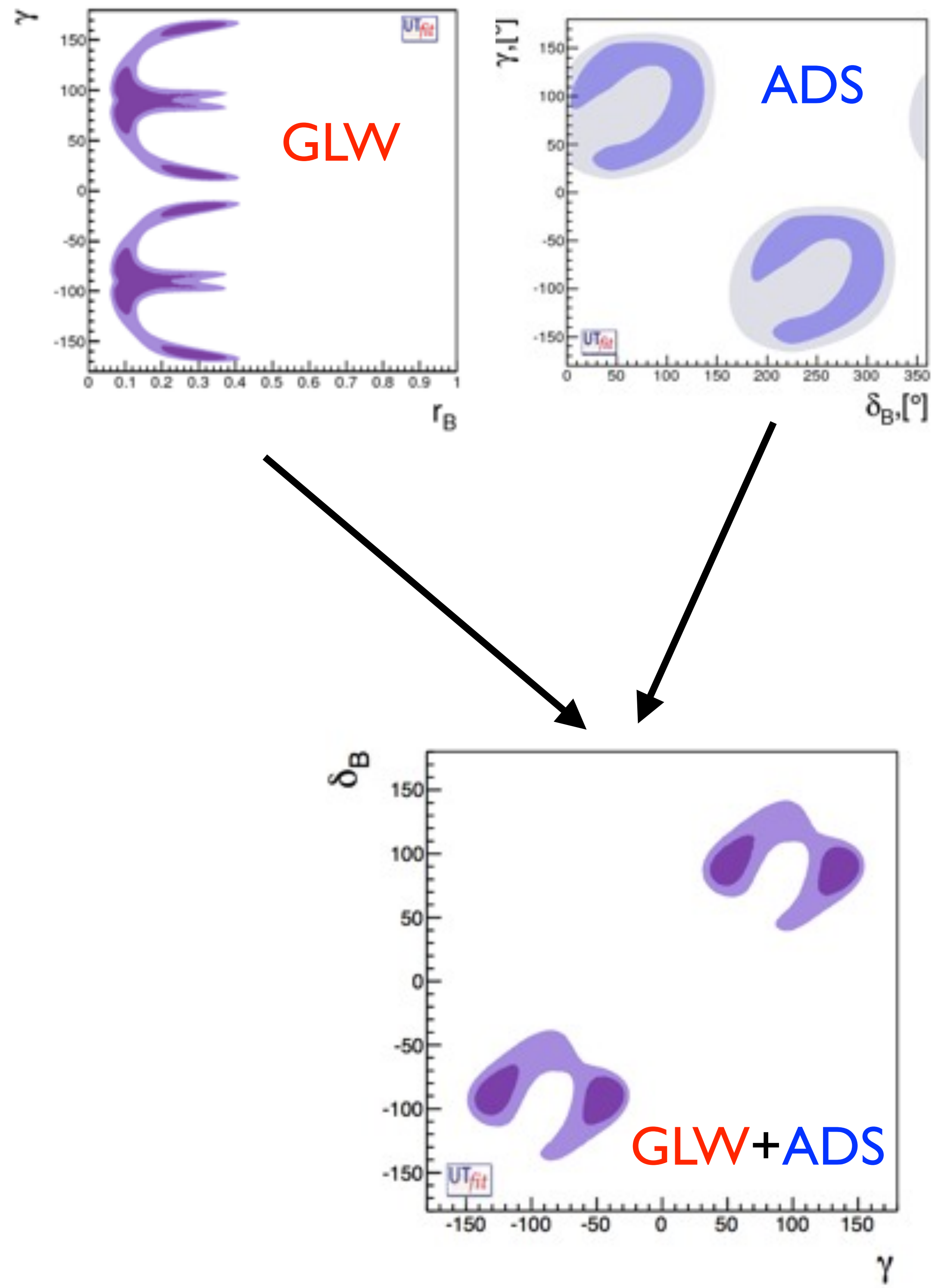
cos(2β)  B→DK, B→Dπ

2β+γ  B→DK, B→Dπ

γ  B→DK, B→Dπ

Gamma methods: Trees





Related variables (depend on the *B* meson decay channel):

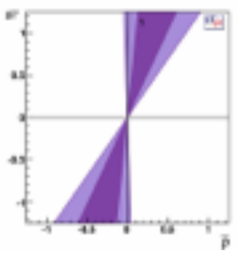
$$r_B = \frac{|A_{b\to u}|}{|A_{b\to c}|} \quad \begin{cases} r_B \sim 0.1 & \text{For charged } B \text{ mesons} \\ r_B \sim 0.3 & \text{For neutral } B \text{ mesons} \end{cases}$$

δ_B strong phase (*CP* conserving)

We currently use the available information coming from the three methods:

- GLW D→CP eigenstate (M. Gronau, D. London, D. Wyler, PLB253,483 (1991); PLB 265, 172 (1991))
- ADS D→Kπ(nπ) (D. Atwood, I. Dunietz and A. Soni, PRL 78, 3357 (1997))
- GGSZ D→$K_S\pi\pi$ (A. Giri, Yu. Grossman, A. Soffer, J. Zupan, PRD 68, 054018(2003))

Same for the decays: $B^+\to D^{(*)}K^{(*)+}$ and $B^0\to DK^{*0}$

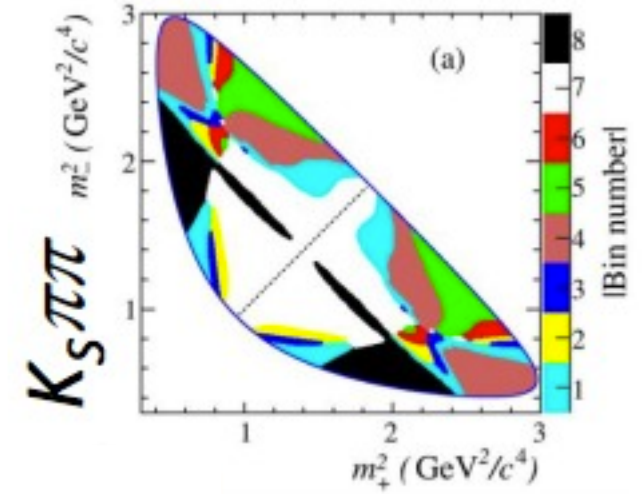


LHCb GGSZ analysis with CLEOc input

A nice example of interplay between different flavour experiments:

- CLEOc has measured the strong phases of *D*→$K_s$hh decays.

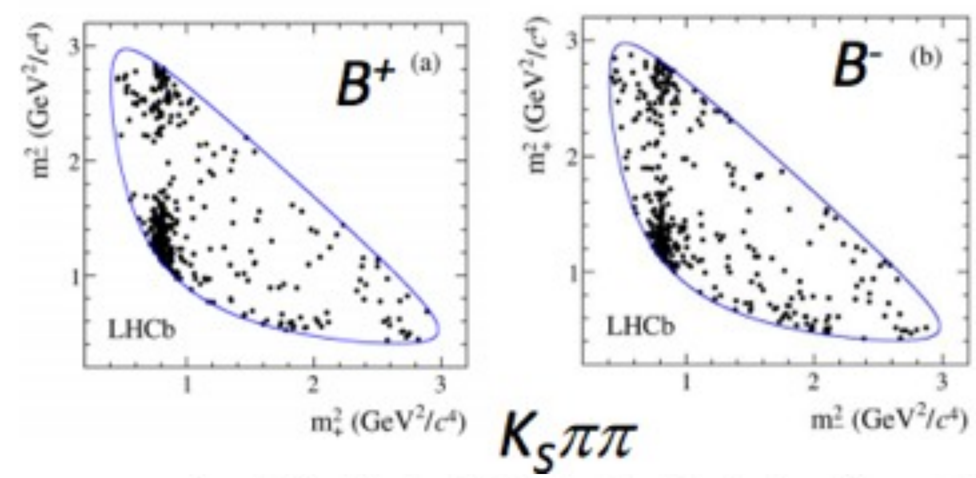
  This can achieved due to the fact that DD pair is produced in the quantum coherent state. Thus, we can extract areas of the Dalitz plain, where the *D*→$K_s\pi\pi$ phase is [almost] constant.



Phys.Rev. D82 (2010) 112006

- Than LHCb implements Dalitz plane binning with similar phases in order to extract the *CP* violating parameters from $B^\pm \to [K_s\pi\pi]_D K^\pm$

$$x_\pm = r_B \cos(\delta_B \pm \gamma)$$
$$y_\pm = r_B \sin(\delta_B \pm \gamma)$$

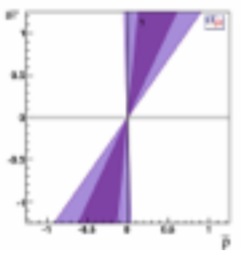


$$x_- = (0.0 \pm 4.3 \pm 1.5 \pm 0.6) \times 10^{-2}$$
$$y_- = (2.7 \pm 5.2 \pm 0.8 \pm 2.3) \times 10^{-2}$$
$$\mathrm{corr}(x_-, y_-) = -0.10$$

$$x_+ = (-10.3 \pm 4.5 \pm 1.8 \pm 1.4) \times 10^{-2}$$
$$y_+ = (-0.9 \pm 3.7 \pm 0.8 \pm 3.0) \times 10^{-2}$$
$$\mathrm{corr}(x_+, y_+) = 0.22$$

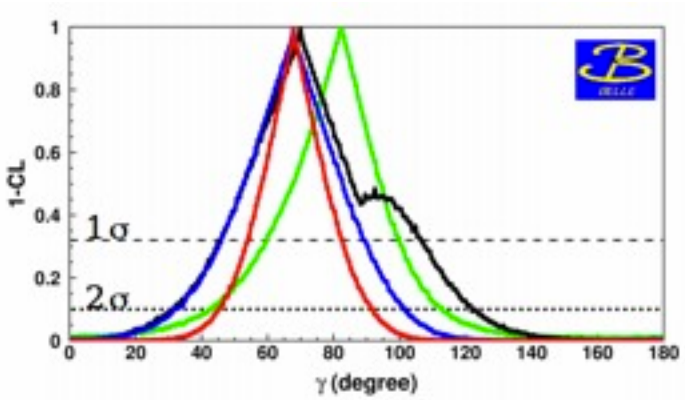
arXiv:1209.5869

The results are consistent with previous measurements by Belle and Babar



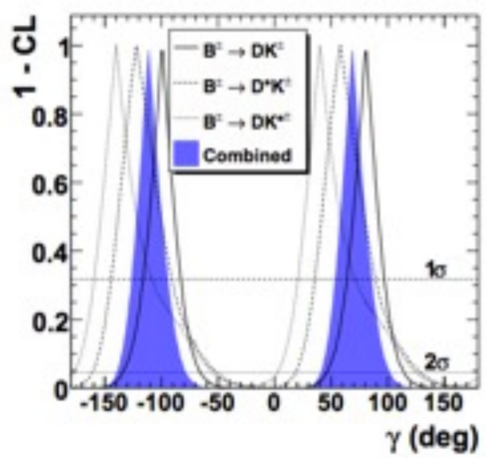
Gamma from Trees status

Analyses were combined within different collaborations:



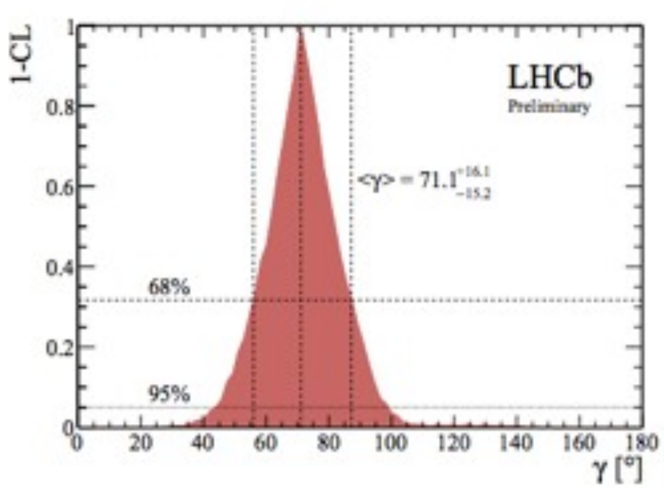
$$\gamma = (68^{+15}_{-14})^\circ$$

CKM2012 preliminary



$$\gamma = (69^{+17}_{-16})^\circ$$

CKM2012 preliminary

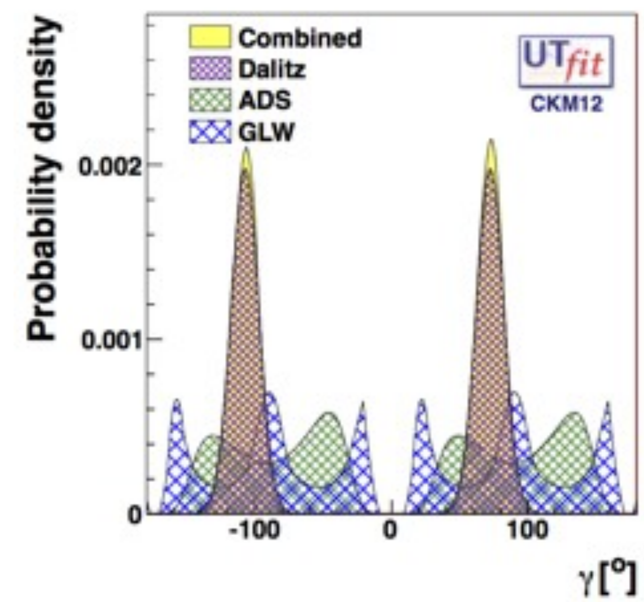


$$\gamma = (71^{+16}_{-15})^\circ$$

LHCb-CONF-2012-032

The agreement is very good

World average (includes also CDF):

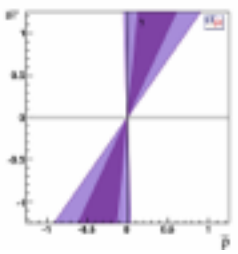


UTFIT gamma average:

γ = (72.3 ±9.3)°

SM gamma prediction:

γ = (68.8 ±3.4)°



LHCb Bs→K^+K^- analysis and implementations

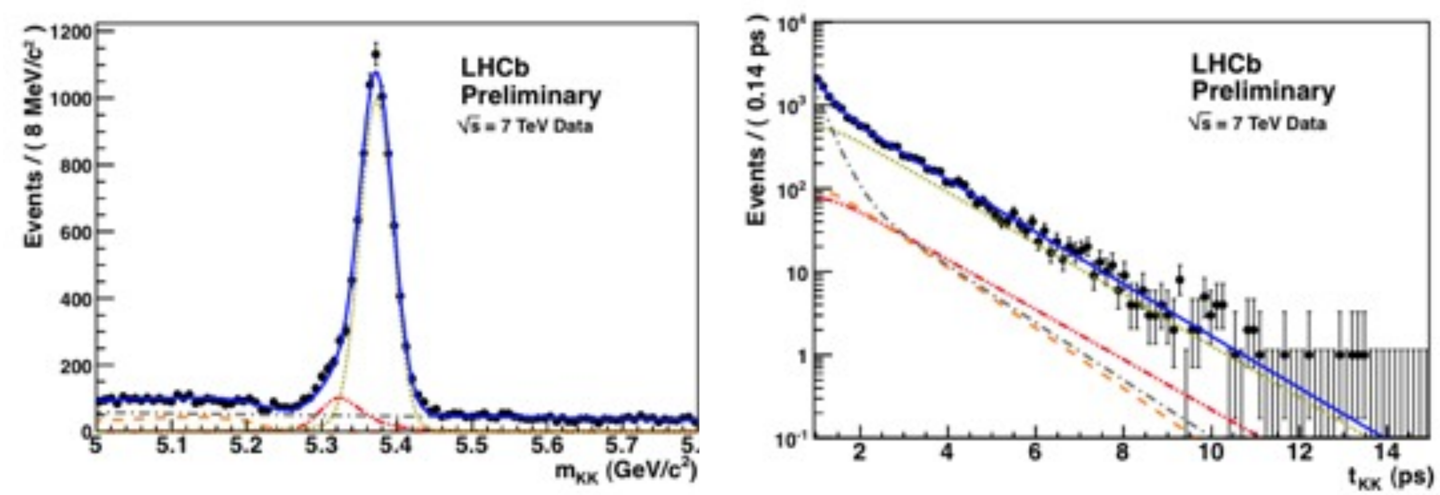
We can also measure gamma from the loops-dominated processes, for example, B→h^+h^-

For this we need an access to the B_s measurements, which can be provided by LHCb:

N_{sig}~7.1k events

Similar analysis to the B_d→$\pi^+\pi^-$modes

$$A^{\rm dir}_{KK} = 0.02 \pm 0.18 \pm 0.04$$
$$A^{\rm mix}_{\pi\pi} = 0.17 \pm 0.18 \pm 0.05$$
$$\rho(A^{\rm dir}_{KK}, A^{\rm mix}_{KK}) = -0.10$$

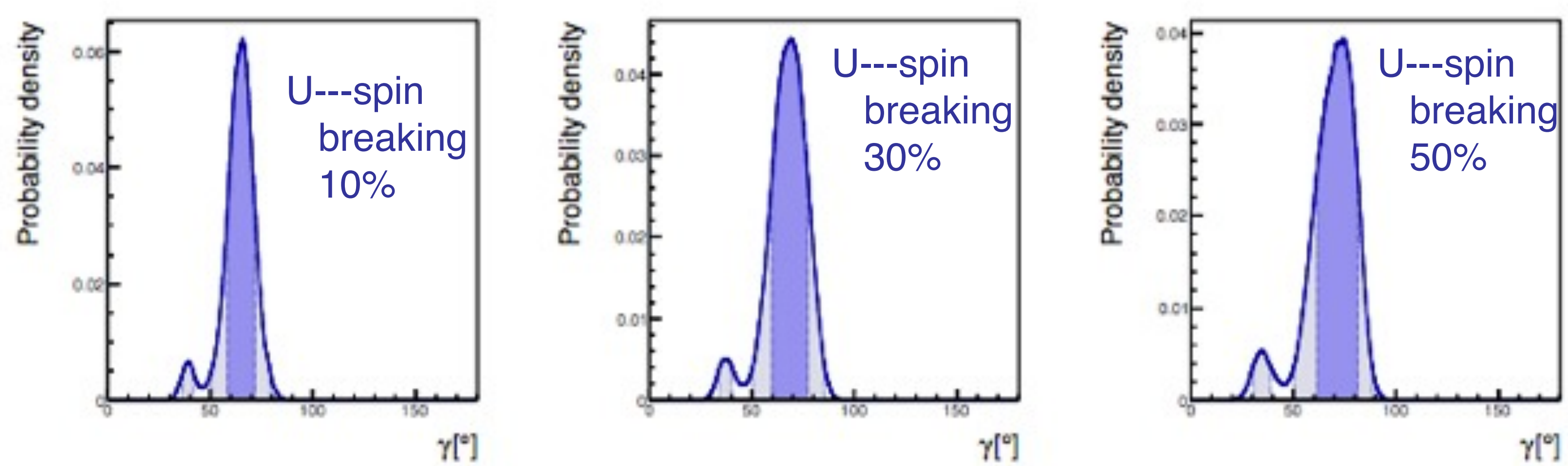


LHCb-CONF-2012-007

This is done simultaneously analyzing B→ππ, B→KK systems (including time-dependent and branching fraction measurements)

Even for the large values of U-spin breaking, we have a good precision.

The precision on Bs→K^+K^- system will improve.

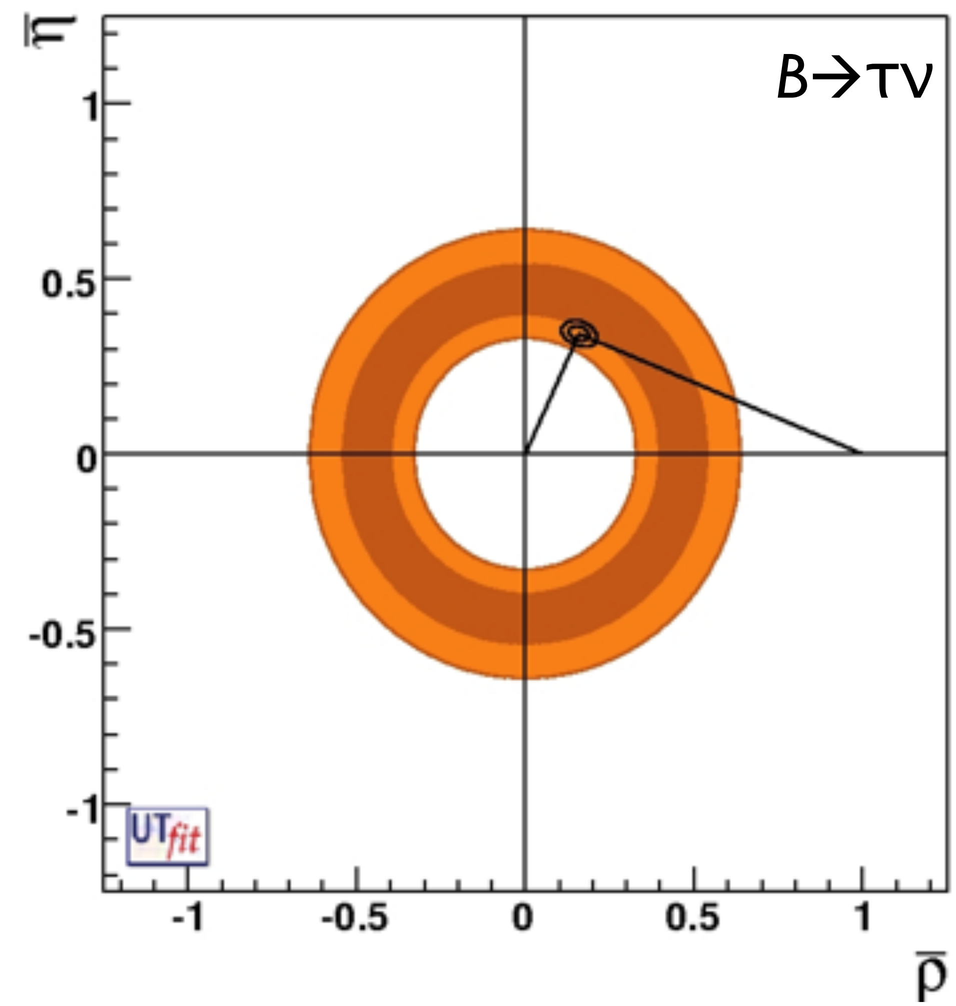


Ciuchini,, Franco ,Mishima, Silvestrini, JHEP 10 (2012) 29

Rare Decays

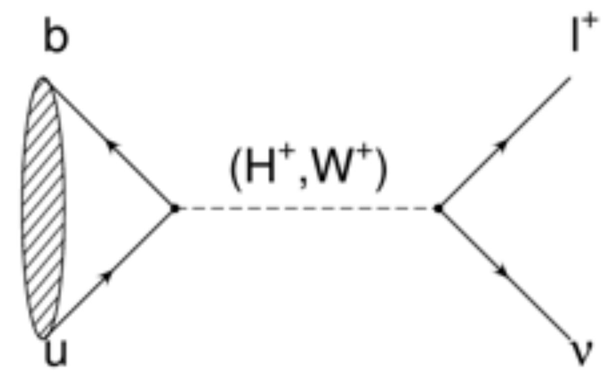
Rare decay search and branching fraction measurement can provide constraints to the {ρ;η} plane, like the one shown in the figure.

Some modes are also interesting per se, as they can give limits to different NP scenarios.



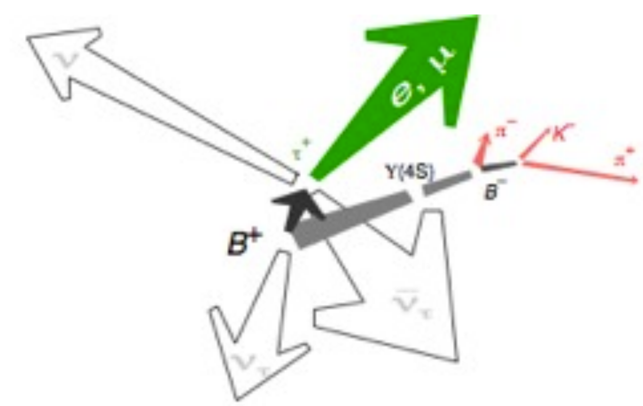
Belle $B \rightarrow \tau\nu$ measurement

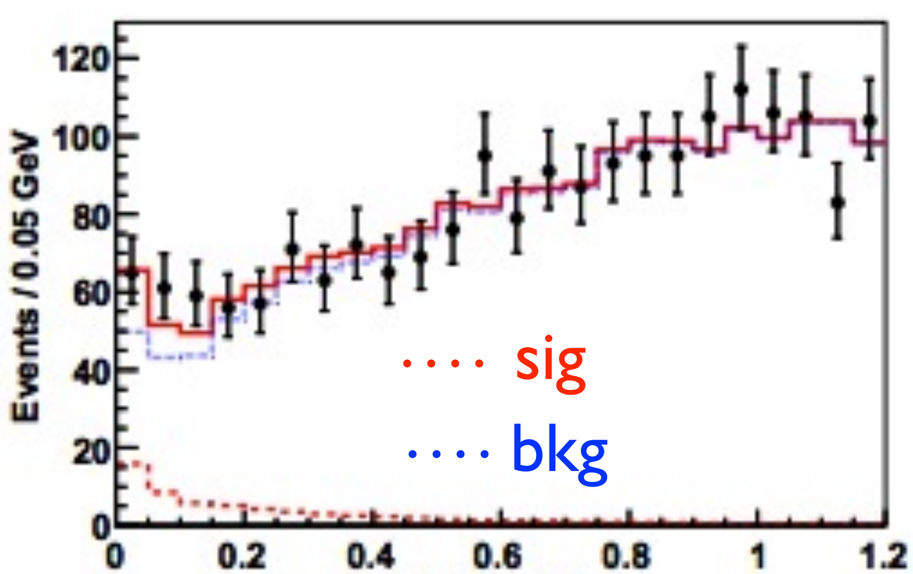
arXiv:1208.4678



Purely leptonic decay, proportional to $f_B^2|V_{ub}|^2$ (in SM) or sensitive to charged Higgs (in type-II 2HDM). Decay constant f_B is known from lattice calculations. In SM B =(0.82±0.08) $\times 10^{-4}$. Until ICHEP 2012 all the results pointed to higher than predicted value

For ICHEP 2012 Belle analyzed full data sample with refined analysis. The analysis uses "hadronic tag": non-signal *B* meson is fully reconstructed into one of the 615 exclusive modes.





Missing Energy (GeV)

Performing the 2D ML fit to missing mass and missing energy, Belle obtains:

$$\mathcal{B}(B \rightarrow \tau\nu) = (0.72^{+0.27}_{-0.25} \pm 0.11) \times 10^{-4}$$

BaBar have confirmed the higher value:

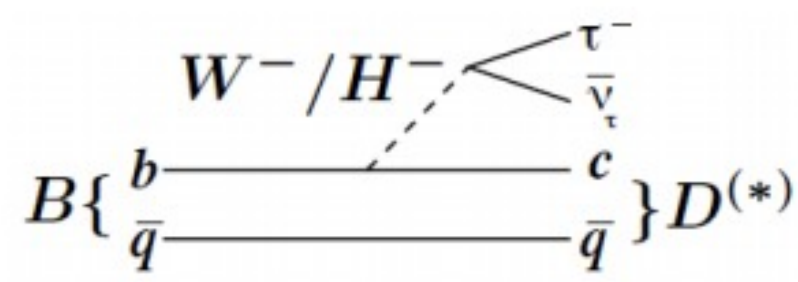
$$\mathcal{B}(B \rightarrow \tau\nu) = (1.83^{+0.53}_{-0.49} \pm 0.24) \times 10^{-4}$$

arxiv:1207.0698

BaBar $B \to D^{(*)}\tau\nu$

Phys.Rev.Lett. 109 (2012) 101802

Another decay, which can be enhanced by 2HDM.



BaBar have performed the measurement of

$$R(D) = \frac{Br(\bar{B} \to D\tau\nu)}{Br(\bar{B} \to D\ell\nu)} \qquad R(D^*) = \frac{Br(\bar{B} \to D^*\tau\nu)}{Br(\bar{B} \to D^*\ell\nu)}$$

using hadronic tags. The SM prediction here is (was):

R(D) = 0.297 ± 0.017 and R(D*) = 0.252 ± 0.003

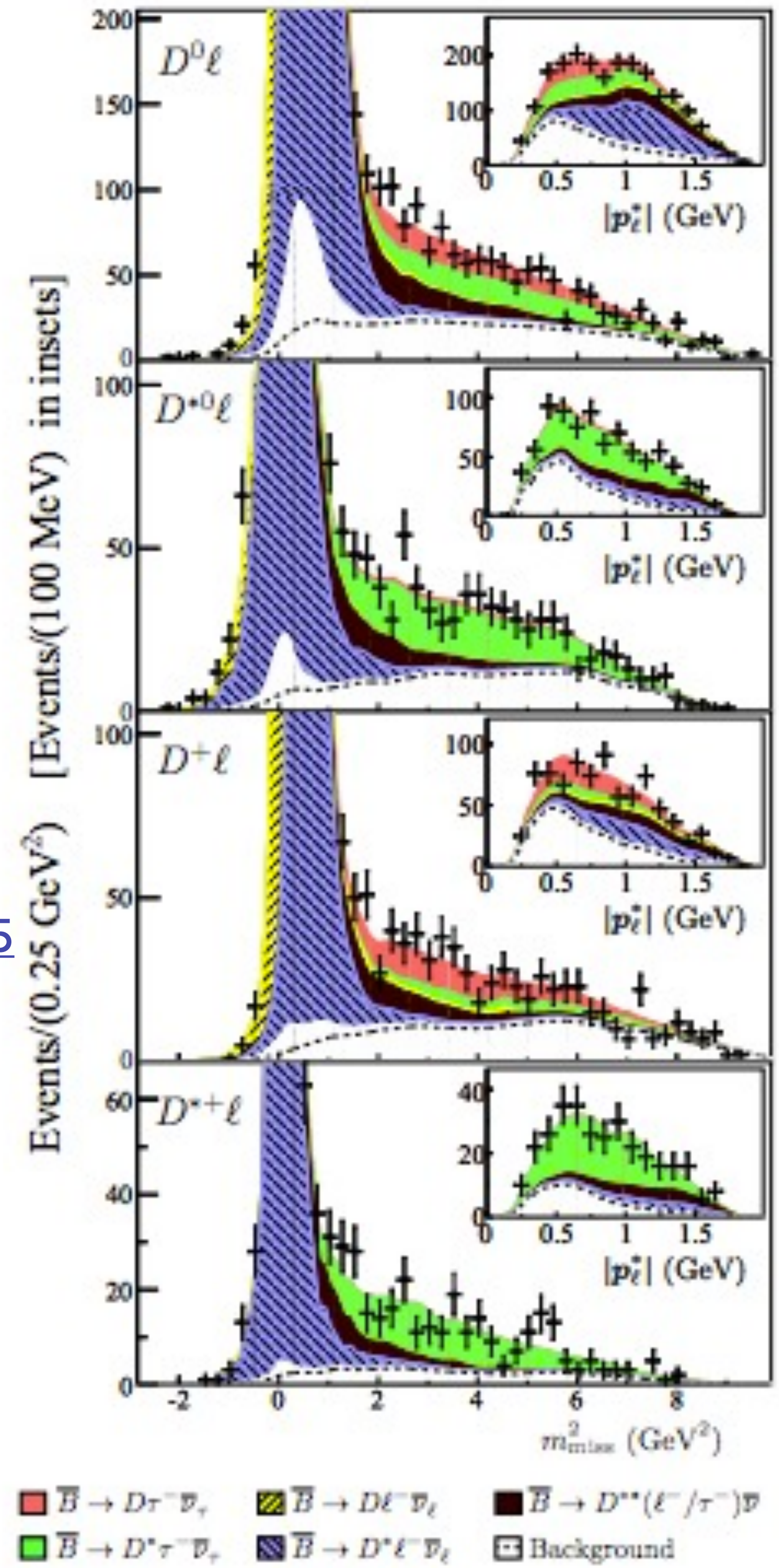
Fajfer et al PRD 85 (2012) 094025

2D ML fit to the lepton three-momentum in the B rest frame and missing mass yields

R(D*) = 0.332 ± 0.024 R(D) = 0.440 ± 0.058

3.4 sigma excess over SM

However, there are papers claiming the R(D) prediction to be underestimated: Becirevic et al Phys.Lett. B716 (2012) 208, Bailey et al PRL 109 (2012) 071802

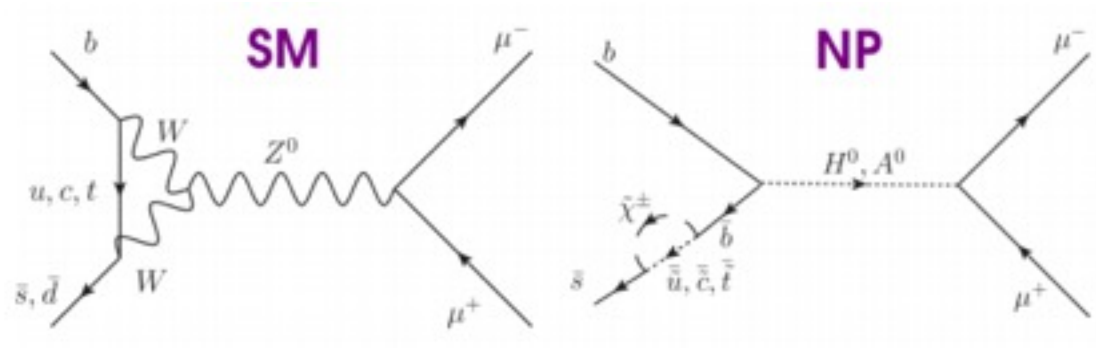


LHCB-PAPER-2012-043

Very affected by different NP scenarios.
Most sensitive experiments are LHCb and CMS
The SM prediction here is

$$\mathcal{B}(B_s \rightarrow \mu^+\mu^-) = (3.47 \pm 0.27) \times 10^{-9}$$

UTFIT

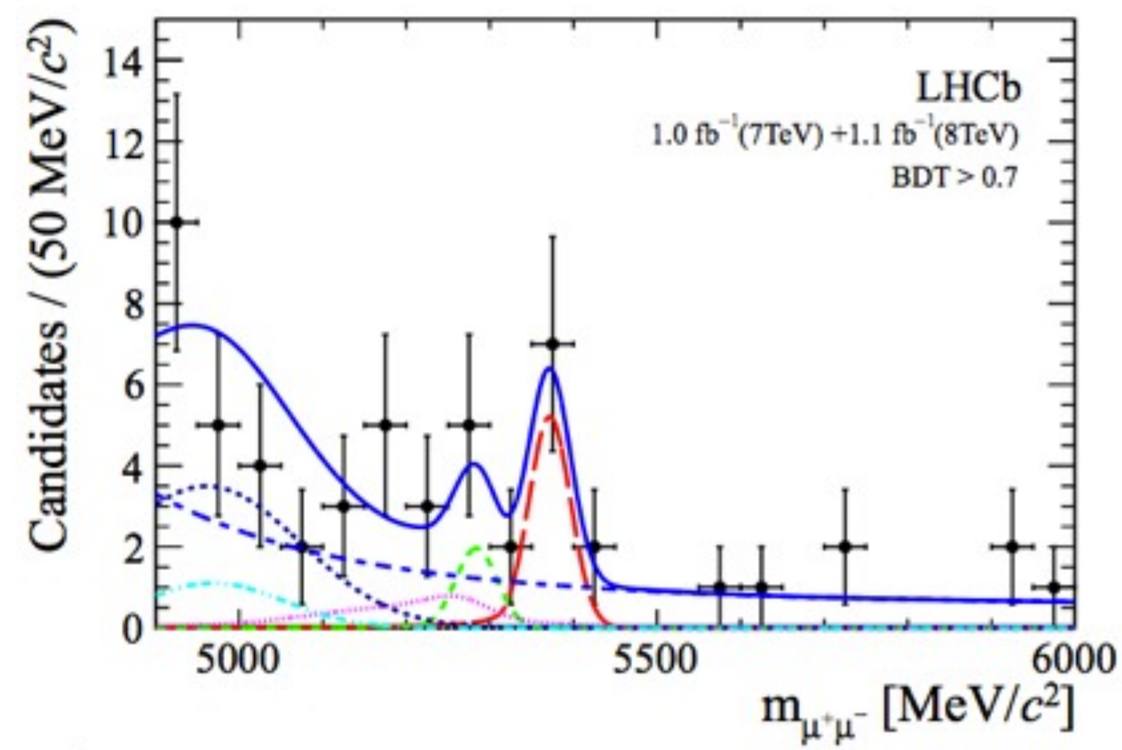


The selection is performed using Boosted Decision Tree trained on the $B \rightarrow hh$ data.

Afterwards, another BDT is trained on simulated events. This BDT is used to split into the remaining sample into bins.

Finally, ML fit is performed to the μμ invariant mass simultaneously in all BDT bins.

Sum of most sensitive BDT-bins



This leads to a result

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

$B_s \rightarrow \mu\mu$ $B \rightarrow hh$ $B \rightarrow \pi\mu\mu$
$B_d \rightarrow \mu\mu$ $B \rightarrow \pi\mu\nu$

Waiting for CMS to confirm

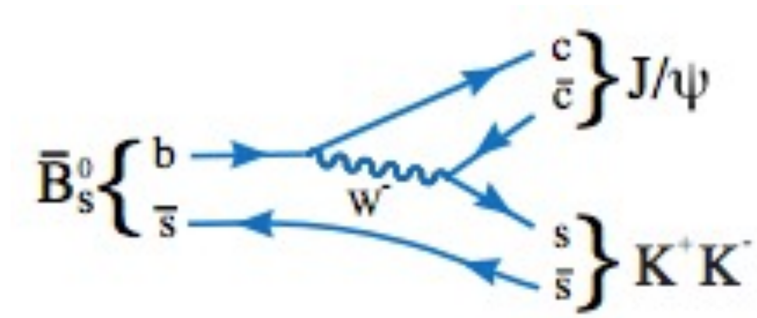
B_s sector

Another (almost degenerate) triangle can be plotted.

This domain is mainly exploited by proton-(anti)proton colliders.

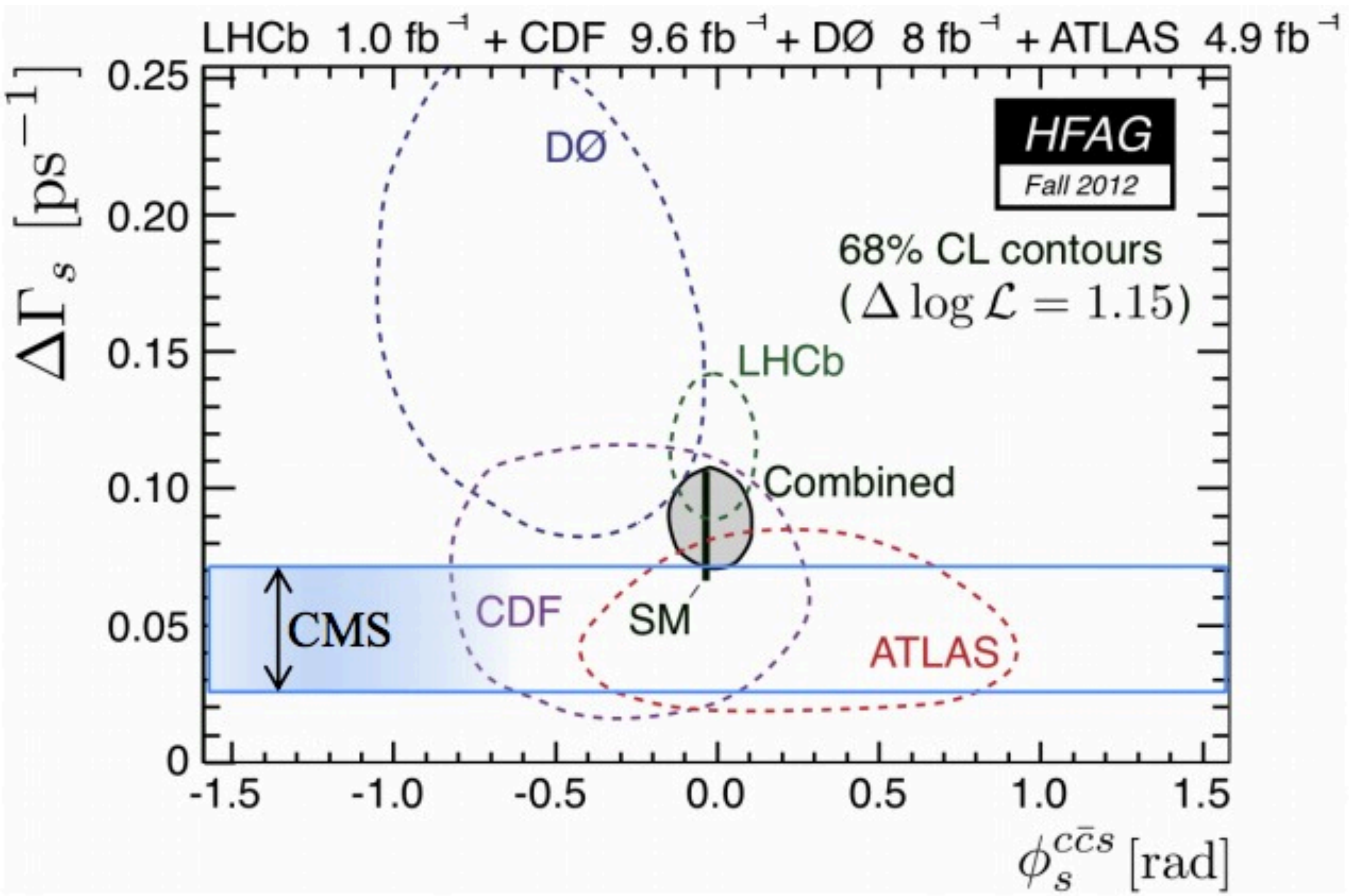
The chapter is dedicated to measurements of the mixing phase φ_S and width difference of the Bs mass eigenstates $\Delta\Gamma_{s.}$

The Bs→J/ψKK decay channel is sensitive to the mixing phase φs



Experiments have performed tagged and untagged analyses of J/ψϕ decays, giving lower sensitivity on φ_s but competitive on $\Delta\Gamma_s$.

CMS result assumes $\varphi_s = 0$



LHCb: LHCb-CONF-2012-002
CMS: Public note BPH-11-006
ATLAS: arXiv: 1208.0572
CDF: PRL 109 (2012) 171802
D0: PRD 85 (2012) 032006

What about charm?

Charm analyses require a big sample of statistics as the effects are tiny compared to the beauty analyses.

For observation of mixing, see backup

PRL 108 (2012) 111602

The analysis is using hadronic tagged decays:

$D^* \rightarrow D^0(KK)\pi$
$D^* \rightarrow D^0(\pi\pi)\pi$

The two asymmetries are constructed:

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

This is connected to the physical asymmetries:

$$A_{\text{raw}}(f) = A_{CP}(f) + A_D(f) + A_D(\pi_s^+) + A_P(D^{*+}).$$

with A_D being detection and A_p production asymmetries

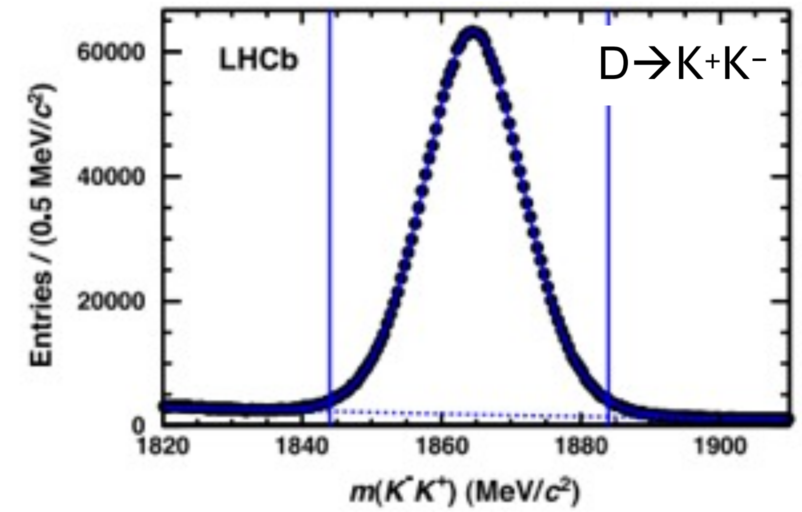
Thus, $\Delta A_{CP} = A_{\text{raw}}(K^-K^+) - A_{\text{raw}}(\pi^-\pi^+)$ depends only on the physical values of A_{cp}, which is ~0 in SM

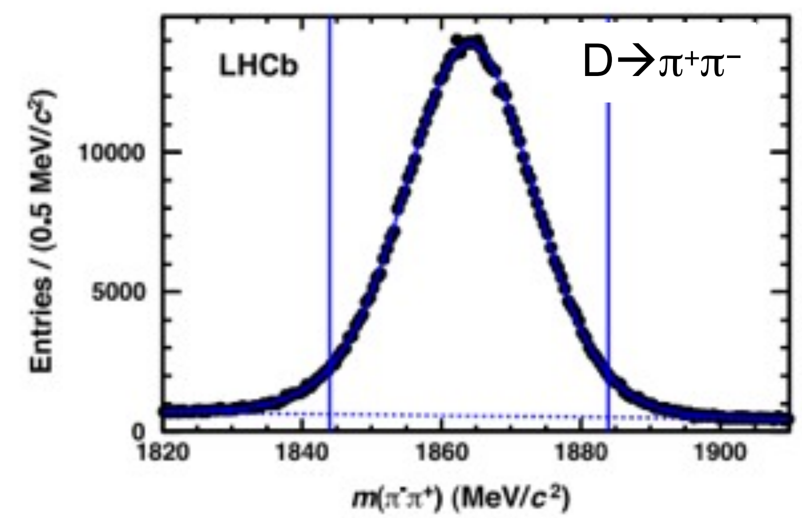
LHCb measured:

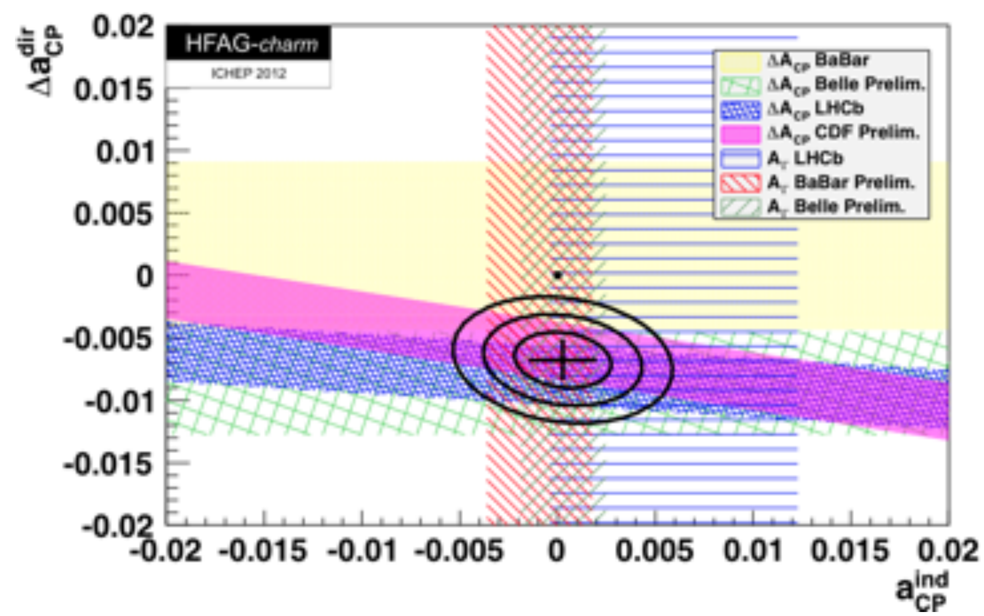
$$\Delta A_{CP} = [-0.82 \pm 0.21(\text{stat}) \pm 0.11(\text{syst})]\%$$

The result is confirmed by CDF and Belle

The current world average is −0.678 ± 0.147, (>4σ)!

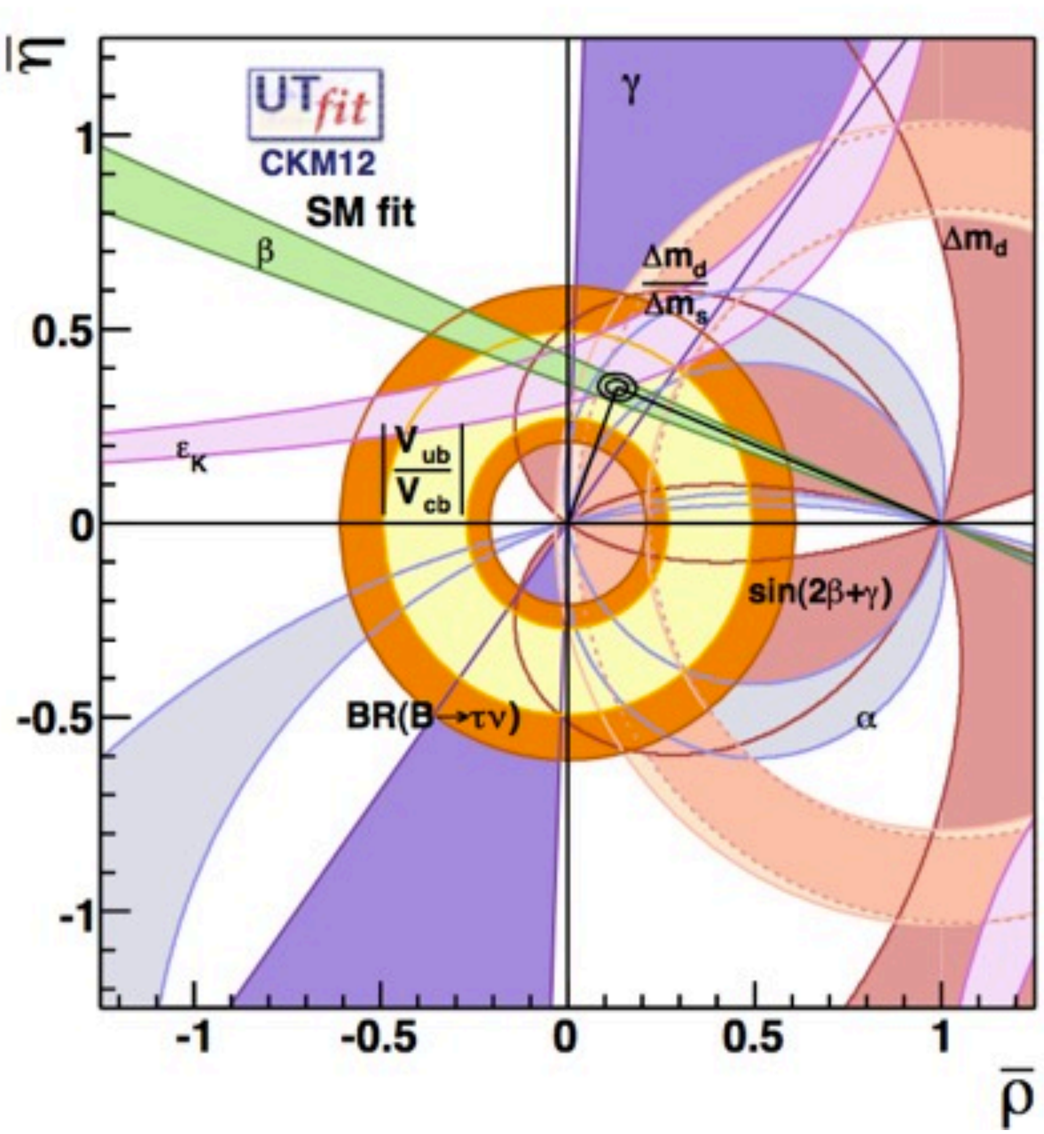






Full fit

UTFIT



$$\bar{\rho} = 0.132 \pm 0.021$$

$$\bar{\eta} = 0.348 \pm 0.015$$

	Prediction	Measurement
α, °	(87.8±3.7)	(90.6±6.8)
sin(2β)	(0.75±0.05)	(0.679±0.024)
γ , °	(68.8±3.4)	(72.2±9.2)
V_{ub}, 10^{-3}	(3.63±0.13)	(3.8±0.6)
V_{cb}, 10^{-3}	(42.3±0.9)	(41.±1.)
ε_K, 10^{-3}	(1.96±0.2)	(2.229±0.010)
Δm_s, ps^{-1}	(17.5±1.3)	(17.69±0.08)
B(B→τν), 10^{-4}	(0.822±0.008)	(0.99±0.25)
β_s, rad*	(0.01876±0.0008)	(0.01±0.05)
B(B_s→ll), 10^{-9}*	(3.47±0.27)	(3.2±1.5)

No real tension in the data observed so far.

What else?

So long we were discussing the *CP* violation. But what about T? Can we do something about T reversal violation?

[The Economist, 01.09.2012]

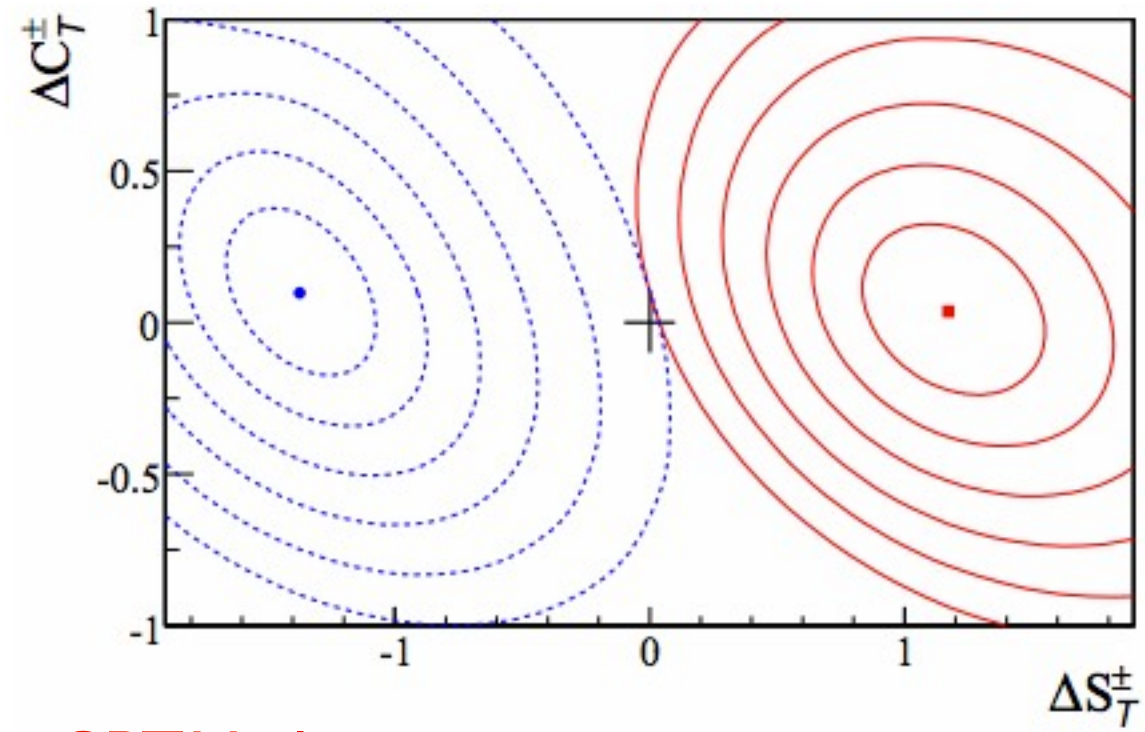
PRL 109 (2012) 211801

The analysis is based on the comparison between the B^0 decays to J/Psi Ks, J/Psi K_L and flavor definite decays.

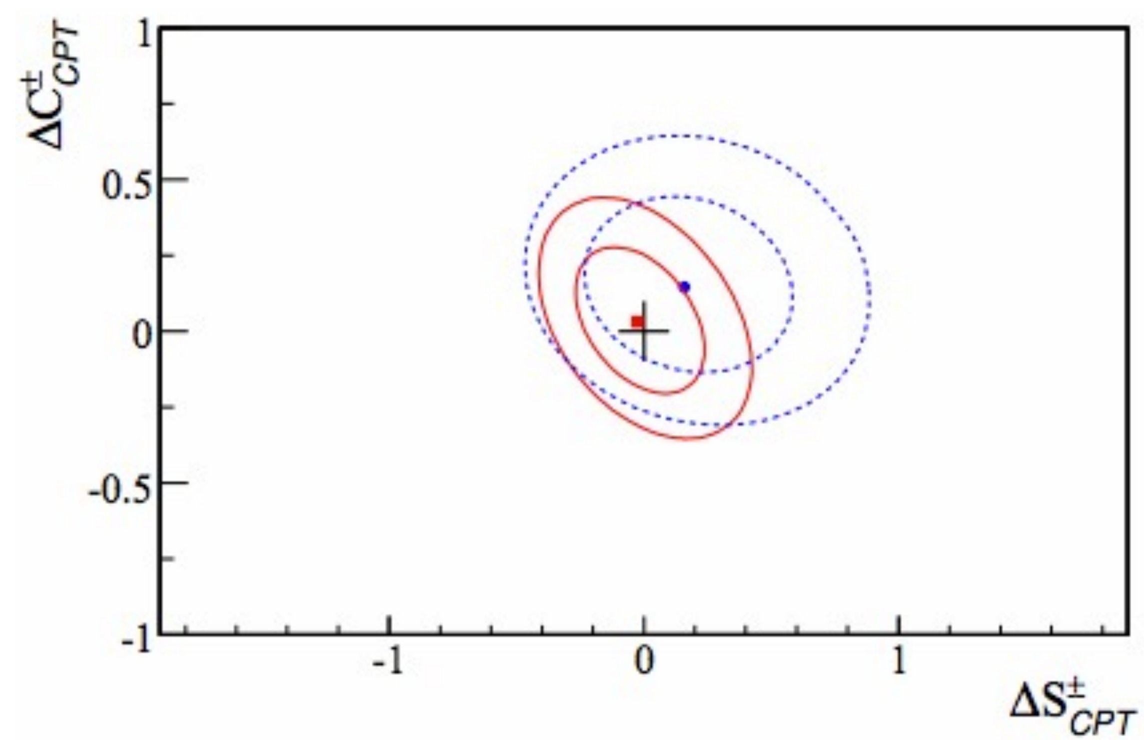
Due to the fact that we have quantum coherent system with $\Upsilon(4S) \rightarrow BB$, we can solve the equation to test simultaneously and independently *CP*, *T* and *CPT* violations

	Parameter	Final result	SM expected val.	
T	ΔS_T^+	$-1.37 \pm 0.14 \pm 0.06$	-1.4	
	ΔS_T^-	$1.17 \pm 0.18 \pm 0.11$	1.4	
	ΔC_T^+	$0.10 \pm 0.14 \pm 0.08$	$0.$	
	ΔC_T^-	$0.04 \pm 0.14 \pm 0.08$	$0.$	
	ΔS_{CP}^+	$-1.30 \pm 0.11 \pm 0.07$	-1.4	CP
	ΔS_{CP}^-	$1.33 \pm 0.12 \pm 0.06$	1.4	
	ΔC_{CP}^+	$0.07 \pm 0.09 \pm 0.03$	$0.$	
	ΔC_{CP}^-	$0.08 \pm 0.10 \pm 0.04$	$0.$	
:PT	ΔS_{CPT}^+	$0.16 \pm 0.21 \pm 0.09$	$0.$	
	ΔS_{CPT}^-	$-0.03 \pm 0.13 \pm 0.06$	$0.$	
	ΔC_{CPT}^+	$0.14 \pm 0.15 \pm 0.07$	$0.$	
	ΔC_{CPT}^-	$0.03 \pm 0.12 \pm 0.08$	$0.$	

T Violation



CPT Violation



Summary of Present Status

CP violation is now well established in different systems.

The CKM matrix provides a good description of the mechanisms.

The measurements are already quite precise to exclude bug New Physics effects.

New horizons are open with evidence of *CP* violation in charm.

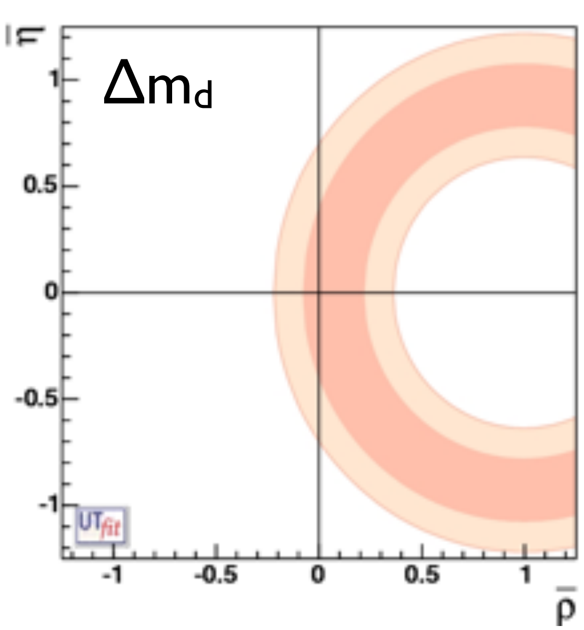
Summary of Future Plans

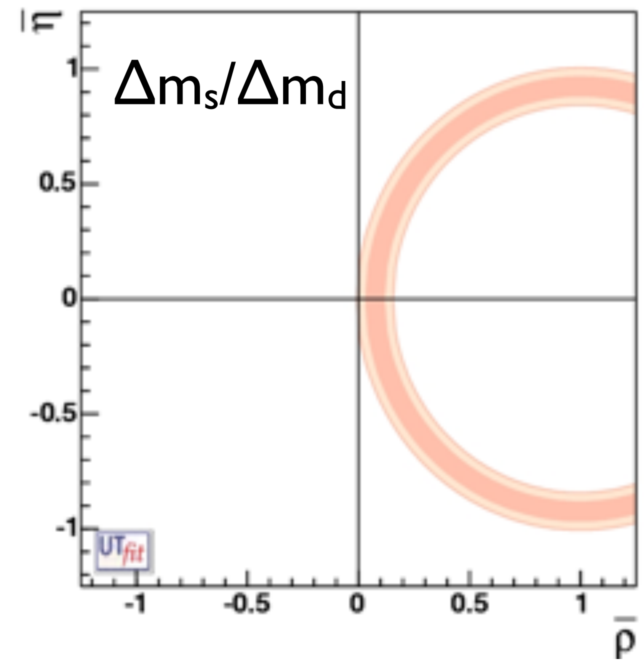
By 2018 LHCb will collect ~7 fb^{-1} (around 7 times more than most analyses shown here). This will give access to a very precise measurements in many areas (γ, φ_s, rare decays).

Belle 2 will start operations in 5 years from now, this will give an opportunity to have results unaccessible by LHCb (missing mass analyses) and start new competition in B_d, B_u, D decays analyses (with LHCb).

Kaon experiments (NA62, KOTO) aimed to measure $K \rightarrow \pi\nu\nu$ will produce the in couple of years giving more constraints to the Unitarity triangle.

Backup





Oscillations

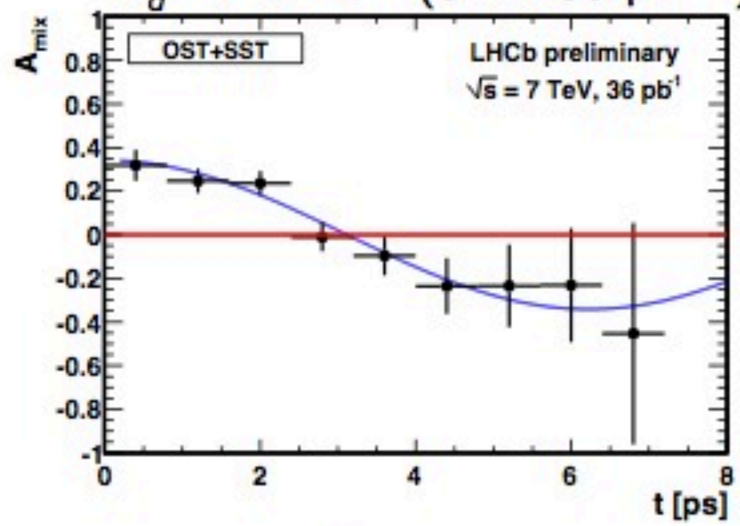
The B_s oscillation is now well established fact. This was one of the first measurements performed by LHCb.

Measurement of the $B_d^0 - \bar{B}_d^0$ mixing frequency LHCb-CONF-2011-010

Preliminary:
$\Delta m_d = 0.499 \pm 0.032(\text{stat}) \pm 0.003(\text{sys})\ ps^{-1}$
($\Delta m_d = 0.507 \pm 0.005\ ps^{-1}$ world average, PDG)

	$\varepsilon_{tag}\mathcal{D}^2$
OS	3.4±0.9%
SSπ+OS	4.3±1.0%

$B_d^0 \to D^-\pi^+$ (6k in 36 pb^{-1})



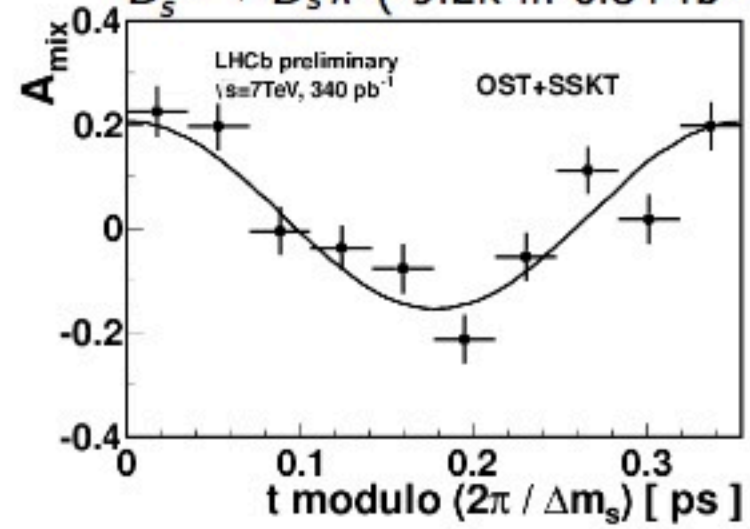
Measurement of the $B_s^0 - \bar{B}_s^0$ mixing frequency Phys.Lett.B 709 (2012) 177, LHCb-CONF-2011-50

Preliminary (most precise):
$\Delta m_s = 17.725 \pm 0.041(\text{stat}) \pm 0.026(\text{sys})\ ps^{-1}$

	$\varepsilon_{tag}\mathcal{D}^2$
OS	3.2±0.8%
SSK	1.3±0.4%

SSK preliminary optimization using prompt $D_s^\pm \to \phi\pi^\pm$

$B_s^0 \to D_s\pi$ (9.2k in 0.34 fb^{-1})



The impact on the global fit now strongly depends on the lattice calculations

Semileptonic Asymmteries

- CPV in mixing $P(B \to \bar{B}) \neq P(\bar{B} \to B)$
- First step to resolving the issue of the D0 di-muon asymmetry anomaly.

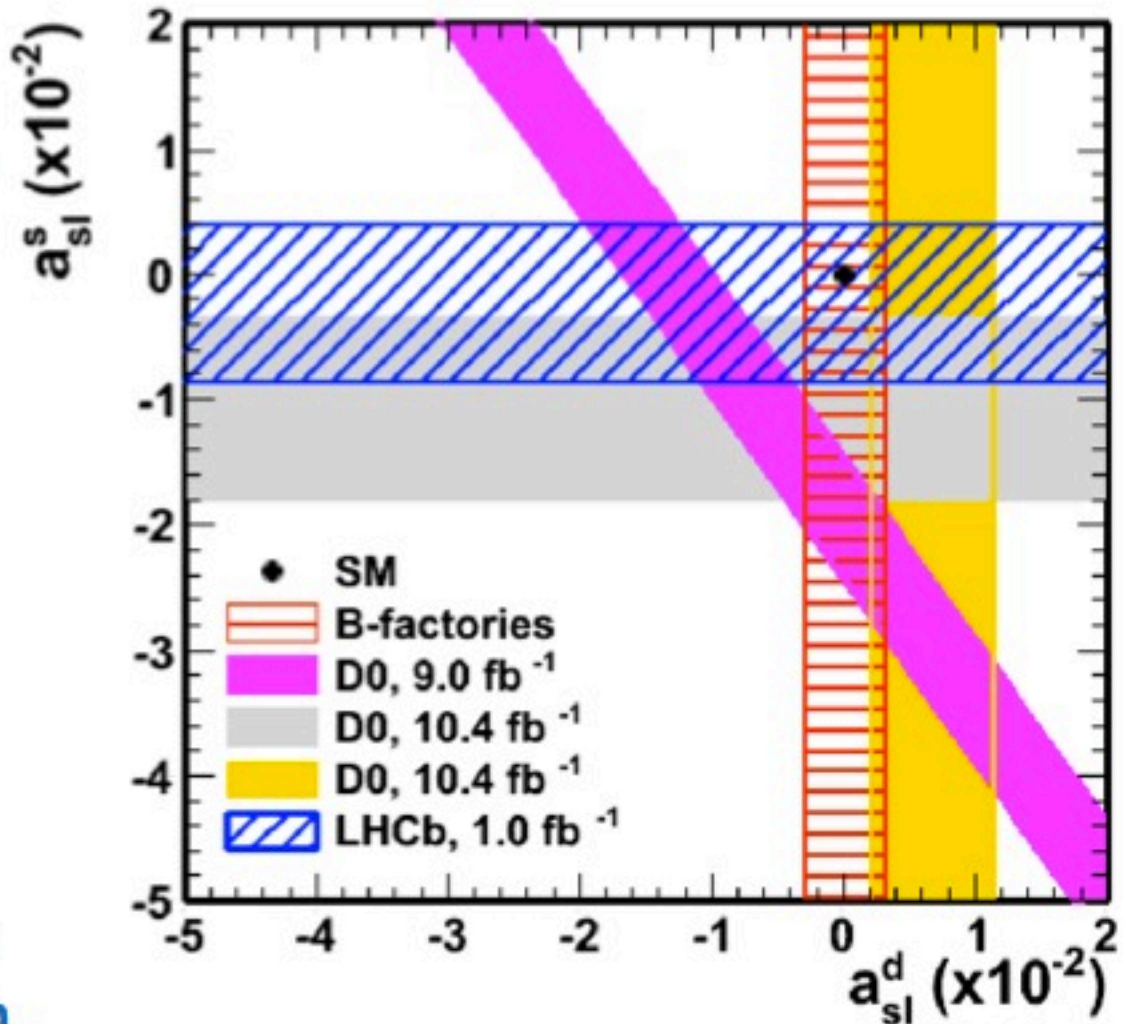
See parallel talk of Thomas Bird

- LHCb preliminary result for a^s_{sl}

$$a^s_{sl} \equiv \frac{\Gamma(B^0_s \to D^-_s \mu^+) - \Gamma(\overline{B}^0_s \to D^+_s \mu^-)}{\Gamma(B^0_s \to D^-_s \mu^+) + \Gamma(\overline{B}^0_s \to D^+_s \mu^-)}$$

$$a^s_{sl} = (-0.24 \pm 0.54 \pm 0.33)\%$$

LHCb-CONF-2012-022



- D0 not confirmed nor ruled out (1.8σ from LHCb result). More coming soon

CP violation asymmetries in 3-body B decays

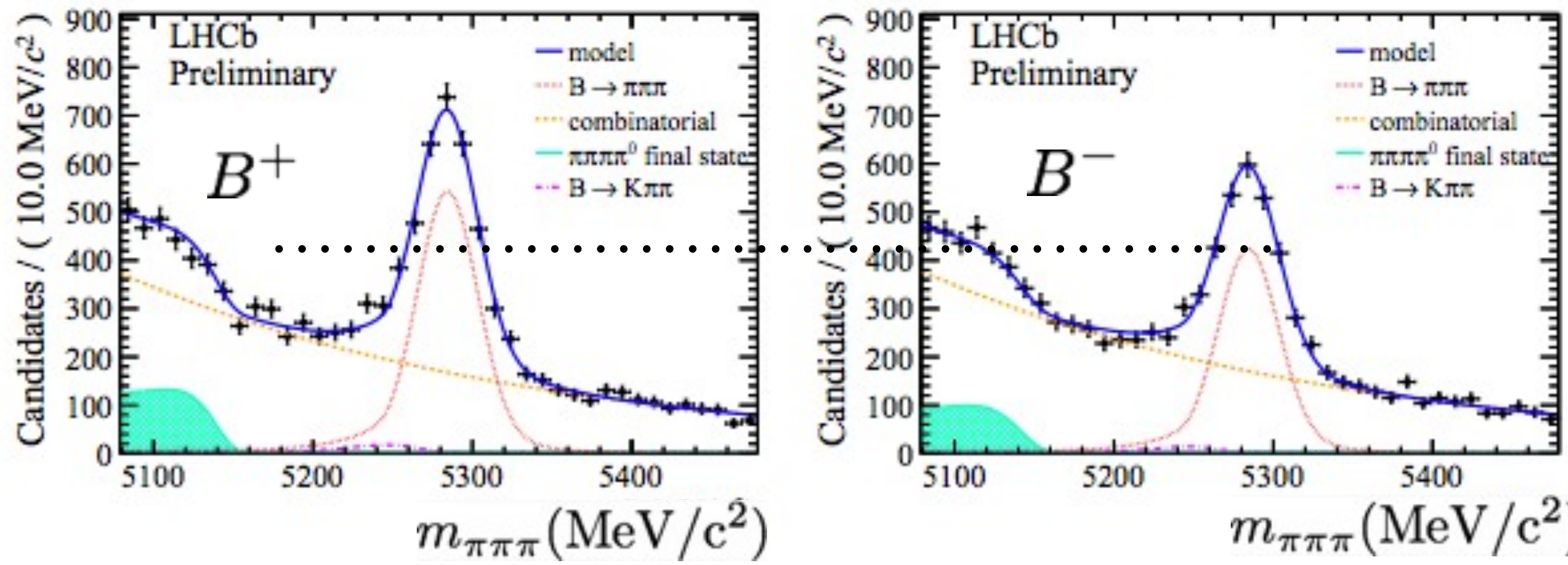
$B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$

CERN-LHCb-CONF-2012-028
CERN-LHCb-CONF-2012-018

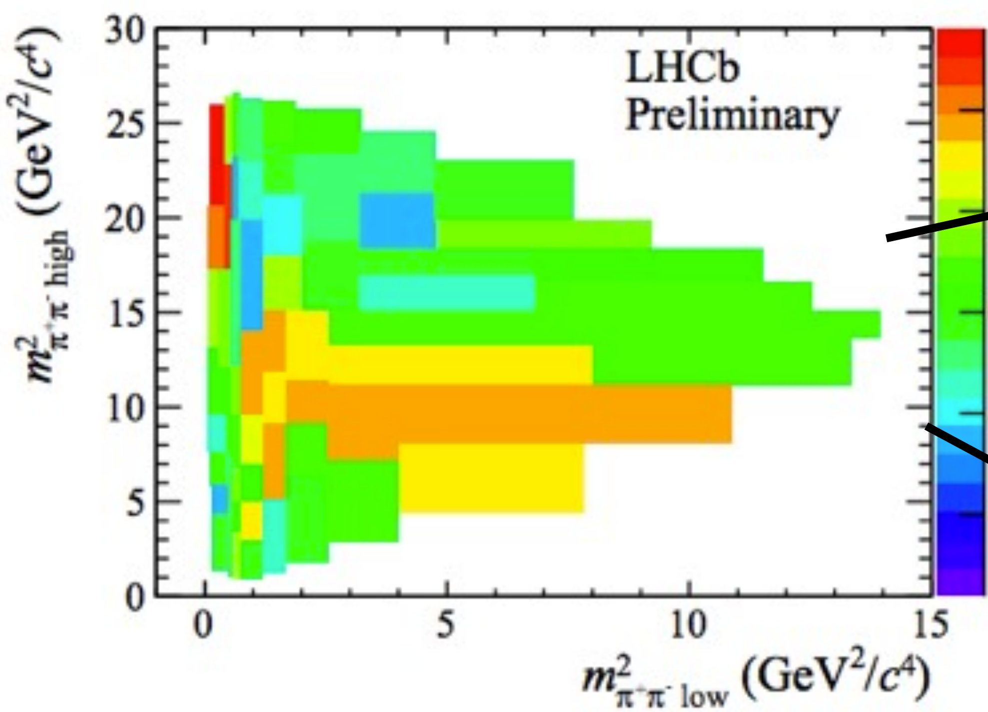
The modes are sensitive to the NP effects and can be studied in Dalitz plain

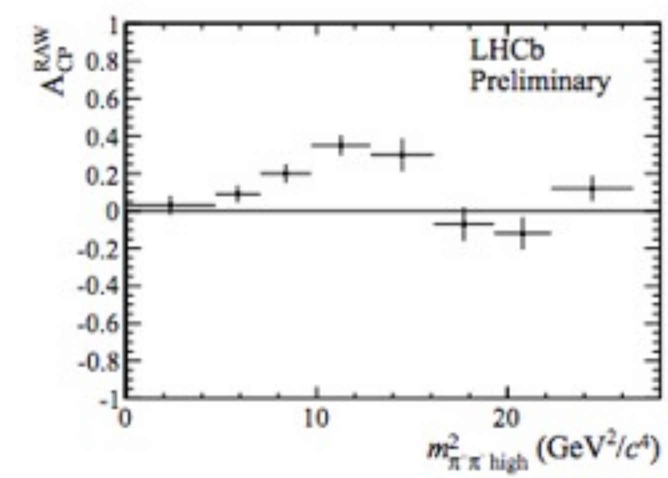
N_{sig}~5k events

Where asymmetry comes from?

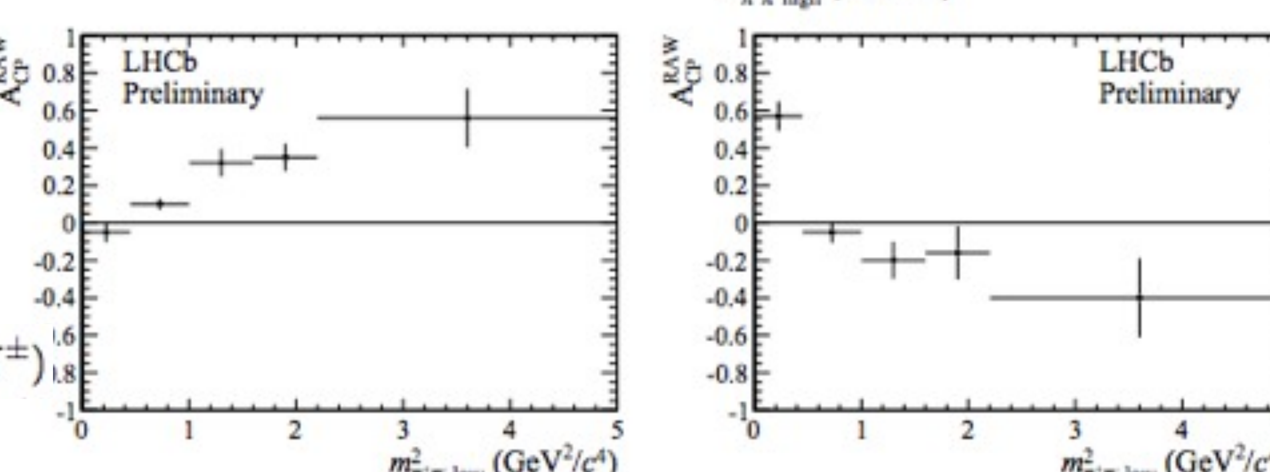


Cutting mass in signal region and making equal population binning:





$A_{CP}(B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}) = +0.120 \pm 0.020(\mathrm{stat}) \pm 0.019(\mathrm{syst}) \pm 0.007(J/\psi K^{\pm})$



$m^2_{\pi^+\pi^-\mathrm{high}} < 15\ \mathrm{GeV}^2/c^4$ $\quad$ $m^2_{\pi^+\pi^-\mathrm{high}} > 15\ \mathrm{GeV}^2/c^4$

What about charm?

The charm mixing was observed before only in combination of several analyses.
Assuming *CP* conservation, LHCb studies

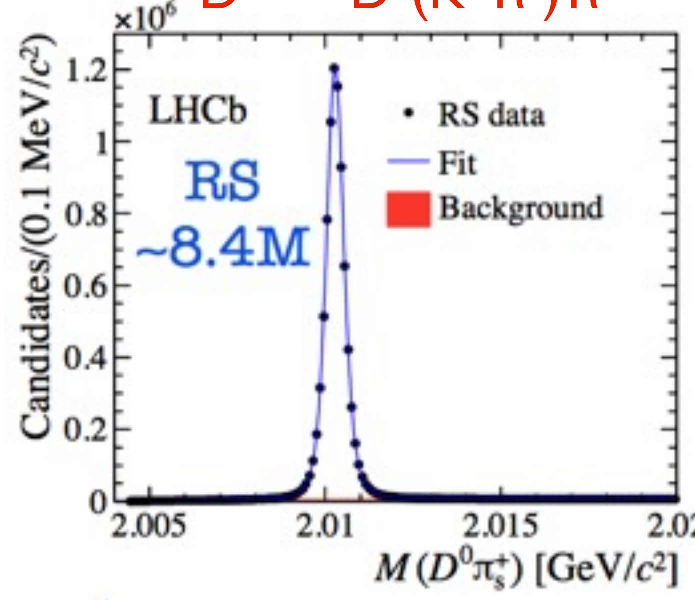
$$R(t) = \frac{N_{WS}(t)}{N_{RS}(t)} = R_D + \sqrt{R_D}y't + \frac{x'^2 + y'^2}{4}t^2$$

With

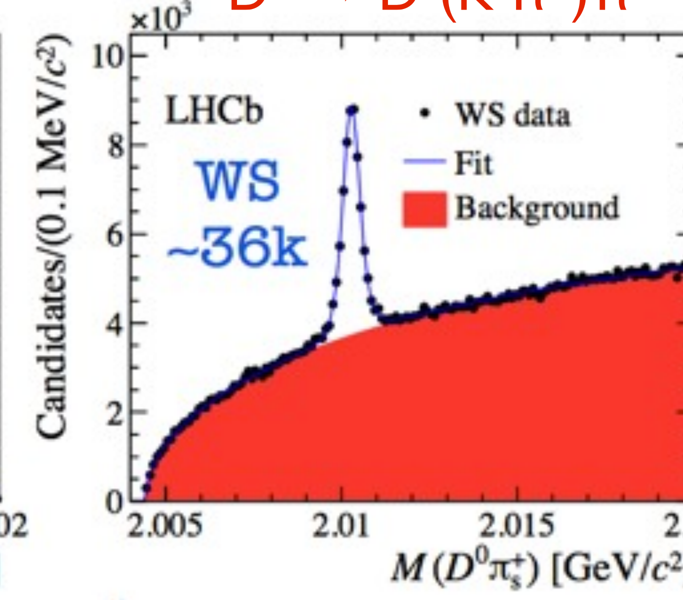
$$x = \frac{M_1 - M_2}{\Gamma} \qquad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}$$

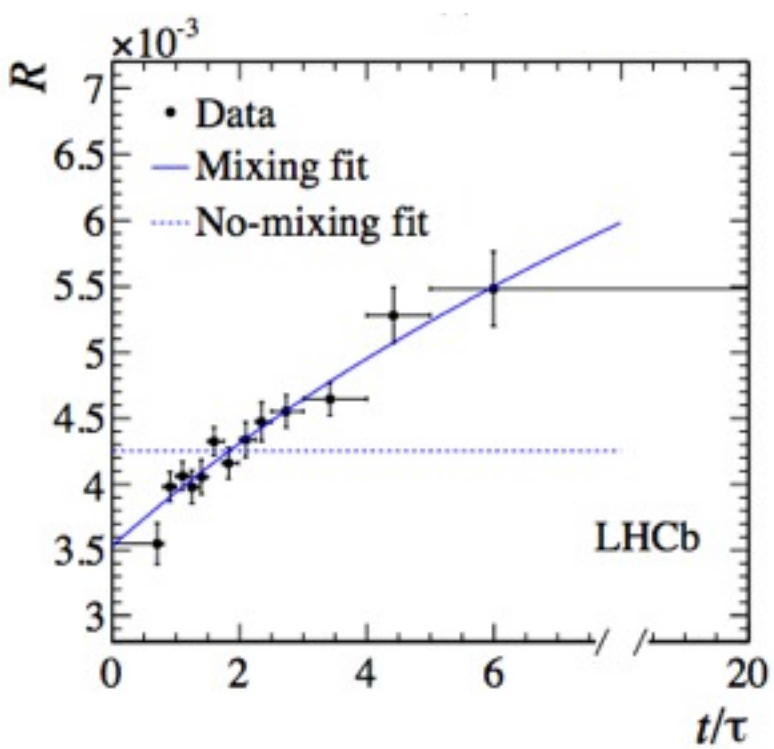
The R(t) dependent on time means mixing

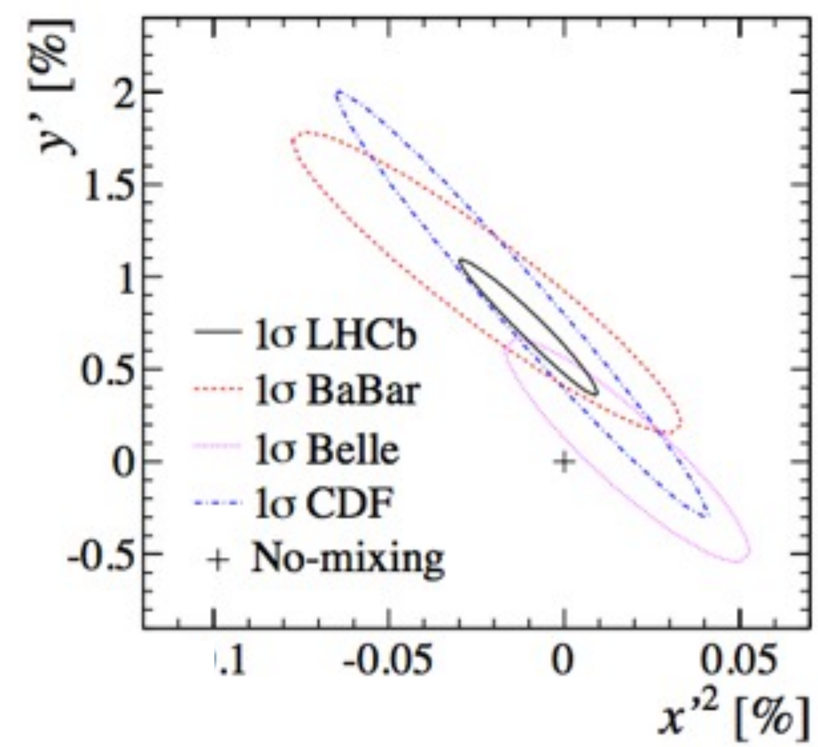
$D^{*+} \rightarrow D^0(K^+\pi^-)\pi^+$



$D^{*+} \rightarrow D^0(K^-\pi^+)\pi^+$







No-mixing hypothesis is now excluded at 9.1σ

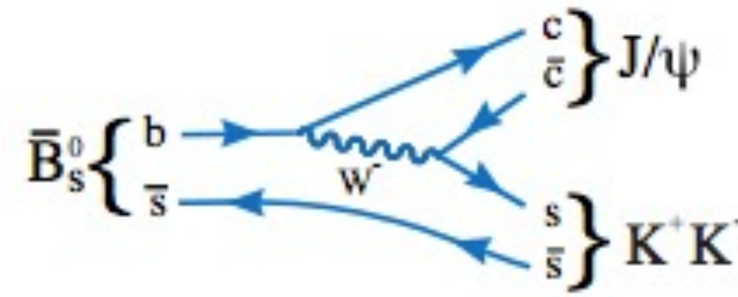
B_s sector

Another (almost degenerate) triangle can be plotted.

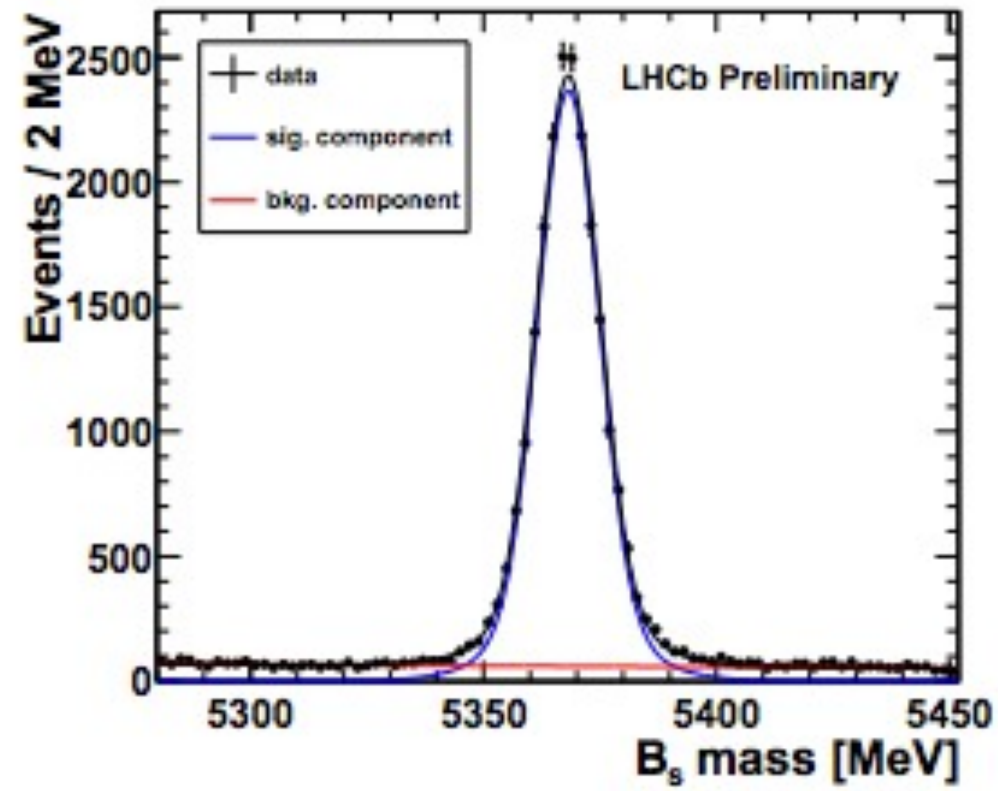
This domain is mainly exploited by proton-(anti)proton colliders.

The chapter is dedicated to measurements of the mixing phase φ_S and width difference of the Bs mass eigenstates $\Delta\Gamma_{s.}$

This decay channel is sensitive to the mixing phase φ_s



The decay is dominated by ϕ resonance, which is vector, so we have to perform the angular analysis with ~21K events



components/polarizations:

- P-wave ($\phi(1020)$):
  - $2 \times$ CP-even ($0 + \|$)
  - $1 \times$ CP-odd ($\perp$)
- S-wave: CP-odd

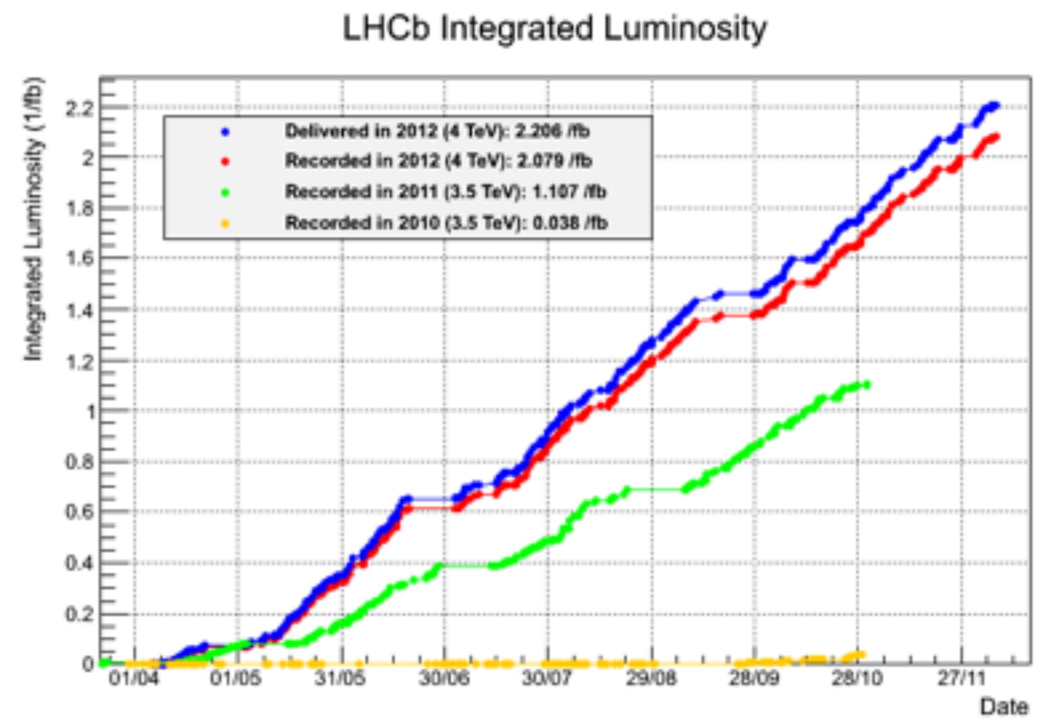
discrete ambiguity:
$(\phi_s^{c\bar{c}s}, \Delta\Gamma_s) \longleftrightarrow (\pi - \phi_s^{c\bar{c}s}, -\Delta\Gamma_s)$

The ambiguity is resolved by analyzing Bs→J/ψππ decays

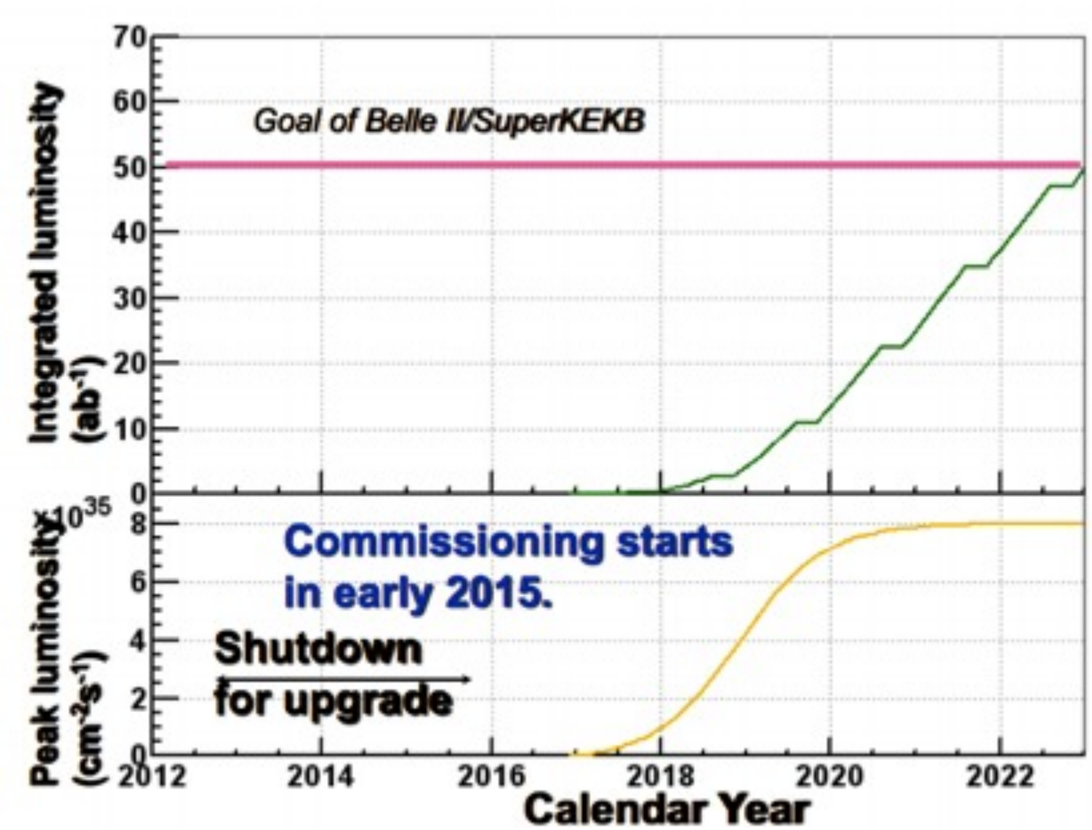
$$\phi_s^{c\bar{c}s} = -0.002 \pm 0.083\,(\text{stat.}) \pm 0.027\,(\text{syst.})\ \text{rad}$$
$$\Delta\Gamma_s = +0.116 \pm 0.018\,(\text{stat.}) \pm 0.006\,(\text{syst.})\ \text{ps}^{-1}$$

What's next?

The analysis of LHCb shown here are mostly based on 2011 data sample (except for $B_s \to \mu\mu$), which means that there is two times more data available. By 2018 there will be around 7 fb^{-1} on tape.

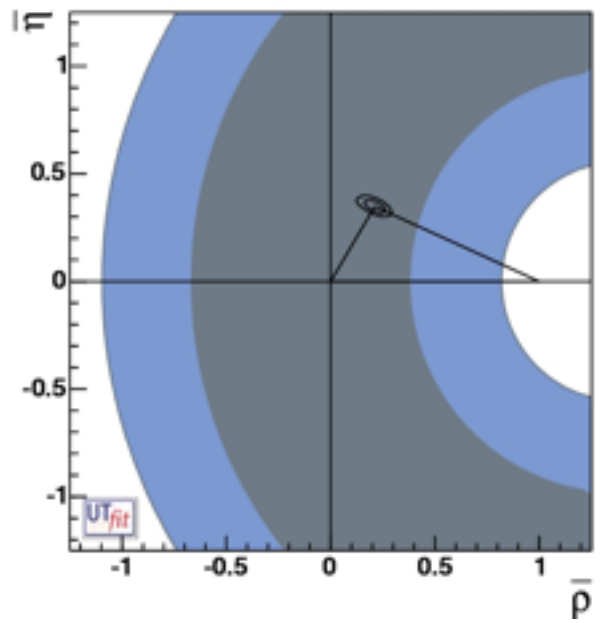


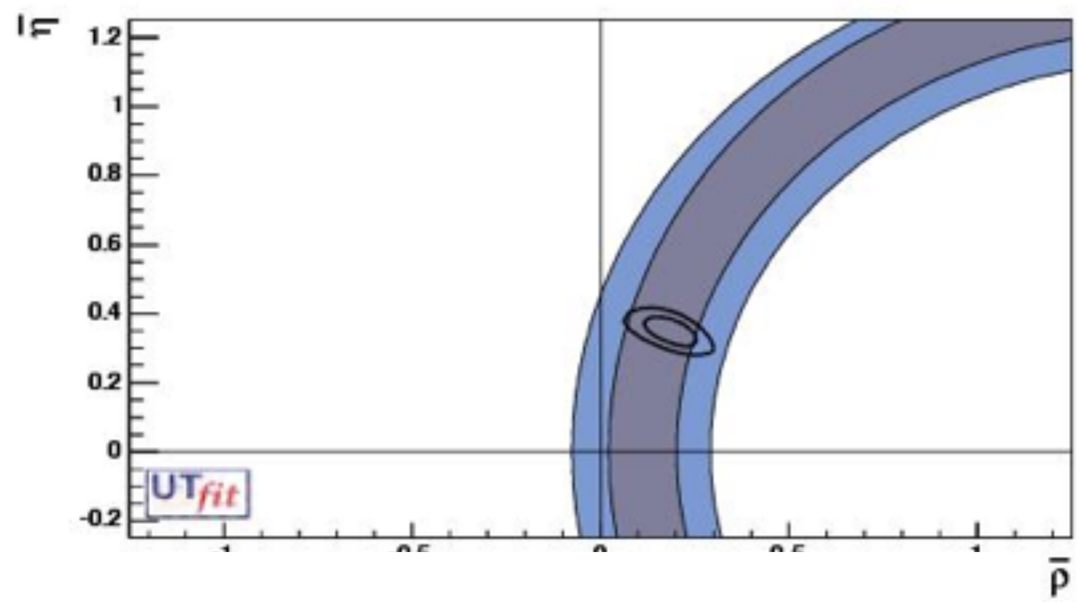
By 2024 Belle II should have collected 50 ab^{-1} (~50 times more than Belle and BaBar). And thus enter in competition with LHCb in B_d, B_u and charm decays.

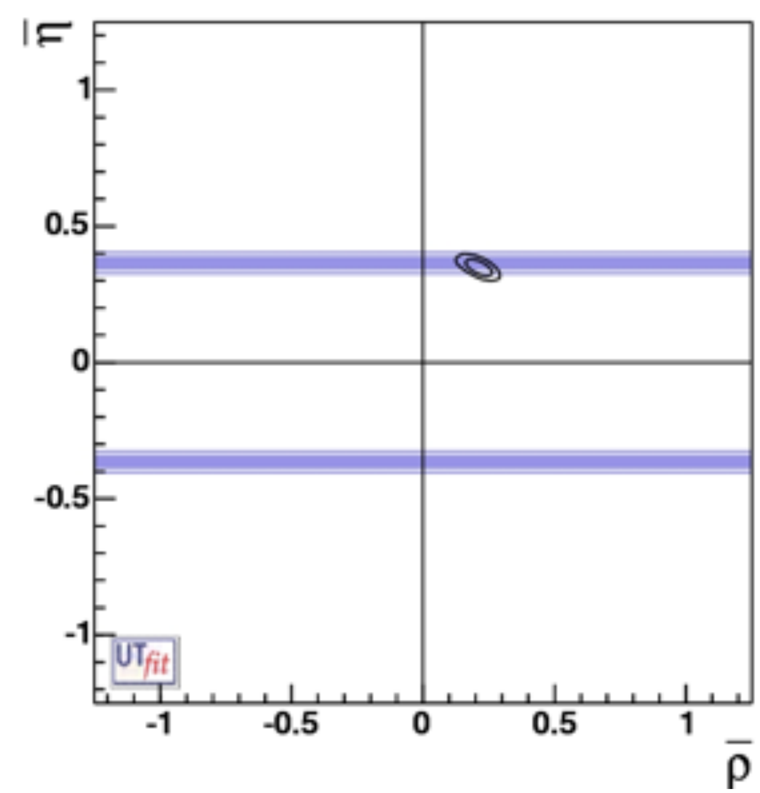


$K^+ \to \pi^+ \nu \bar{\nu}$ decay is under study by NA62 (CERN) and ORKA (Fermilab) projects.

NA62 expects to collect ~110 events by 2016







KOTO (JPARC) experiment is due to be operational in 2013. It will be searching for $K^0 \to \pi^0 \nu \bar{\nu}$

It aims to discover this decay at Step I and continue its measurements. For 10% error on BF

UTFit: Credits and methods

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Fabrizio Parodi	University of Genova
Maurizio Pierini	CERN
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Viola Sordini	IPNL-IN2P3 Lyon
Achille Stocchi	LAL-IN2P3 Orsay
Cecilia Tarantino	University of Roma Tre
Vincenzo Vagnoni	INFN Sezione di Bologna

Use the Bayesian statistics to extract the observables. Extract the credibility interval from the fit.

Gaussian PDFs are used to represent statistical and systematic uncertainties.

The results included into this talk are based on experimental studies that were public before this conference.