Recent results from the B factories and perspectives on SuperB

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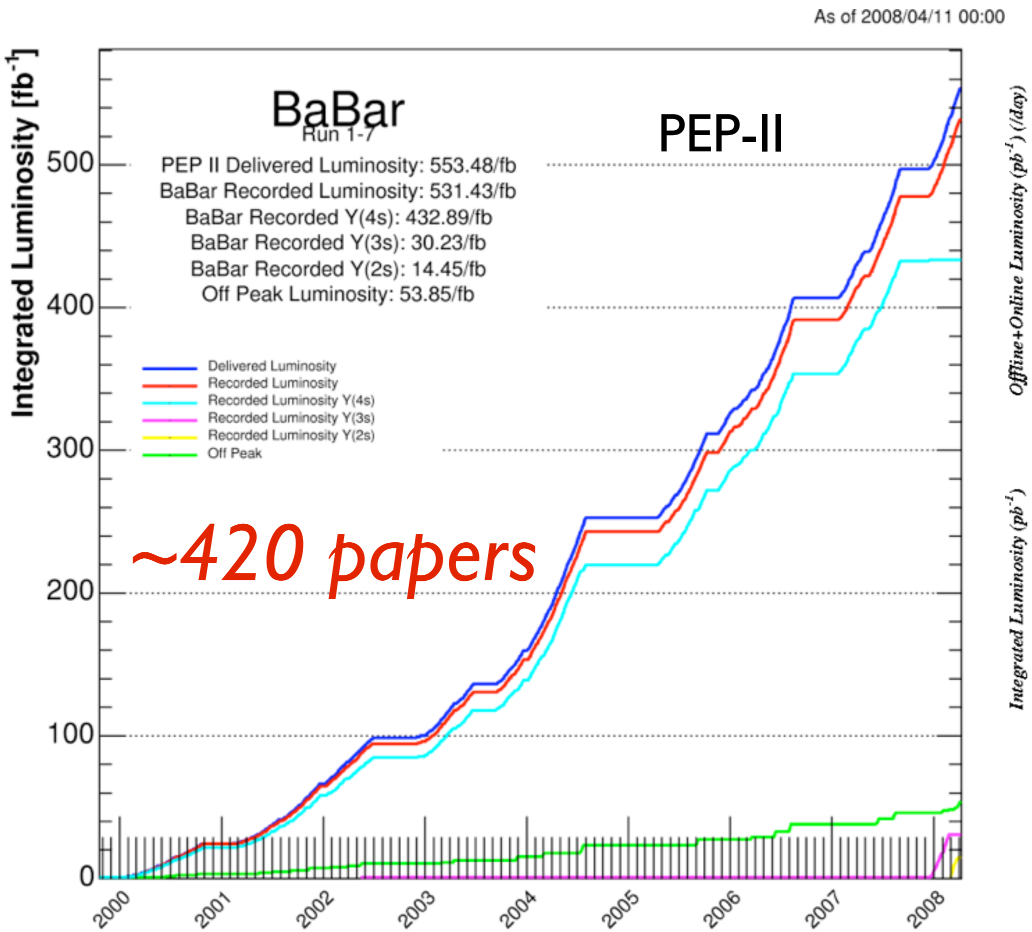
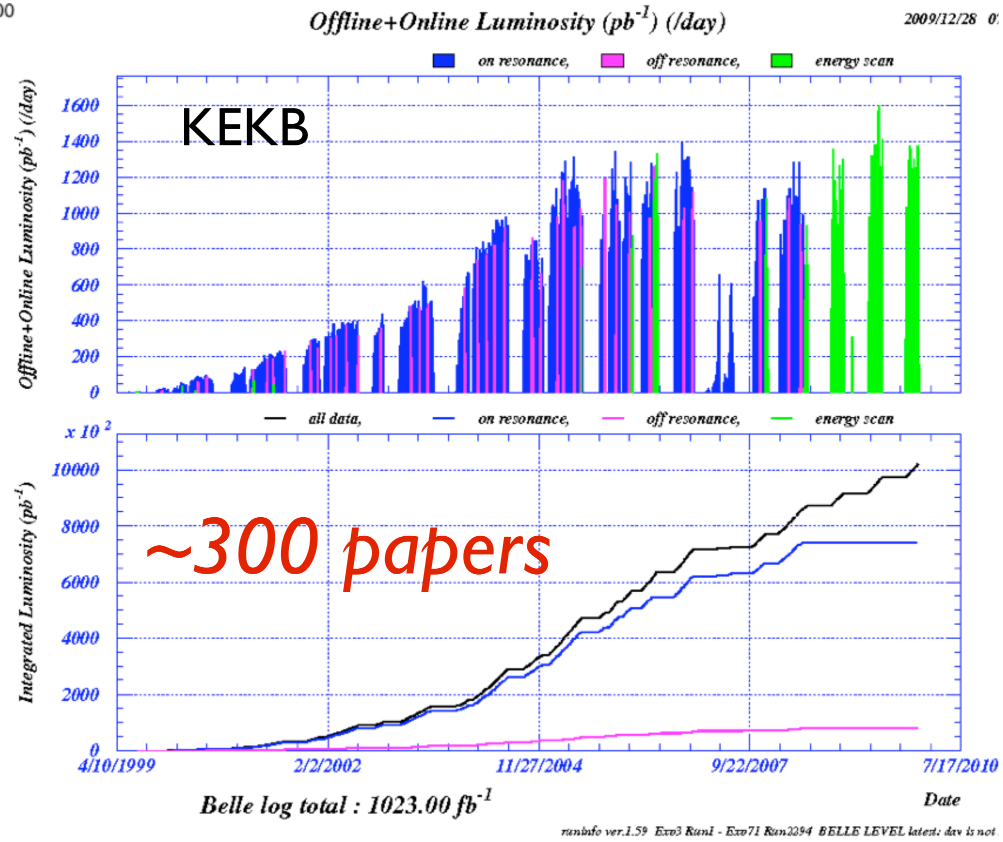
atisse ou the Matisse detector

Outline

- Introduction to the B factories
- Recent results from the B factories
  - measurement of the CKM angle γ
- Perspectives on SuperB physics reach
- Conclusions

Asymmetric B factories running mostly at the $\Upsilon(4S)$ 10.58 GeV with c.m.s. boosted: $\beta\gamma=0.55$ (PEPII) and $\beta\gamma=0.425$ (KEK).

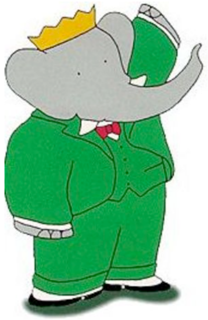


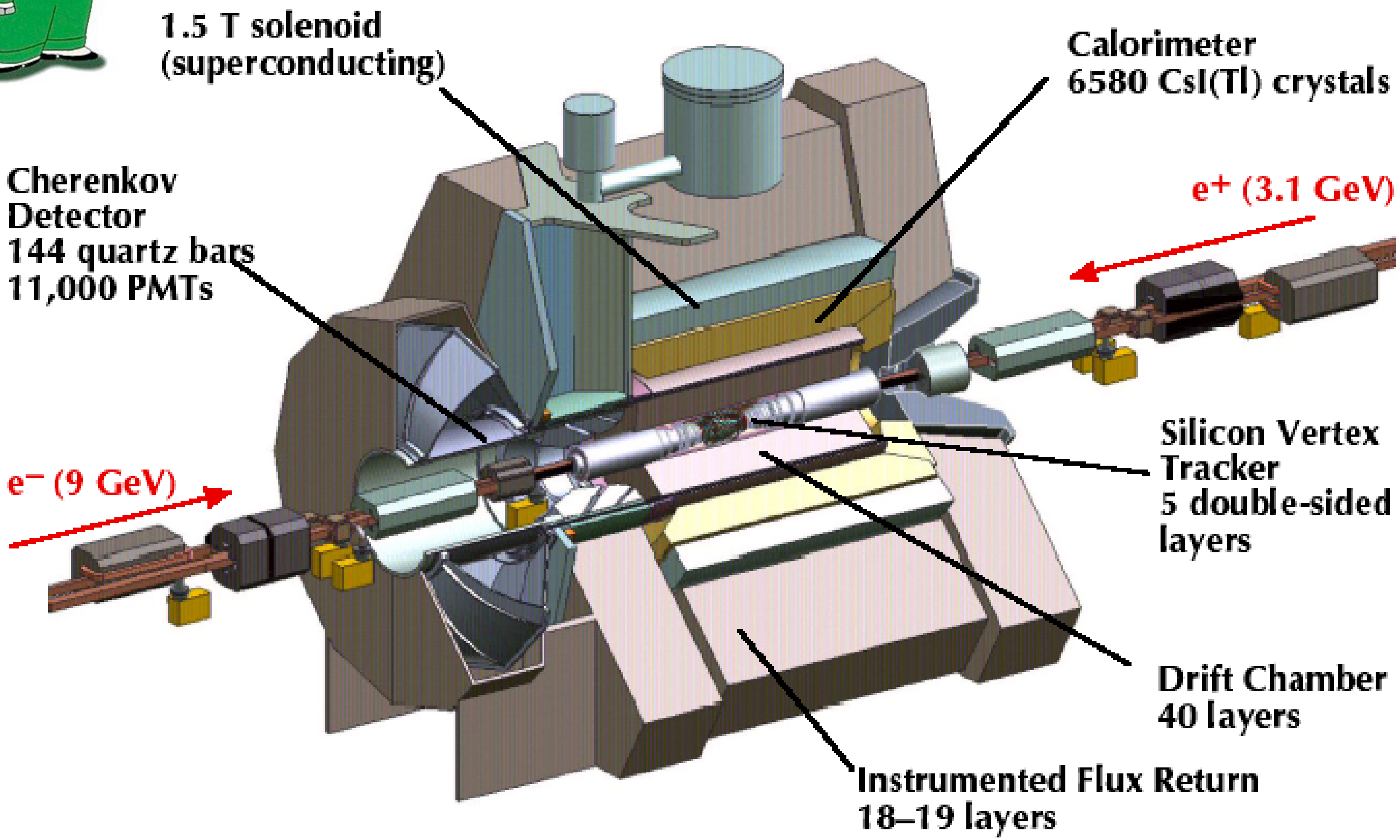


B factories - World Record Luminosities

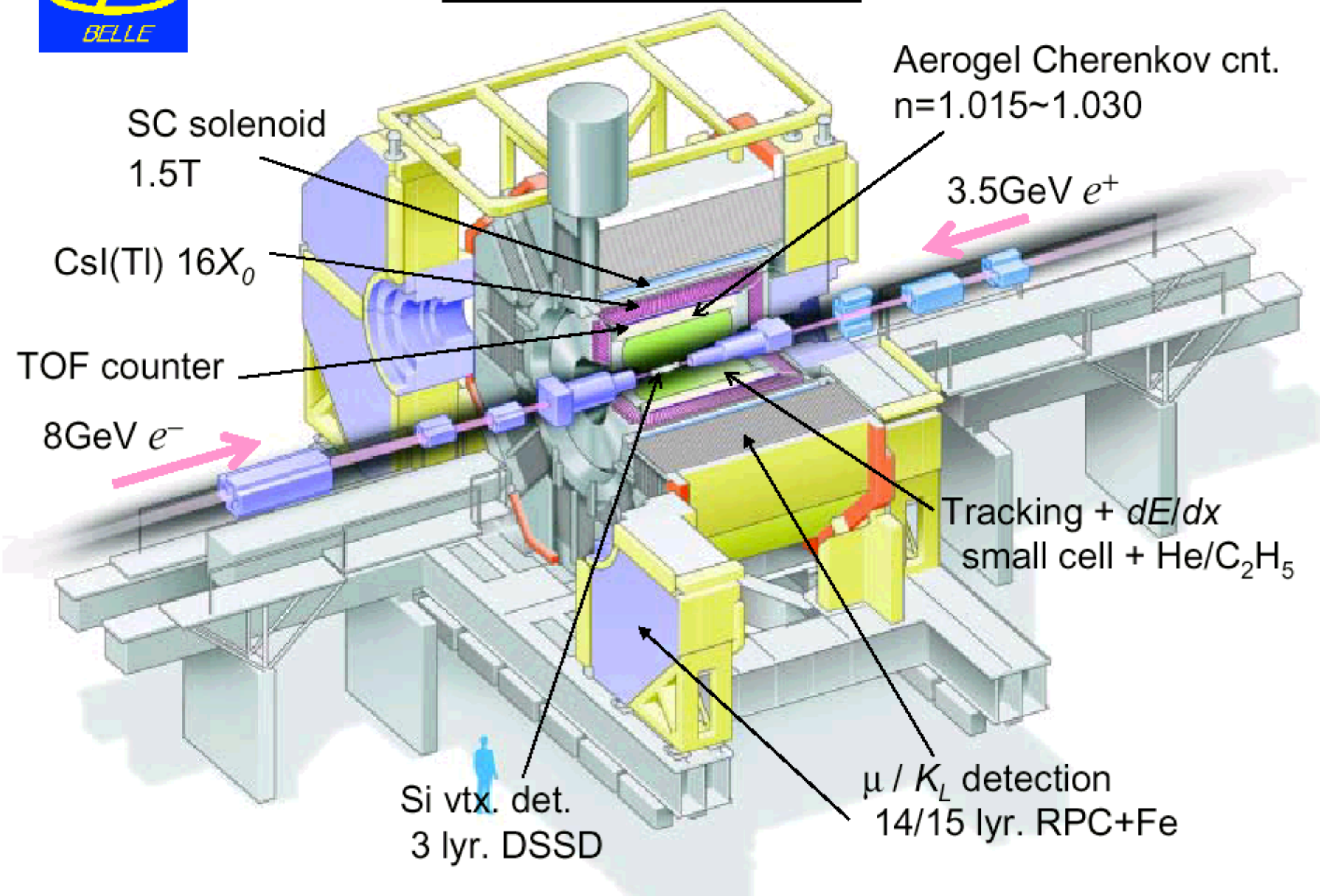
Recorded luminosity ~530 fb^{-1} Peak luminosity ~$12\times10^{33}cm^{-2}s^{-1}$	Recorded luminosity = ~1.02 ab^{-1} Peak luminosity ~$21\times10^{33}cm^{-2}s^{-1}$

The BaBar detector





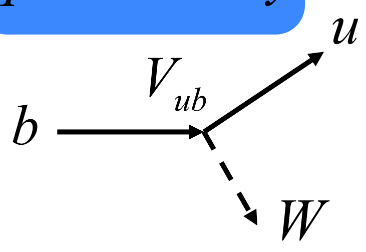
Belle Detector



Main goal of the B factories

- *Verify the Cabibbo-Kobayashi-Maskawa (CKM) mechanism of quark mixing and CP violation with 3 generations of quarks.*

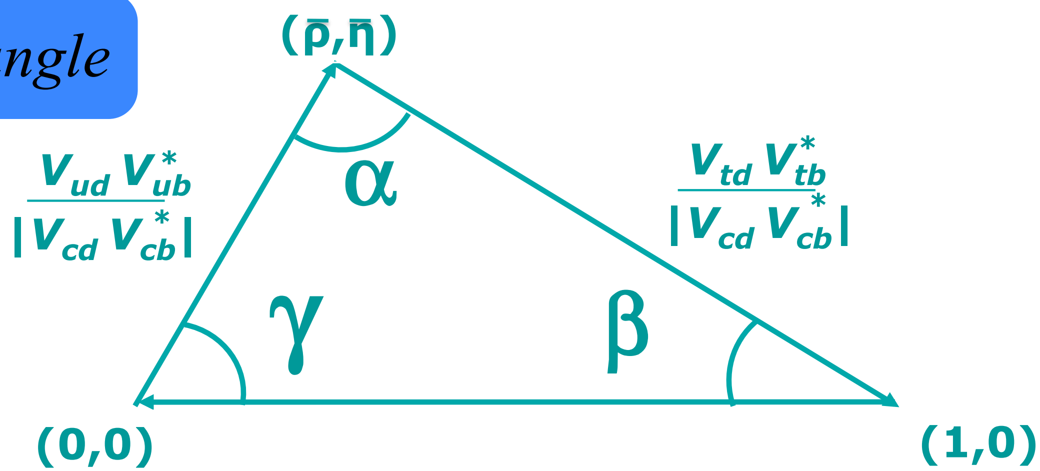
quark decay



CKM matrix

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

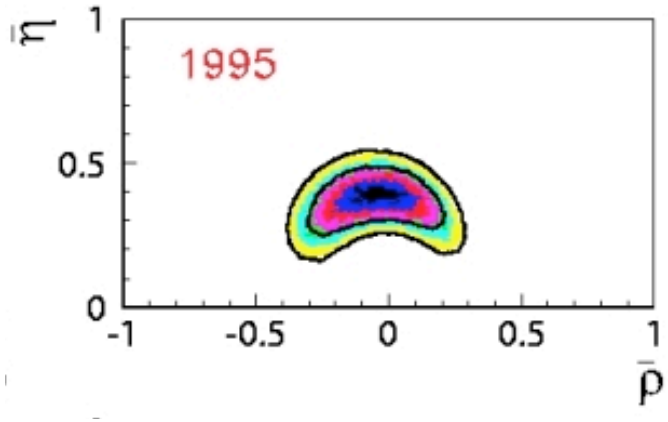
Unitarity Triangle



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

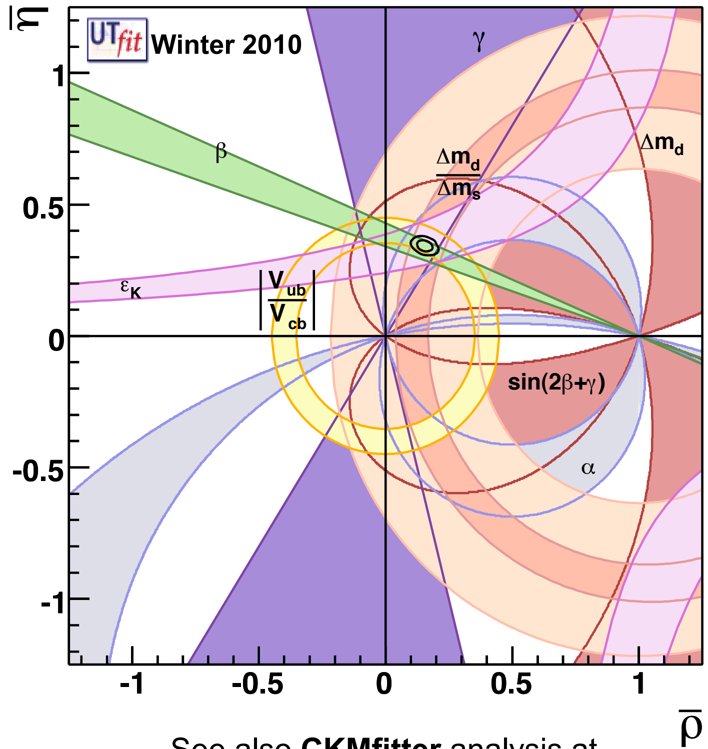
The legacy of the B factories, *in one slide*

Before the B factories



Constraints on the Unitarity Triangle
see <http://www.utfit.org/>

...and after the B factories

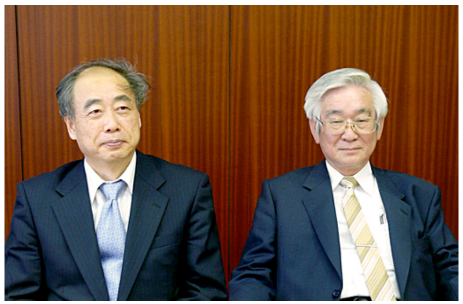


See also **CKMfitter** analysis at
<http://ckmfitter.in2p3.fr/>

The CKM mechanism is confirmed

Nicola Cabibbo

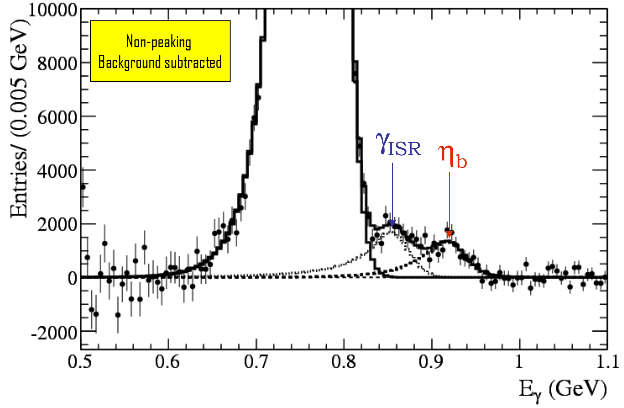
Kobayashi and Maskawa awarded half of 2008 N.P.



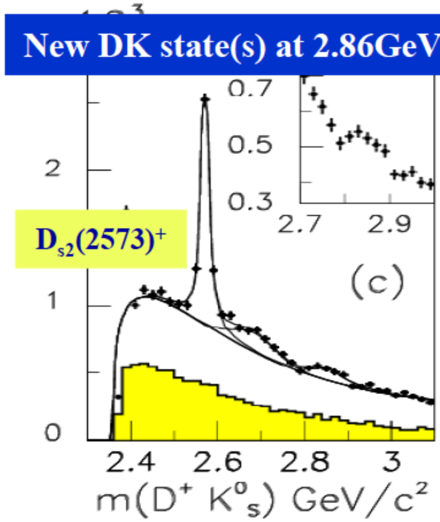
Recent results from the B factories:
well beyond the original goal

B factories recent results

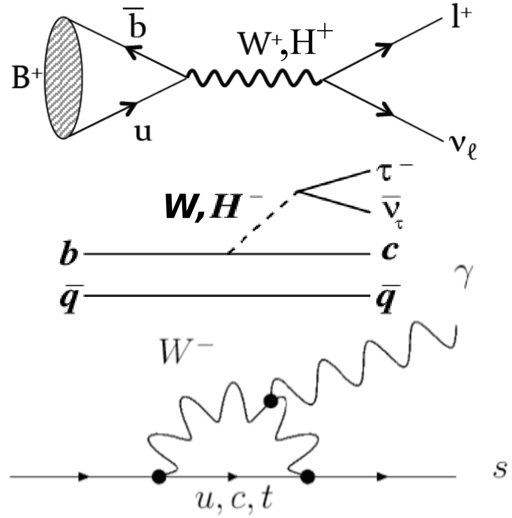
η_b *discovery* $\Upsilon(3S)\to\gamma\eta_b(1S)$

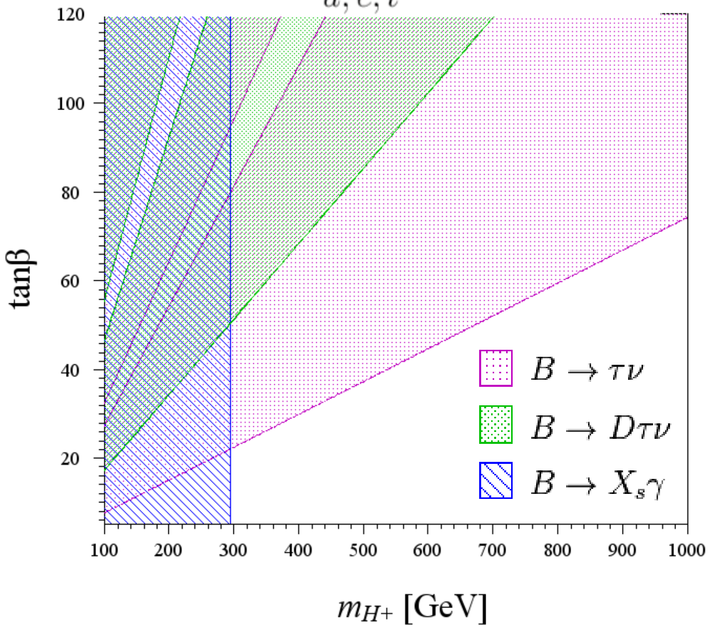


New DK state(s) at 2.86GeV/c²



Limits on New Physics (2HDM-II) from B rare decays

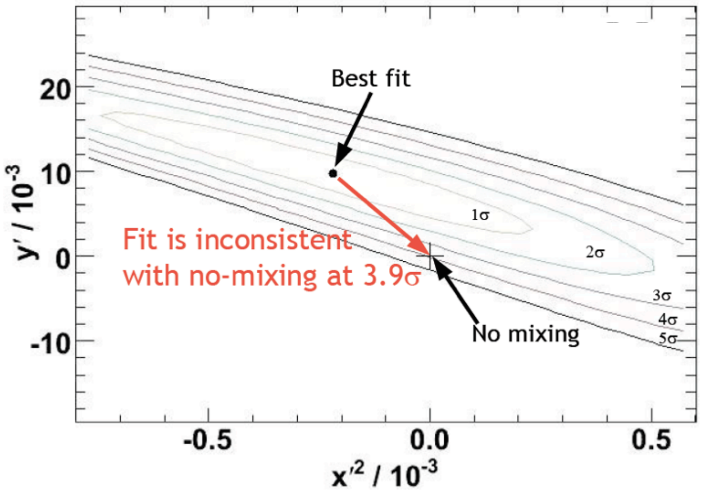




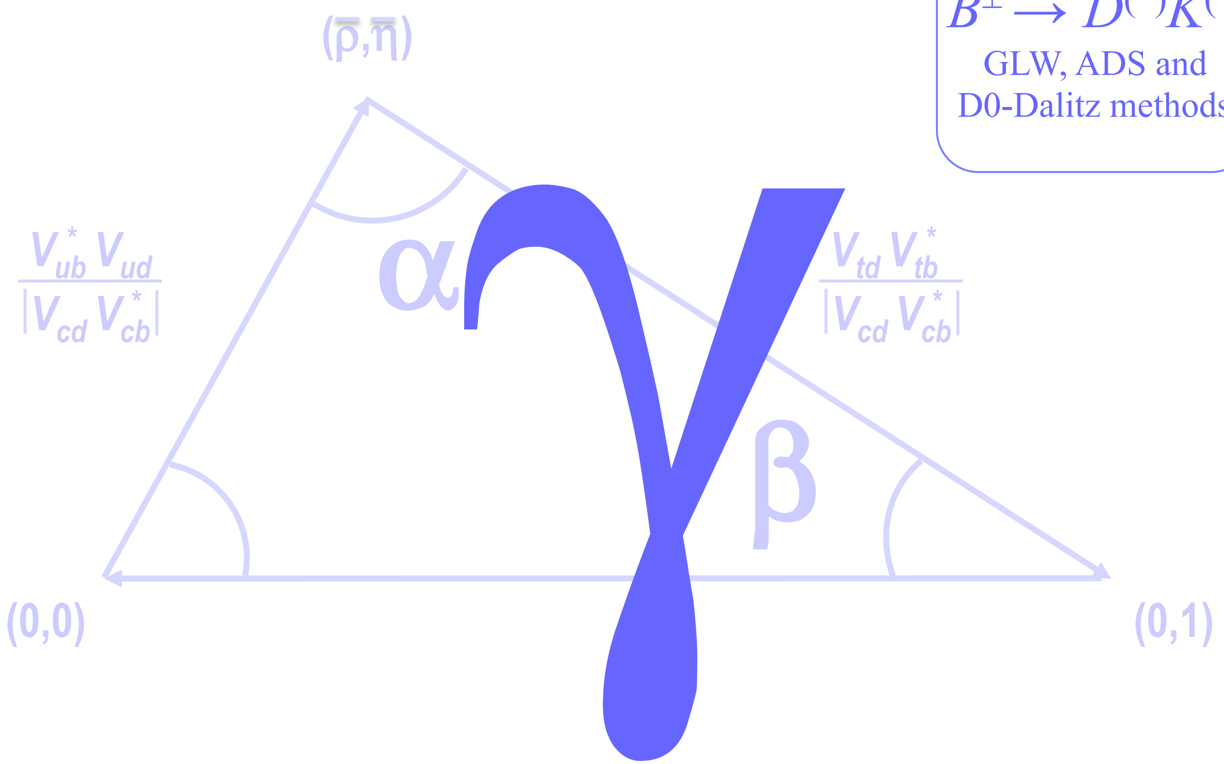
Evidence of D^0 mixing

See backup slides

See G. Casarosa talk at this conference



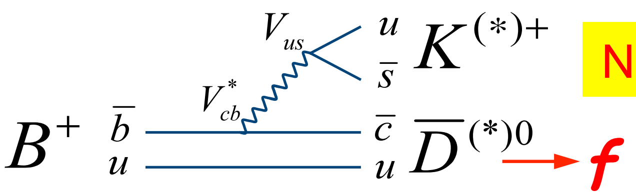
- Measurement of the CKM angle γ
  - example of a measurement of unexpected success:
    - a new analysis method proposed in 2003 (**Phys.Rev.D68:054018, 2003**) allowed measuring γ with unexpected precision at B factories.



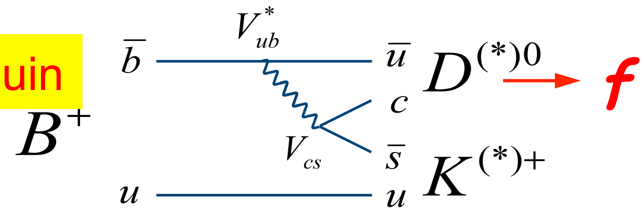
$B^{\pm} \longrightarrow D^{(*)}K^{(*)}$
GLW, ADS and
D0-Dalitz methods

γ from $B^{\pm} \to D^{(*)}K^{(*)\pm}$ decays

Extraction of γ from the interference of the decay amplitudes $b \to u\bar{c}s \ (\propto V_{ub})$ and $b \to c\bar{u}s$



No penguin



Color **favorite amplitude** b→c　　Color **suppressed amplitude** b→u

$A \propto \lambda^3$

$\lambda = |V_{us}|$

$$a = A(B^+ \to \overline{D}^0 K^+) \propto V^*_{cb} V_{us}$$

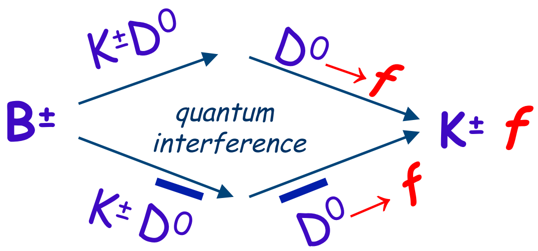
$$A(B^+ \to D^0 K^+) \propto V^*_{ub} V_{cs} = a r_B\, e^{i\delta_B} e^{i\gamma}$$

γ is here

δ_B: relative strong phase

Crucial parameter for sensitivity to γ: (not precisely measured)

$$r_B = \frac{|A(B^+ \to D^0 K^+)|}{|A(B^+ \to \overline{D}^0 K^+)|} \approx \frac{|V_{ub}||V_{cs}|}{|V_{cb}||V_{us}|} \cdot f_{COL} \approx 0.10$$



***f* = Three-body (Dalitz plot fit)**

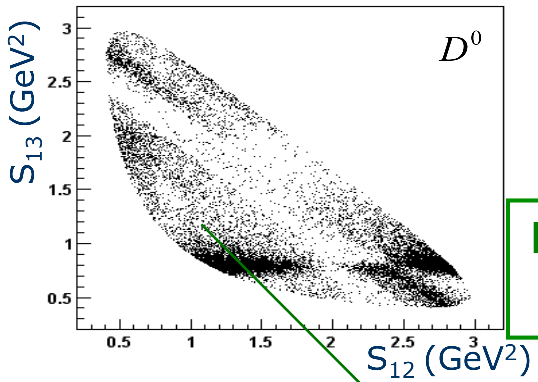
***f* = CP modes KK, ππ, $K_S\pi^0$, $K_S\omega$, $K_S\phi$ (GLW)**

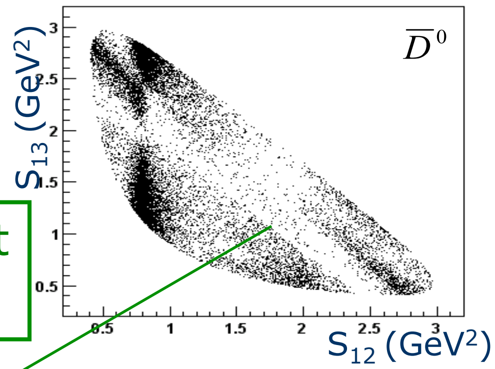
***f* = DCS doubly-Cabibbo-suppressed decays (ADS)**

$B^{\pm} \rightarrow D^{(*)} K^{(*)\pm}$ Dalitz analysis

$f = K_S h^+ h^-$

$(h = \pi, K)$





D^0 3-body decay → Dalitz plot distribution $|A_D(s_{12}, s_{13})|^2$

CP

$A(B^-) = A_D(s_{12}, s_{13}) + r_B\, e^{i(-\gamma+\delta_B)} A_D(s_{13}, s_{12})$

Assuming CP is conserved in D decays

$A(B^+) = A_D(s_{13}, s_{12}) + r_B\, e^{i(\gamma+\delta_B)} A_D(s_{12}, s_{13})$

γ from interference term

$|A(B^-)|^2 = |A_D(s_{12}, s_{13})|^2 + r_B^2\, |A_D(s_{13}, s_{12})|^2 +$

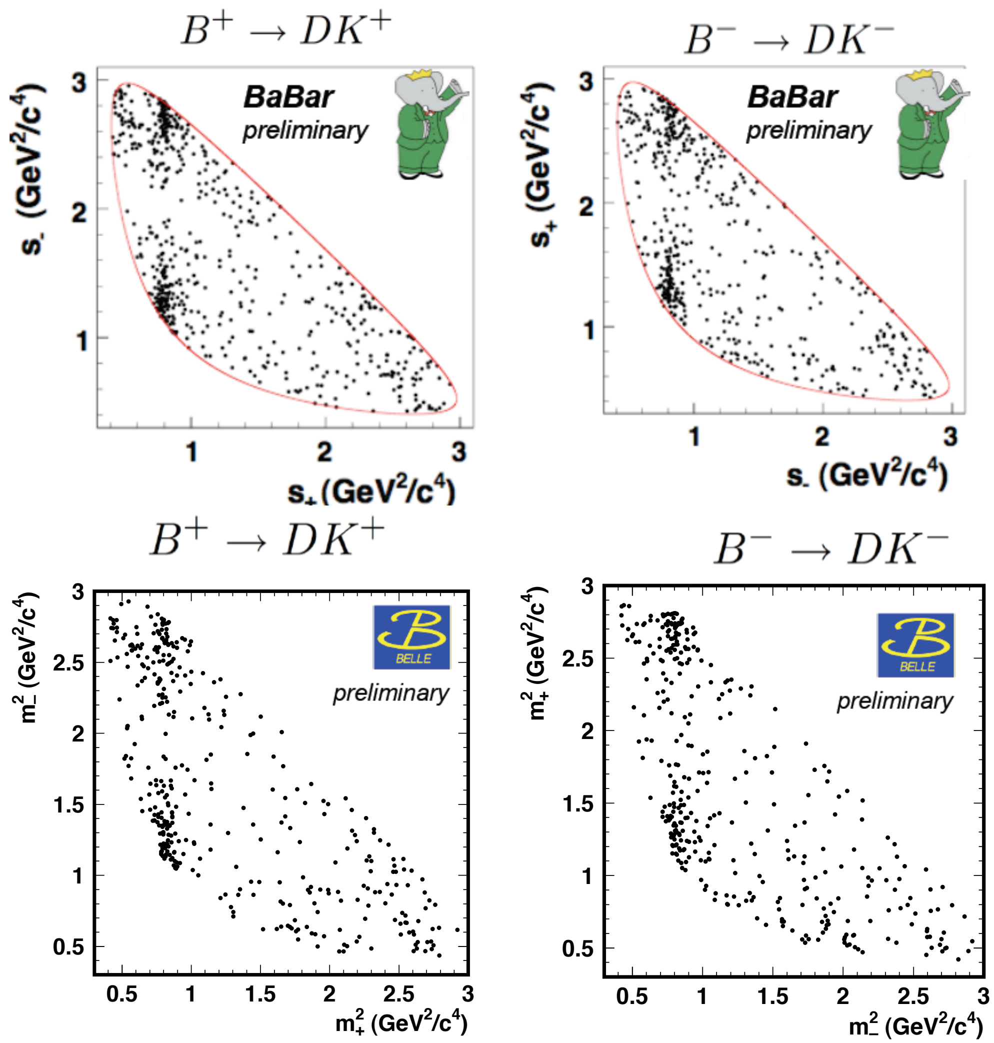
$+2 r_B \mathrm{Re}[A_D(s_{12}, s_{13})\, A_D(s_{13}, s_{12})^* \, e^{-i(-\gamma+\delta_B)}]$

Distribution of events over the D^0 Dalitz plot

Extraction of γ with a discrete ambiguity: $(\gamma, \delta_B) \rightarrow (\gamma+\pi, \delta_B+\pi)$

Theory: PRD63 (2001)036005
PRD68 (2003) 054018

$B^{\pm} \to DK^{\pm}$, $D \to K_S\pi\pi$ Dalitz plots



BELLE 605 fb^{-1} (657 MB$\bar{B}$) *BaBar 425 fb^{-1} (468 MB$\bar{B}$)*

B decay mode	***BELLE*** ($K_s\pi^+\pi^-$) ***657 MB$\bar{B}$***	***BaBar*** ($K_s\pi^+\pi^-$) ***468 MB$\bar{B}$***
$B^{\pm} \to DK^{\pm}$	757 ± 30	920 ± 35

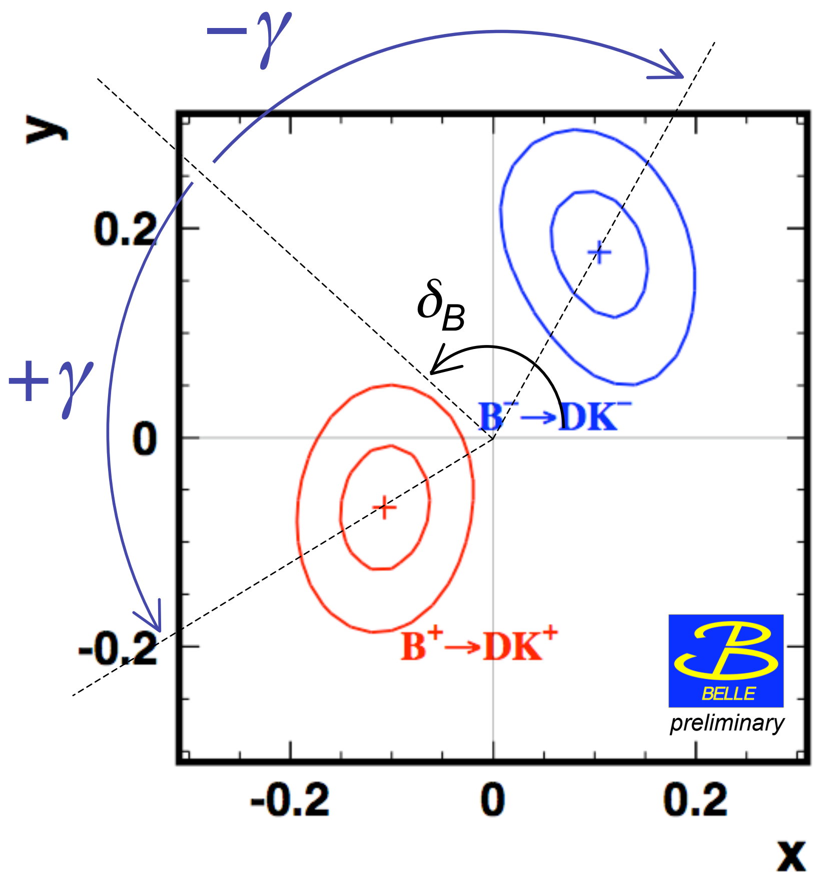
Dalitz plot variables

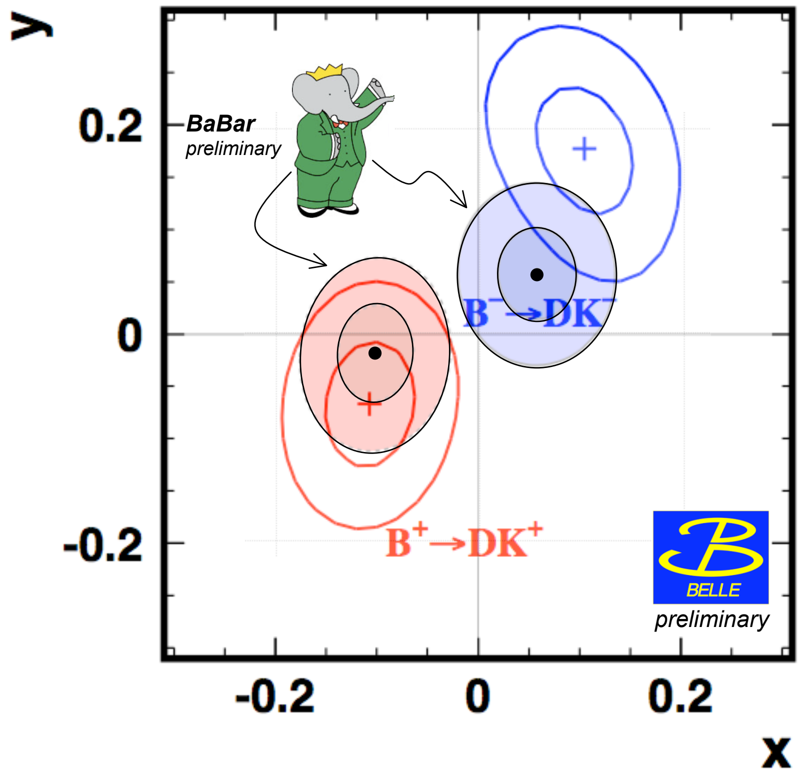
$$s_{\pm} \equiv m_{\pm}^2 = m^2(K_S^0 h^{\pm})$$

Interference terms in intensity proportional to

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

$B^{\pm} \rightarrow DK^{\pm}$ fit results

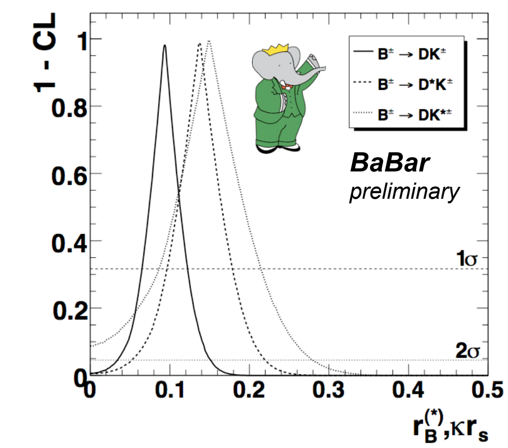


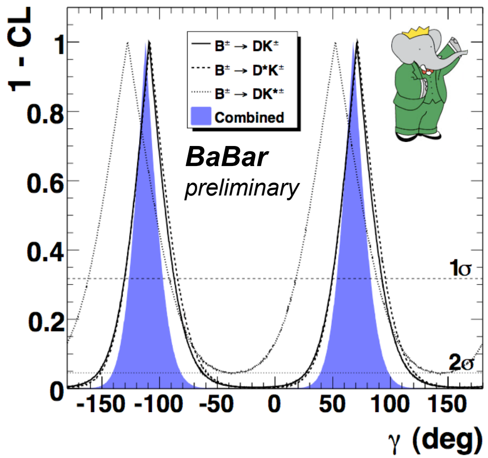


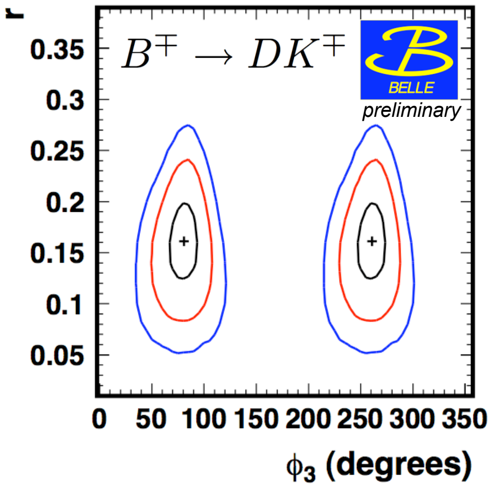
Contours are 1 and 2 sigma.

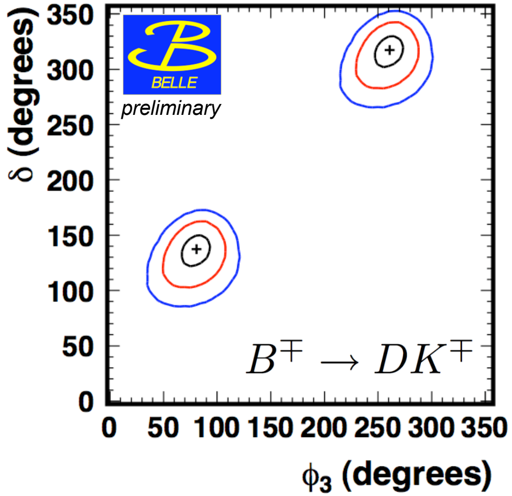
Discrete ambiguity: can add 180º to γ and δ_B.

$B^{\pm} \rightarrow D^{(*)}K^{(*)\pm}$ results: interpretation









See O. Long talk at Moriond EW, 2010

BaBar 425 fb^{-1} (468 MB$\bar{B}$)

BaBar *preliminary*

$\gamma = (68 \pm 14 \pm 4 \pm 3)^o$

(*value* ± *stat.* ± *sys.* ± *model*)^o

Excludes γ =0 at 3.5 std.dev.

$r_B(DK) = (9.4\ ^{+2.8}_{-2.9})\%$

(*value* ± *total error*)%

Error breakdown (±0.5 *expt.*, ±0.4 *model*)%

arXiv:1003.3360v2

BELLE 605 fb^{-1} (657 MB$\bar{B}$)

BELLE *preliminary*

$\gamma = (78.4\ ^{+10.8}_{-11.6} \pm 3.6 \pm 8.9)^o$

(*value* ± *stat.* ± *sys.* ± *model*)^o

*B→DK and B→D*K only, 657 MB$\bar{B}$*

Excludes γ =0 at 3.5 std.dev.

$r_B(DK) = (16.0\ ^{+4.0}_{-3.8} \pm 0.011\ ^{+5.0}_{-1.0})\%$

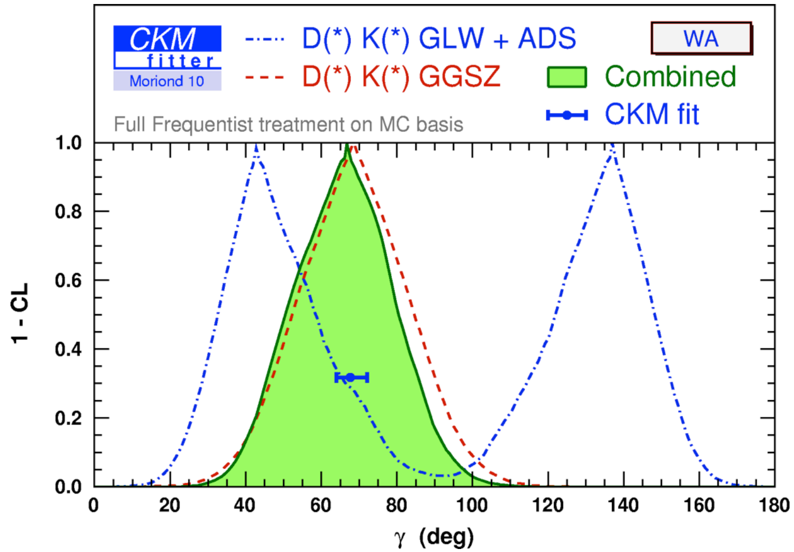
(*value* ± *stat.* ± *sys.* ± *model*)%

B decay mode	**BELLE** ($K_s\pi^+\pi^-$) 657 MB$\bar{B}$	**BaBar** ($K_s\pi^+\pi^-$) 468 MB$\bar{B}$	**BaBar** ($K_sK^+K^-$) 468 MB$\bar{B}$
$B^{\pm} \rightarrow DK^{\pm}$	757 ± 30	920 ± 35	142 ± 14
$B^{\pm} \rightarrow D^*(D\pi^0)K^{\pm}$	168 ± 15	246 ± 22	53 ± 11
$B^{\pm} \rightarrow D^*(D\gamma)K^{\pm}$	83 ± 10	191 ± 19	31 ± 7
$B^{\pm} \rightarrow DK^{*\pm}$	(*not updated to 657 MB$\bar{B}$*)	163 ± 17	28 ± 6

γ determination when combining all $B^{\pm} \to D^{(*)}K^{(*)\pm}$ results

Frequentist interpretation

http://ckmfitter.in2p3.fr



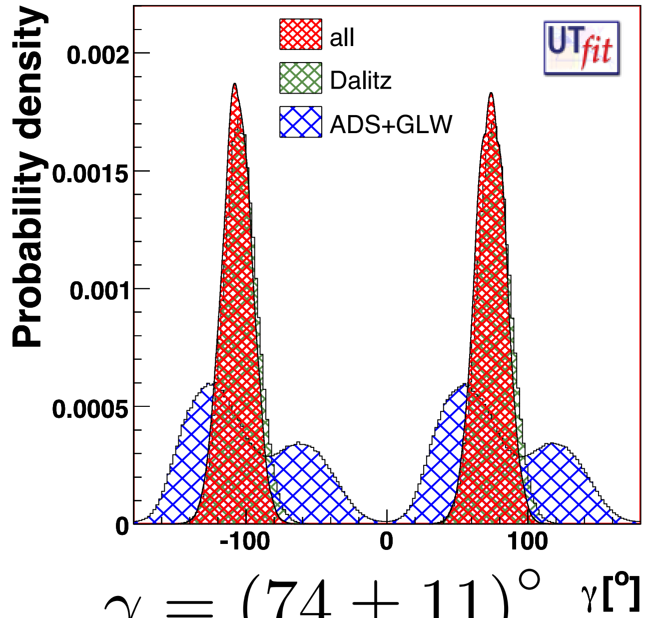
$$\gamma = (67^{+19}_{-21})^{\circ}$$

CKM fitter uses "supremum method": conservative approach but guarantees coverage.

See Karim Trabelsi's talk at CKM 2008 for details.

Bayesian interpretation

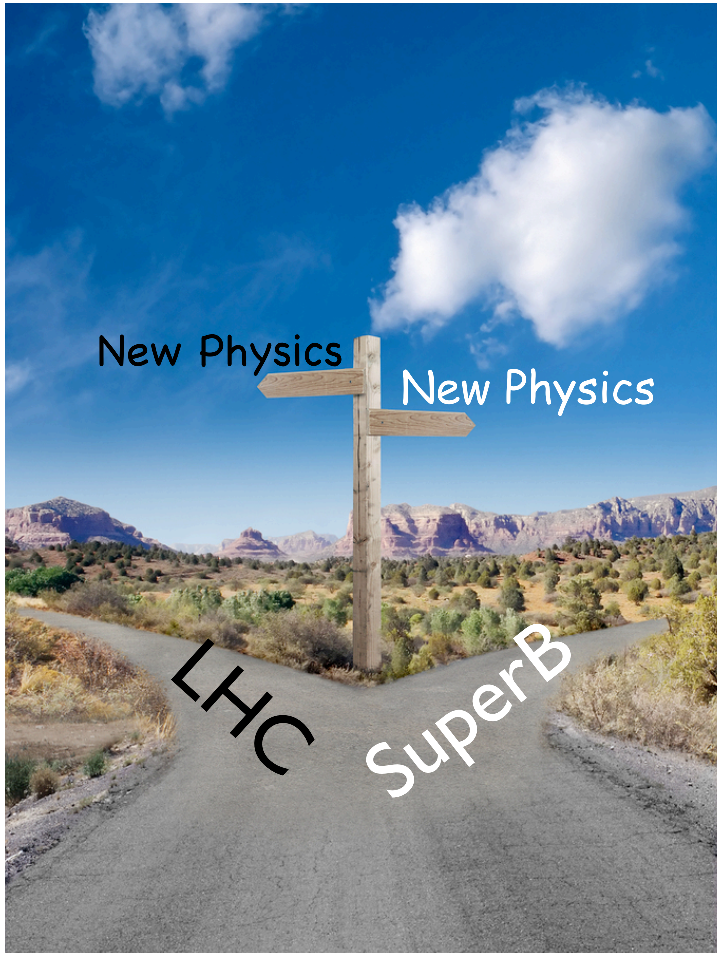
http://www.utfit.org



$$\gamma = (74 \pm 11)^{\circ}$$

- *Theoretically clean.*
- *Statistically limited.*
- *Model independent approach exists.*
- *Large improvements using higher statistics data samples at LHCb, SuperB.*

A perspective on the future



...a different path to New Physics wrt LHC.

SuperB a very high luminosity Flavor Factory.

The SuperB path to New Physics

- New Physics (NP) is expected beyond the Standard Model (SM) but the energy scale is basically unknown: 1, 10, 100, 1000... TeV?
- Possible scenarios:
  1. LHC finds New Physics (very good!) then SuperB can study the flavor structure of NP measuring the flavor couplings;
  2. LHC doesn't find NP: SuperB has the possibility to explore NP scale beyond the LHC reach (up to 10 TeV or more) looking for indirect signals.
- Complementary to LHC:
  - sensitive to off diagonal terms of the squarks mixing matrix, to the flavor structure of NP.
  - many rare decays are only accessible to SuperB;
  - search for NP in tau decays: Lepton Flavor Violation (*LFV*), *CP* violation;

    See F. Renga talk at this conference
  - search for CP violation in *D* decays;

SuperB: at the luminosity frontier

- Detection of the effects of new heavy quanta contributing in loop (tree) diagrams requires very precise measurements:
  - Statistics greater than 50 ab^{-1} is necessary to reduce the experimental error below the theoretical one for most sensitive analyses.
- SuperB baseline Luminosity: $L=10^{36}\ cm^{-2}\ s^{-1}$. Five years of running at $L=10^{36}\ cm^{-2}\ s^{-1} \rightarrow 75 ab^{-1}$. A data set almost 2 orders of magnitude larger than present B factories.
- possibility of running at $\Psi(3770)\rightarrow DD$,$Y(5S)\rightarrow B_sB_s$
- use longitudinal polarized beam (>85%), effective especially for tau physics
- above dataset with:

  -increased detector hermiticity, improved tracking and PID performance w.r.t. BaBar;

  -limited machine backgrounds (beam currents similar to B-factories);

  -reasonable electricity costs;

B Physics @ $\Upsilon(4S)$

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi K^0)$	0.018	0.005 (†)
$\cos(2\beta)$ $(J/\psi K^{*0})$	0.30	0.05
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi\,\pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03
$S(\phi K^0)$	0.13	0.02 (∗)
$S(\eta' K^0)$	0.05	0.01 (∗)
$S(K^0_s K^0_s K^0_s)$	0.15	0.02 (∗)
$S(K^0_s \pi^0)$	0.15	0.02 (∗)
$S(\omega K^0_s)$	0.17	0.03 (∗)
$S(f_0 K^0_s)$	0.12	0.02 (∗)
γ $(B \to DK,\ D \to CP$ eigenstates$)$	$\sim 15^\circ$	2.5°
γ $(B \to DK,\ D \to$ suppressed states$)$	$\sim 12^\circ$	2.0°
γ $(B \to DK,\ D \to$ multibody states$)$	$\sim 9^\circ$	1.5°
γ $(B \to DK$, combined$)$	$\sim 6^\circ$	1–2°
α $(B \to \pi\pi)$	$\sim 16^\circ$	3°
α $(B \to \rho\rho)$	$\sim 7^\circ$	1–2° (∗)
α $(B \to \rho\pi)$	$\sim 12^\circ$	2°
α (combined)	$\sim 6^\circ$	1–2° (∗)
$2\beta+\gamma$ $(D^{(*)\pm}\pi^\mp,\ D^\pm K^0_s \pi^\mp)$	20°	5°

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\vert V_{cb}\vert$ (exclusive)	4% (∗)	1.0% (∗)
$\vert V_{cb}\vert$ (inclusive)	1% (∗)	0.5% (∗)
$\vert V_{ub}\vert$ (exclusive)	8% (∗)	3.0% (∗)
$\vert V_{ub}\vert$ (inclusive)	8% (∗)	2.0% (∗)
$\mathcal{B}(B \to \tau\nu)$	20%	4% (†)
$\mathcal{B}(B \to \mu\nu)$	visible	5%
$\mathcal{B}(B \to D\tau\nu)$	10%	2%
$\mathcal{B}(B \to \rho\gamma)$	15%	3% (†)
$\mathcal{B}(B \to \omega\gamma)$	30%	5%
$A_{CP}(B \to K^*\gamma)$	0.007 (†)	0.004 († ∗)
$A_{CP}(B \to \rho\gamma)$	~ 0.20	0.05
$A_{CP}(b \to s\gamma)$	0.012 (†)	0.004 (†)
$A_{CP}(b \to (s+d)\gamma)$	0.03	0.006 (†)
$S(K^0_S \pi^0 \gamma)$	0.15	0.02 (∗)
$S(\rho^0\gamma)$	possible	0.10
$A_{CP}(B \to K^*\ell\ell)$	7%	1%
$A^{FB}(B \to K^*\ell\ell)s_0$	25%	9%
$A^{FB}(B \to X_s\ell\ell)s_0$	35%	5%
$\mathcal{B}(B \to K\nu\bar{\nu})$	visible	20%
$\mathcal{B}(B \to \pi\nu\bar{\nu})$	–	possible

Charm mixing and CP

Mode	Observable	$\Upsilon(4S)$ (75 ab^{-1})	$\psi(3770)$ (300 fb^{-1})
$D^0 \to K^+\pi^-$	x'^2	3×10^{-5}	
	y'	7×10^{-4}	
$D^0 \to K^+K^-$	y_{CP}	5×10^{-4}	
$D^0 \to K^0_S \pi^+\pi^-$	x	4.9×10^{-4}	
	y	3.5×10^{-4}	
	$\vert q/p\vert$	3×10^{-2}	
	ϕ	2°	
$\psi(3770) \to D^0\overline{D}^0$	x^2		$(1-2) \times 10^{-5}$
	y		$(1-2) \times 10^{-3}$
	$\cos\delta$		$(0.01-0.02)$

Charm FCNC

Channel	Sensitivity
$D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$	1×10^{-8}
$D^0 \to \pi^0 e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$	2×10^{-8}
$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$	3×10^{-8}
$D^0 \to K^0_S e^+e^-$, $D^0 \to K^0_S \mu^+\mu^-$	3×10^{-8}
$D^+ \to \pi^+e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$	1×10^{-8}
$D^0 \to e^\pm\mu^\mp$	1×10^{-8}
$D^+ \to \pi^+e^\pm\mu^\mp$	1×10^{-8}
$D^0 \to \pi^0 e^\pm\mu^\mp$	2×10^{-8}
$D^0 \to \eta e^\pm\mu^\mp$	3×10^{-8}
$D^0 \to K^0_S e^\pm\mu^\mp$	3×10^{-8}
$D^+ \to \pi^-e^+e^+$, $D^+ \to K^-e^+e^+$	1×10^{-8}
$D^+ \to \pi^-\mu^+\mu^+$, $D^+ \to K^-\mu^+\mu^+$	1×10^{-8}
$D^+ \to \pi^-e^\pm\mu^\mp$, $D^+ \to K^-e^\pm\mu^\mp$	1×10^{-8}

τ Physics

Process	Sensitivity
$\mathcal{B}(\tau \to \mu\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell K^0_S)$	2×10^{-10}

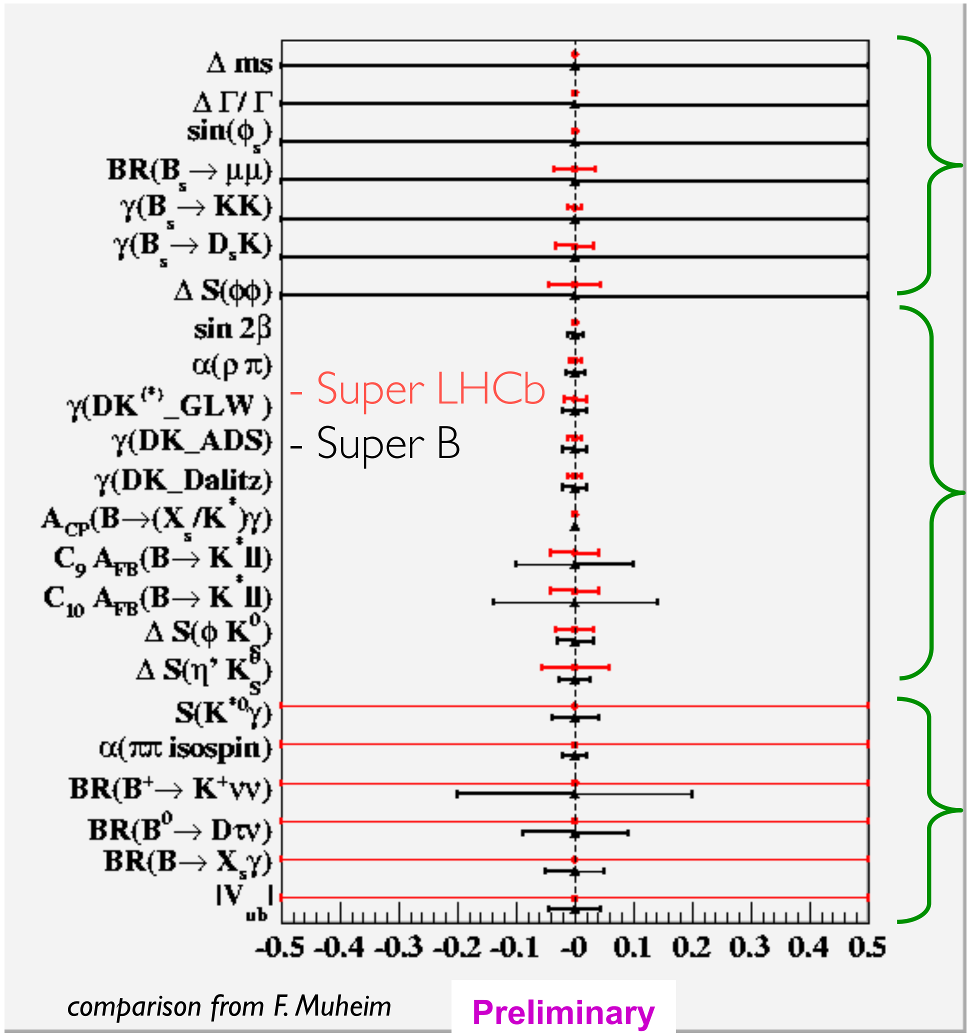
B_s Physics @ $\Upsilon(5S)$

Observable	Error with 1 ab^{-1}	Error with 30 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}	0.03 ps^{-1}
Γ	0.07 ps^{-1}	0.01 ps^{-1}
β_s from angular analysis	20°	8°
A^s_{SL}	0.006	0.004
A_{CH}	0.004	0.004
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-	$< 8 \times 10^{-9}$
$\vert V_{td}/V_{ts}\vert$	0.08	0.017
$\mathcal{B}(B_s \to \gamma\gamma)$	38%	7%
β_s from $J/\psi\phi$	10°	3°
β_s from $B_s \to K^0\bar{K}^0$	24°	11°

Spectroscopy

SuperB vs. Super LHCb

Super LHCb 100 fb^{-1} vs SuperB 50 ab^{-1}



B_s time dependent analysis only accessible to LHCb

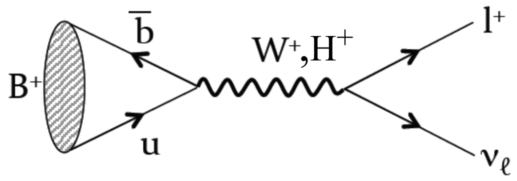
Common

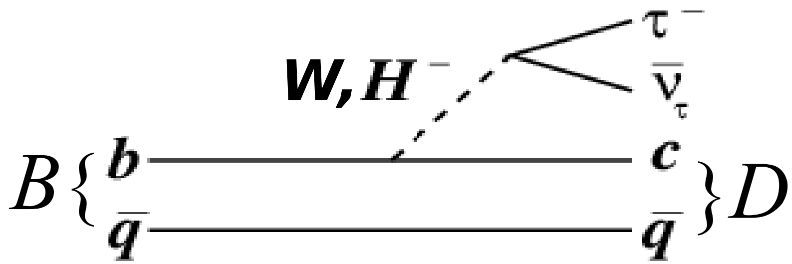
Decays with neutrinos, neutrals, only accessible to SuperB

Constraints on NP from $B \to \tau\nu, B \to D\tau\nu$

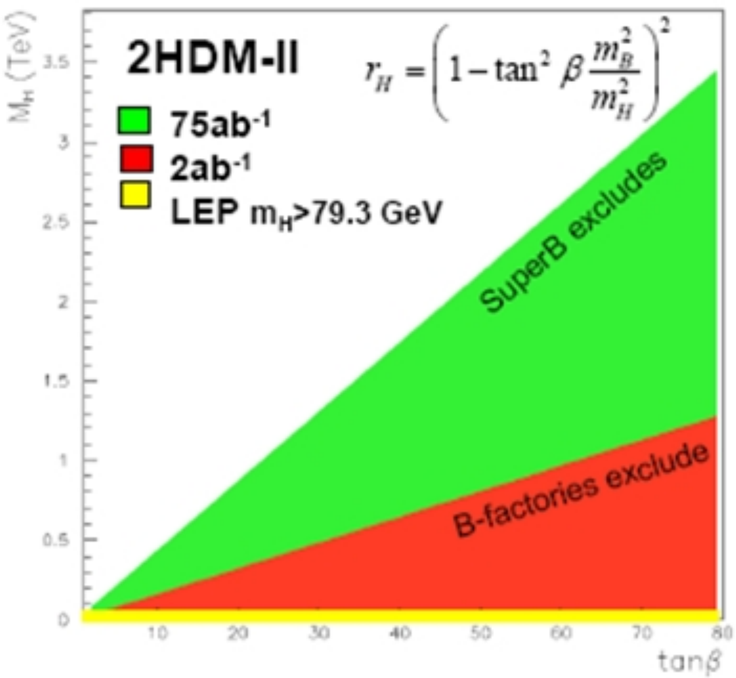
Charged Higgs contribution in 2HDM-II

$$\mathcal{B}(B \to l\nu)_{2HDM} = \mathcal{B}(B \to l\nu)_{SM} \times (1 - tan^2\beta \frac{m_B^2}{m_H^2})^2$$

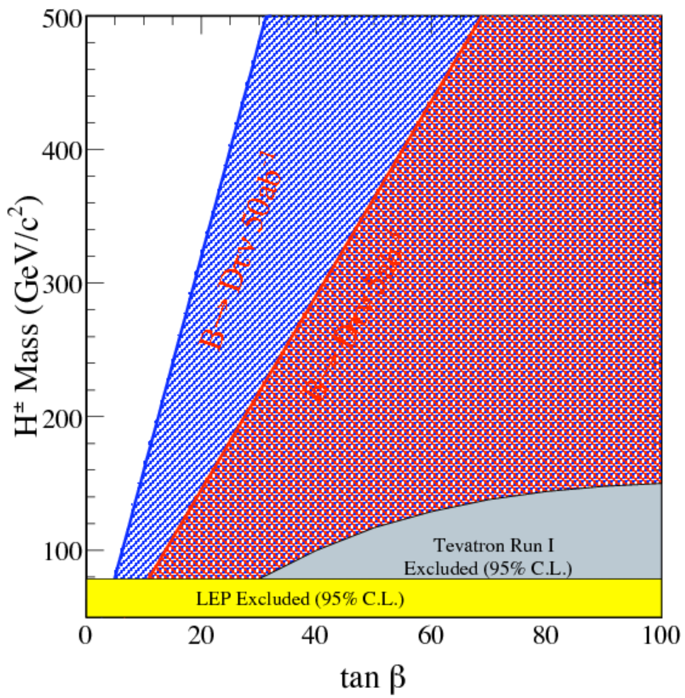




Regions in the (mH+,tanβ) parameter space of the 2HDM-II excluded at 95% probability by B→τν and B→lν



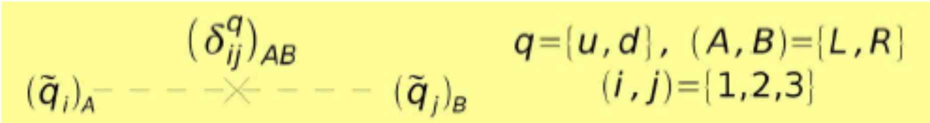
Regions in the (mH+,tanβ) parameter space of the 2HDM-II excluded at 95% probability by B→Dτν



Constraints on NP with mass insertions

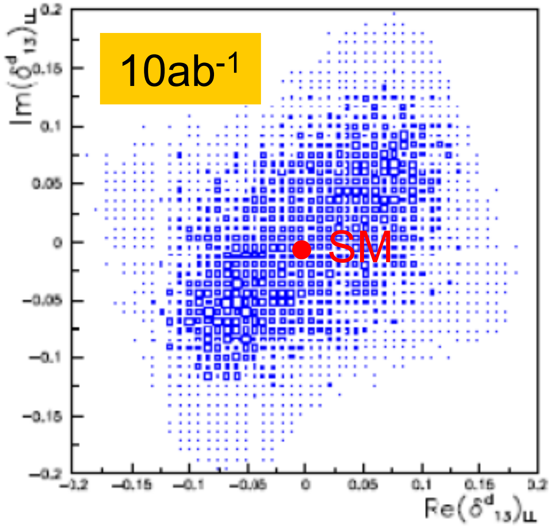
D. Becirevic, *et. al.*, Nucl.Phys.B634:105-119,2002

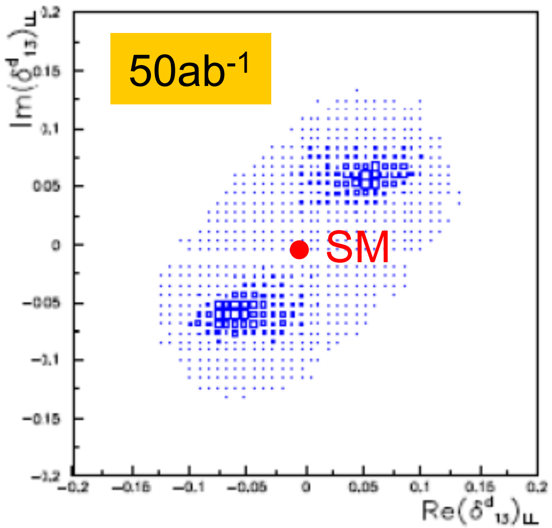
MSSM with generic squark mass matrices



$(\delta_{ij}^q)_{AB}$= SUSY mass insertions parameters

constraints on $(\delta_{13})_{LL}$ *from* $\Delta m_d, \beta$ *and* $\bar{\rho}, \bar{\eta}$





for $m_{\tilde{q}} = m_{\tilde{g}} = 1$ TeV and $(\delta_{13}^d)_{LL} = 0.085 e^{i\pi/4}$

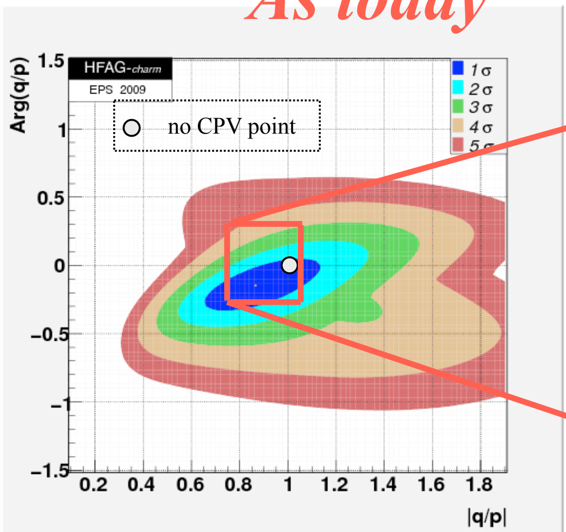
CP violation in Charm sector

- Recent evidence of *D* mixing from BaBar, Belle and CDF opens new windows to search for New Physics.
- CP violation in charm decays would represent a signal of New Physics.
- The SuperB data sample would allow to improve the sensitivity on CPV almost by a factor 10.

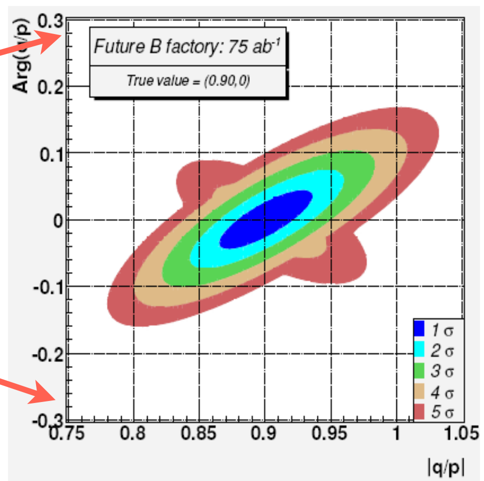
$L = 10^{36} cm^{-2} s^{-1}$ $L = 10^{35} cm^{-2} s^{-1}$

SuperB will be able to run both at $\Upsilon(4S)$ and $\Psi(3770)$

As today



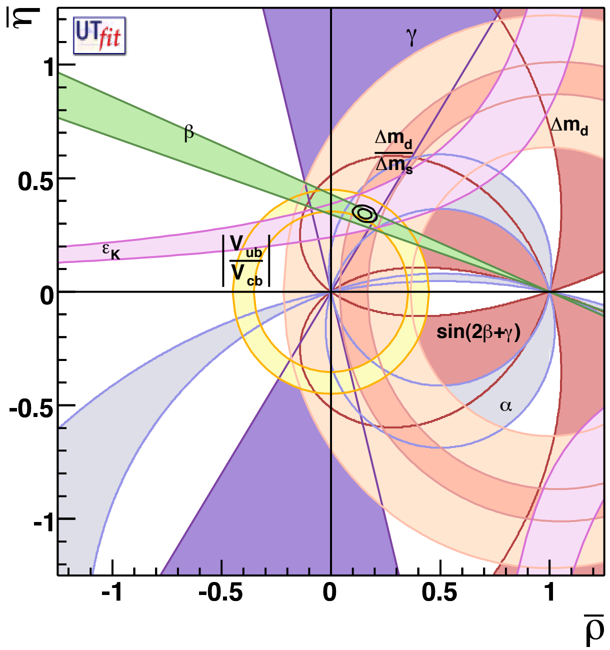
At SuperB



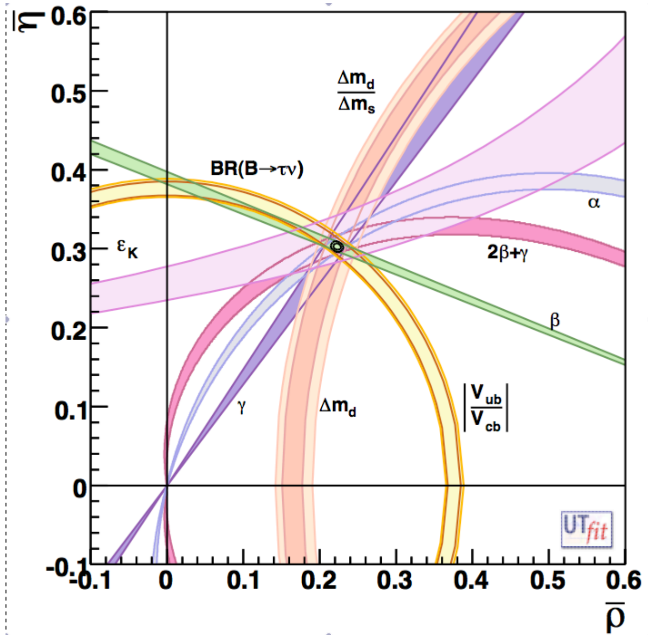
Mode	Observable	$\Upsilon(4S)$ (75 ab^{-1})	$\psi(3770)$ (300 fb^{-1})	LHCb (10 fb^{-1})
$D^0 \to K^+\pi^-$	x'^2	3×10^{-5}	*2 month running*	6×10^{-5}
	y'	7×10^{-4}		9×10^{-4}
$D^0 \to K^+K^-$	y_{CP}	5×10^{-4}		5×10^{-4}
$D^0 \to K^0_S\pi^+\pi^-$	x	4.9×10^{-4}		
	y	3.5×10^{-4}		
	$\lvert q/p \rvert$	3×10^{-2}		
	ϕ	2°		
$\psi(3770) \to D^0\overline{D}^0$	x^2		$(1-2) \times 10^{-5}$	
	y		$(1-2) \times 10^{-3}$	
	$\cos\delta$		$(0.01-0.02)$	

CKM precision measurements

As today



At SuperB (with 50 ab^{-1})



Parameters	UT Fit Today	UT fit at SuperB (50 ab^{-1})
$\bar{\rho}$	0.154 ± 0.022	±0.0028
$\bar{\eta}$	0.342 ± 0.014	±0.0024
α(°)	92.0 ± 3.4	±0.45
β(°)	22.0 ± 0.8	±0.17
γ(°)	65.6 ± 3.3	±0.38

Expected an improvement in sensitivity of about an order of magnitude.

Test of CKM mechanism better than 1% level precision.

Conclusions

- B factories (BaBar and Belle) confirmed the success of the CKM mechanism:
  - results well beyond the original physics goal:
    - discovery of new states, evidence of D^0 mixing, sizable constraints on New Physics models, many more...
    - analyses sensitive to New Physics effects are statistically limited.
- SuperB experiment represents an alternative path to New Physics wrt LHC program:
  - explore NP scale beyond the LHC reach looking for indirect signals.
  - study the flavor structure of NP

Next SuperB meeting: http://www.pi.infn.it/bfactory/elba2010.html

XIII SuperB General Meeting - Isola d'Elba from 30 May 2010 to 05 June 2010

Backup Slides

B factories physics program

- B physics:
  - CKM matrix and Unitarity Triangle (UT):
  - Rare decays: leptonic decays, radiative decays
  - Searches for Standard Model forbidden processes
  - Spectroscopy

- Charm physics:
  - D^0 mixing and search for CP violation:
  - Rare decays: leptonic decays, radiative decays
  - Searches for Standard Model forbidden processes
  - Spectroscopy

- Tau physics:
  - Searches for lepton flavor violating (LFV) decays
  - Lepton universality

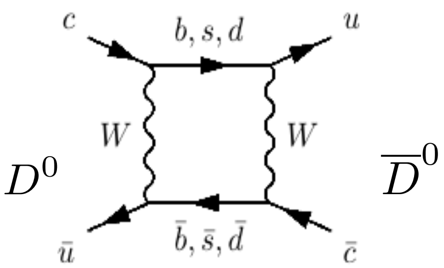
- Upsilon(2S), (3S) physics:
  - Searches for Standard Model forbidden processes

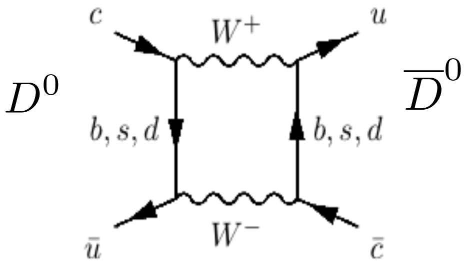
- Initial State Radiation (ISR)physics:
  - Spectroscopy, form factors

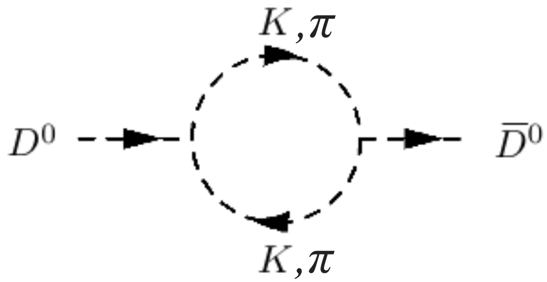
BaBar published about 420 papers

Belle published about 300 papers

- $D^0 - \overline{D}^0$ mixing and search for CP violation







- Select D^0 candidates from $e^+e^- \to c\bar{c}$ events:
  - "flavor tagged" at production according to the pion charge $D^{*+} \to D^0\pi^+$.
  - "flavor untagged" 4 times statistics wrt "flavor tagged" sample but with lower purity.

- Flavor mixing occurs when flavor eigenstates differ from mass eigenstates: well established phenomena in neutral K, B_d, B_s systems.

$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle \qquad |q|^2 + |p|^2 = 1$$

- Mixing parameters are expressed in terms of *x*, *y* parameters, proportional to the mass and decay width differences of the mass eigenstates:

$$x = \frac{m_1 - m_2}{\Gamma}; \quad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}, \text{ where } \Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$$

Large theoretical uncertainties on x, y values. In SM expected $|x| < 10^{-2}$, $|y| < 10^{-2}$.
Observation of large CP violation in $D^0 - \overline{D}^0$ *system would be evidence of new physics.*

Mixing in lifetime ratio of the CP-even eigenstates $D^0 \to K^+K^-, \pi^+\pi^- \ vs \ K^-\pi^+$

- Mixing and CPV will alter the decay time distribution of CP eigenstates to exponential with effective lifetimes $\tau_{hh}^{\pm}$:

$$\tau_{hh}^{+} = \tau(D^0 \to h^+h^-)$$
$$\tau_{hh}^{-} = \tau(\overline{D}^0 \to h^+h^-)$$
$$\tau_{K\pi} = \tau(D^0 \to K^-\pi^+)$$

→ *measured quantities*

Mixing and CP violation (CPV) observables

Mixing: $y_{CP} = \frac{\tau_{K\pi}}{\langle\tau_{hh}\rangle} - 1$

CPV: $\Delta Y = \frac{\tau_{K\pi}}{\langle\tau_{hh}\rangle} A_\tau; \ \left(\Delta Y = -\frac{\tau_{K\pi}}{\langle\tau_{hh}\rangle} A_\Gamma\right)$

$$\langle\tau_{hh}\rangle \overset{def.}{=} \frac{\tau_{hh}^{+} + \tau_{hh}^{-}}{2}$$

$$A_\tau = \frac{\tau_{hh}^{+} - \tau_{hh}^{-}}{\tau_{hh}^{+} + \tau_{hh}^{-}} = -A_\Gamma$$

If CP is conserved $y_{CP} \equiv y$ *and* $\Delta Y = A_\Gamma = 0$

Belle results for CP-even decays: y_{CP}, A_Γ

Using 540 fb^{-1} of data

PRL 98:211803,2007

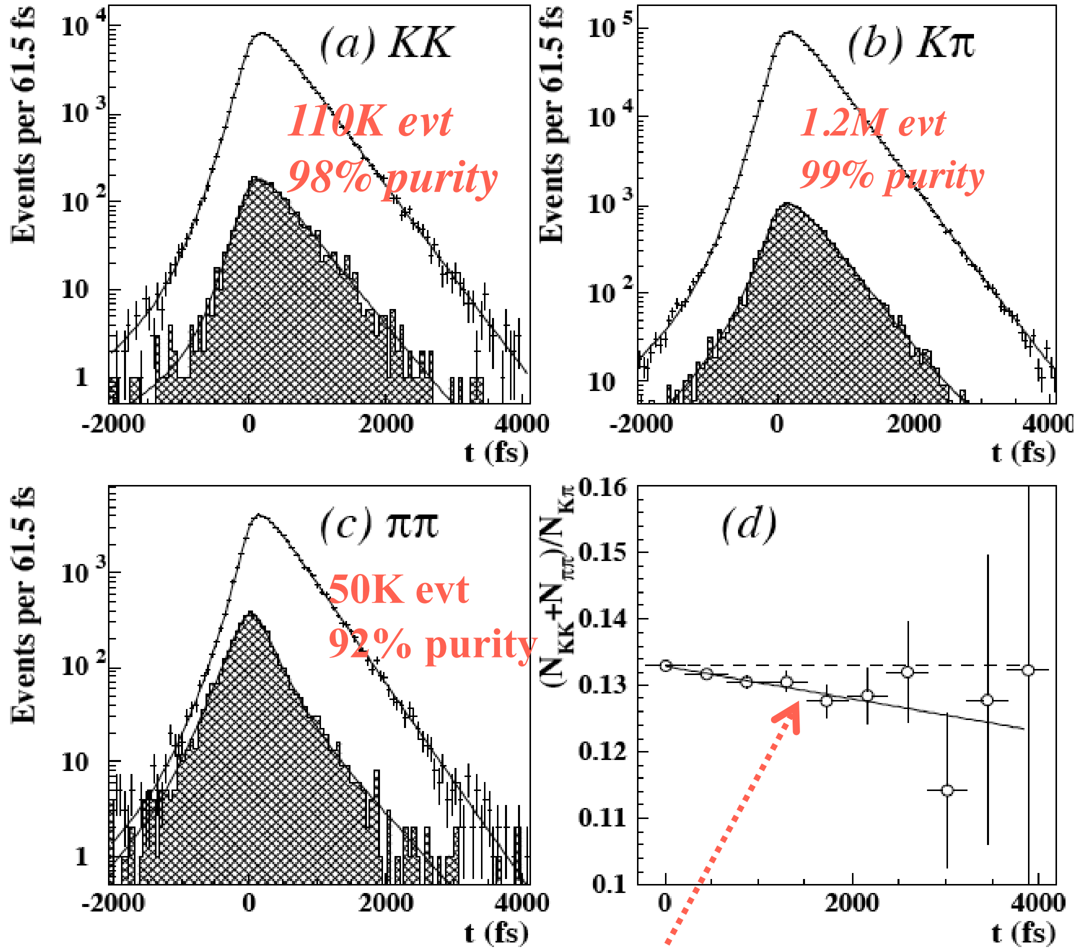
Use only D^* tagged events

	y_{CP} (%)	A_Γ(%)
KK	1.25±0.39±0.28	0.15±0.34±0.16
ππ	1.44±0.57±0.42	-0.28±0.52±0.30
KK+ππ	1.31±0.32±0.25	0.01±0.30±0.15

$$A_\Gamma \simeq -\Delta Y$$

Evidence of mixing at 3.2σ level.

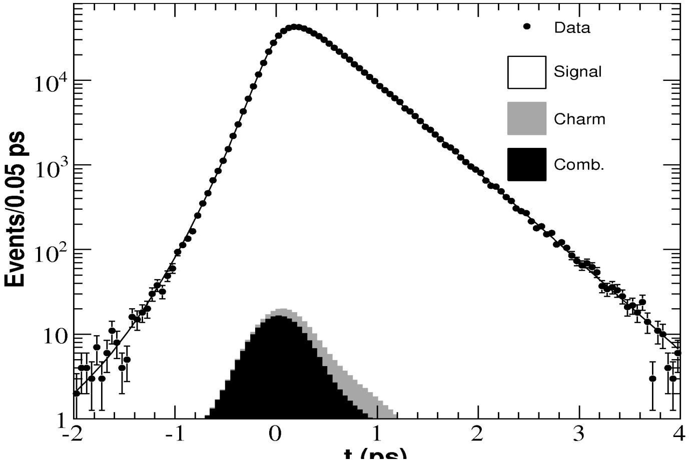
No evidence for CP violation



Ratio of D^0_{CP}/D^0 events varies as a function of time due to lifetime difference ($y_{CP} \neq 0$)

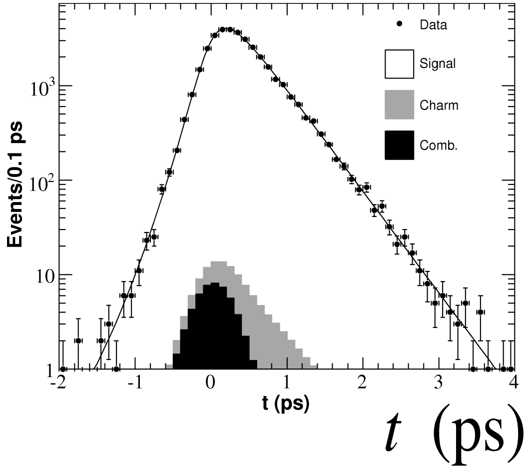
BaBar results for "tagged" sample

$D^0 \to K^-\pi^+$ +c.c.

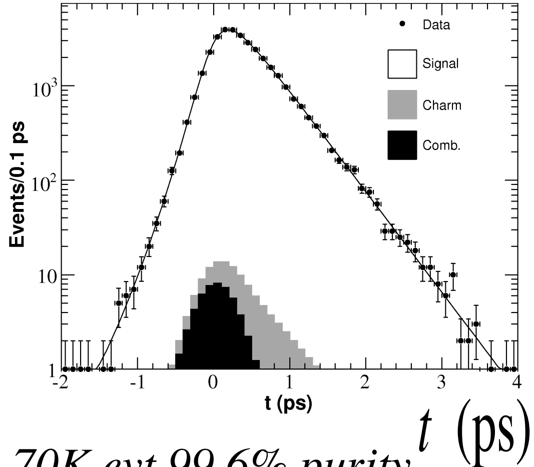


730K evt 99.9% purity

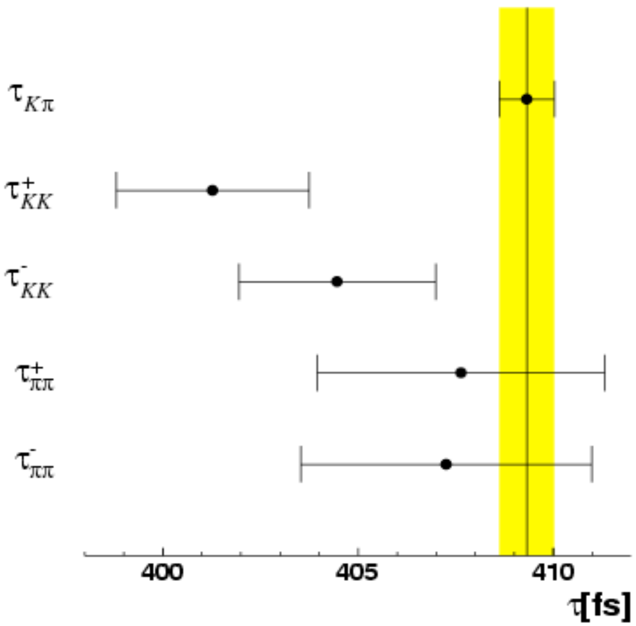
$D^0 \to K^+K^-$



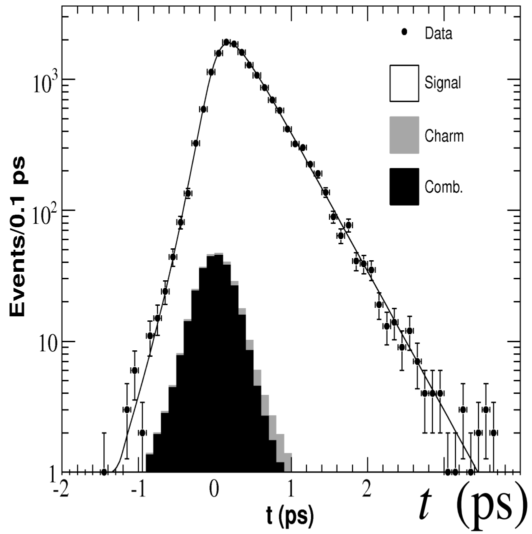
$\overline{D}^0 \to K^+K^-$



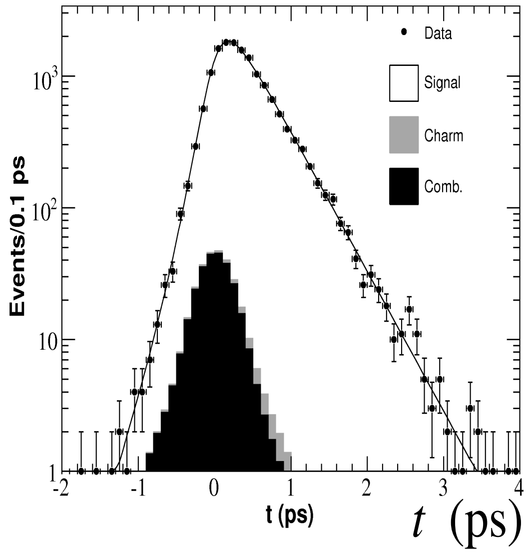
70K evt 99.6% purity



$D^0 \to \pi^+\pi^-$



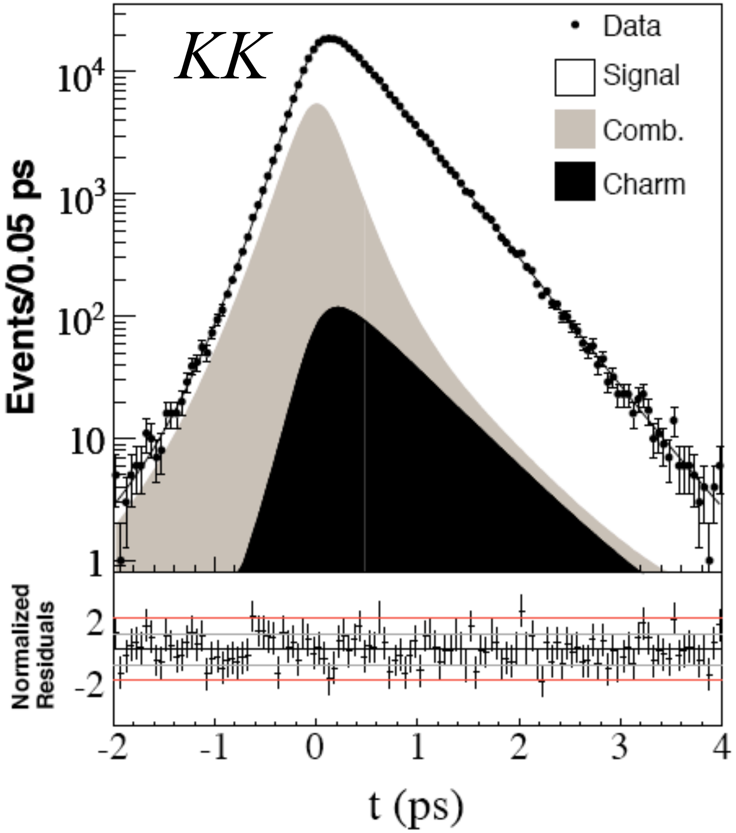
$\overline{D}^0 \to \pi^+\pi^-$

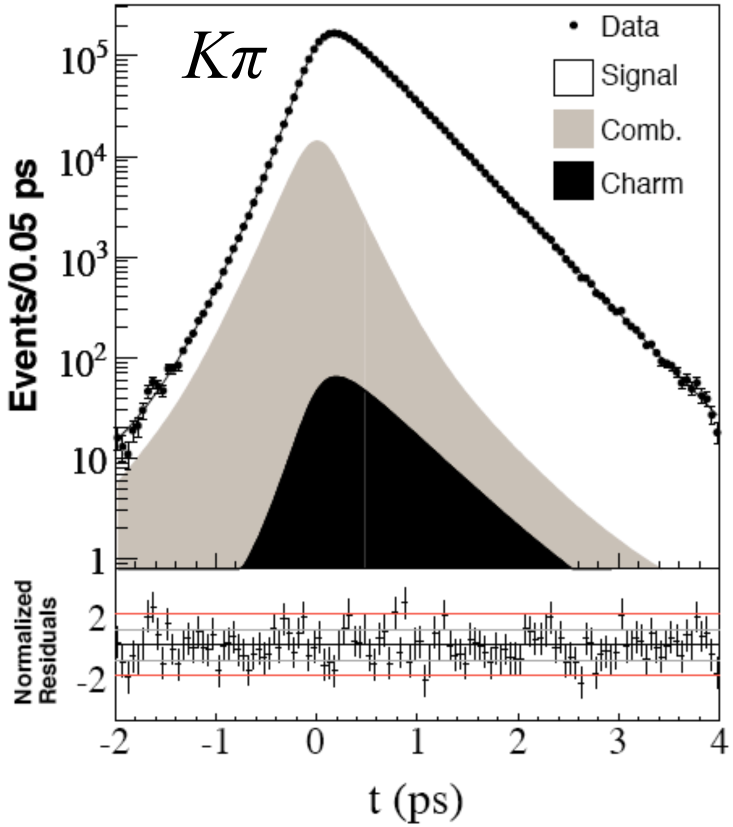


30K evt 98.0% purity

***K*π and *KK* lifetimes differ!**

BaBar results for "untagged" sample





t_{KK} *(fs) = 405.85 ± 1.00 (stat.)*

$t_{K\pi}$ *(fs) = 410.39 ± 0.38 (stat.)*

BaBar results based on 384 fb^{-1} of data

- "Flavor Tagged" analysis: ***PRD 78 011105(R) (2008)***

Sample	y_{CP}	ΔY
K^-K^+	$(1.60 \pm 0.46 \pm 0.17)\%$	$(-0.40 \pm 0.44 \pm 0.12)\%$
$\pi^-\pi^+$	$(0.46 \pm 0.65 \pm 0.25)\%$	$(\ \ 0.05 \pm 0.64 \pm 0.32)\%$
Combined	$(1.24 \pm 0.39 \pm 0.13)\%$	$(-0.26 \pm 0.36 \pm 0.08)\%$

Evidence of mixing at 3σ level *No evidence of CP violation*

- Combined y_{CP} result: "Tagged" + "Untagged" analysis:

statistically uncorrelated samples, conservatively assuming 100% correlation in systematic errors

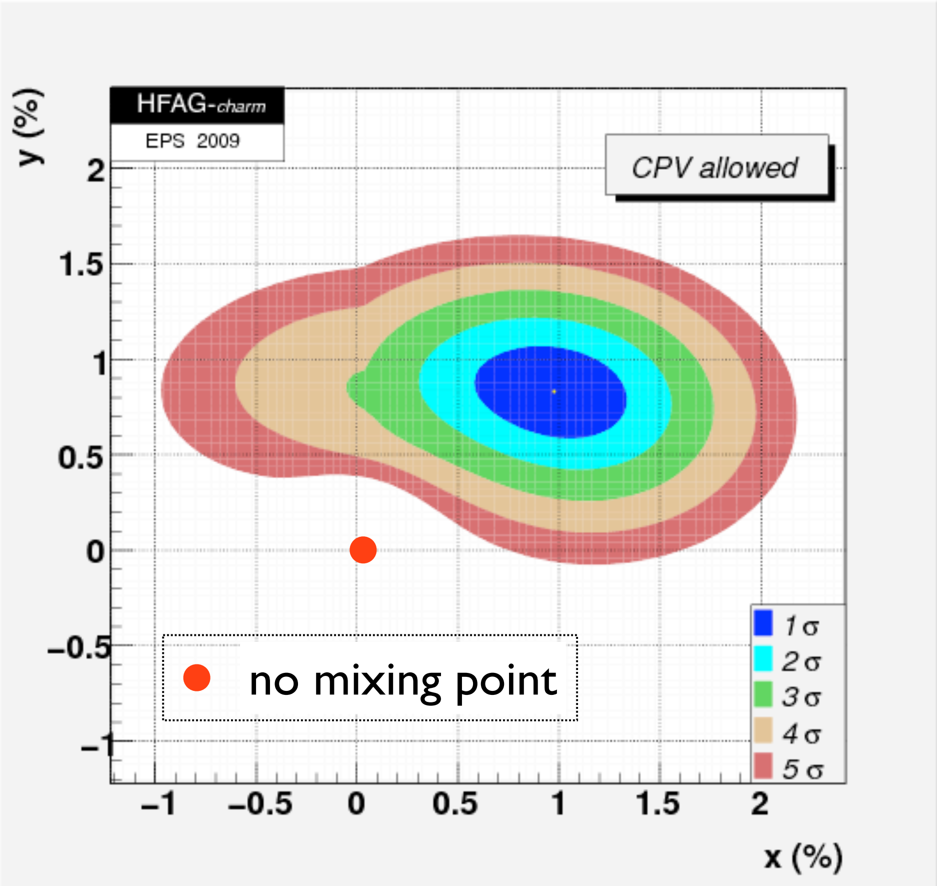
$$y_{CP} = [\ 1.16 \pm 0.22\ (\text{stat}) \pm 0.18\ (\text{syst})\ ]\%$$

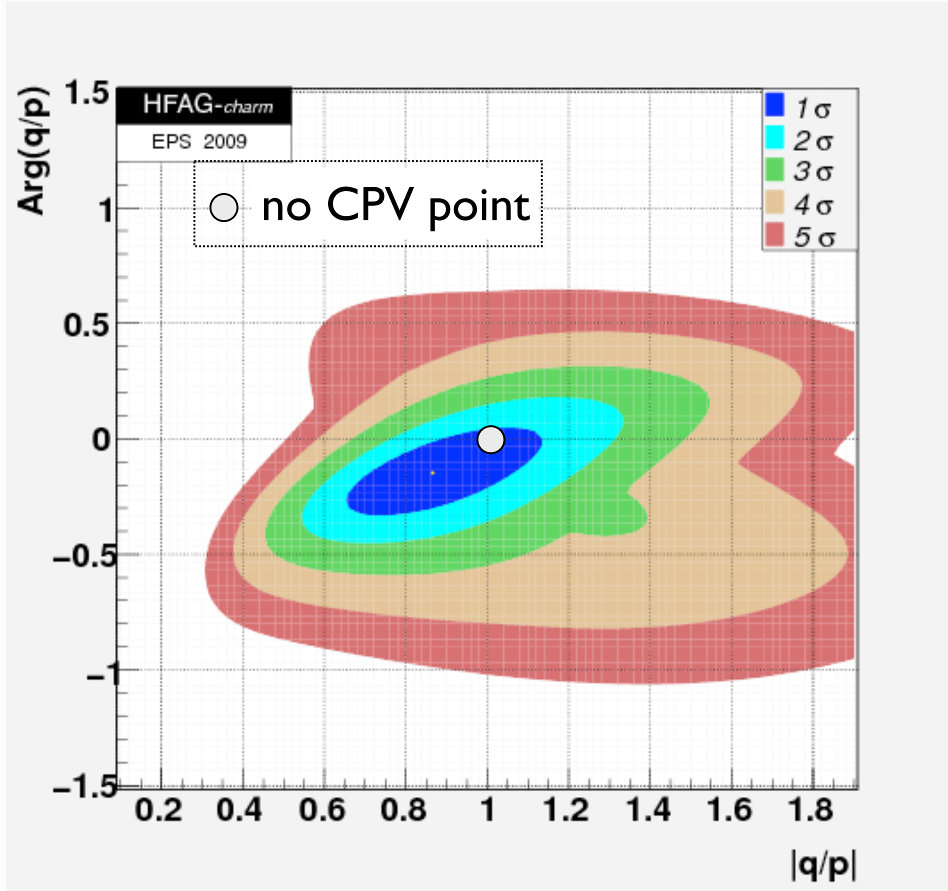
Evidence of mixing at 4.1σ level

PRD 80, 071103(R) (2009)

HFAG average for mixing and CPV parameters

Updated averages (CPV allowed) with all available measurements: mostly from B Factories (also CDF).





$x = (0.976 \pm 0.249)\%$
$y = (0.833 \pm 0.160)\%$

$|q/p| = 0.866 \pm 0.160$
$\varphi = -0.148 \pm 0.126$ rad

Evidence of D^0 mixing exceeds 10σ combining all experimental results:
though no single measurement exceeds 5σ.