Experiments at e^+-e^- flavour factories and LHCb

Part 2: Belle and BaBar II

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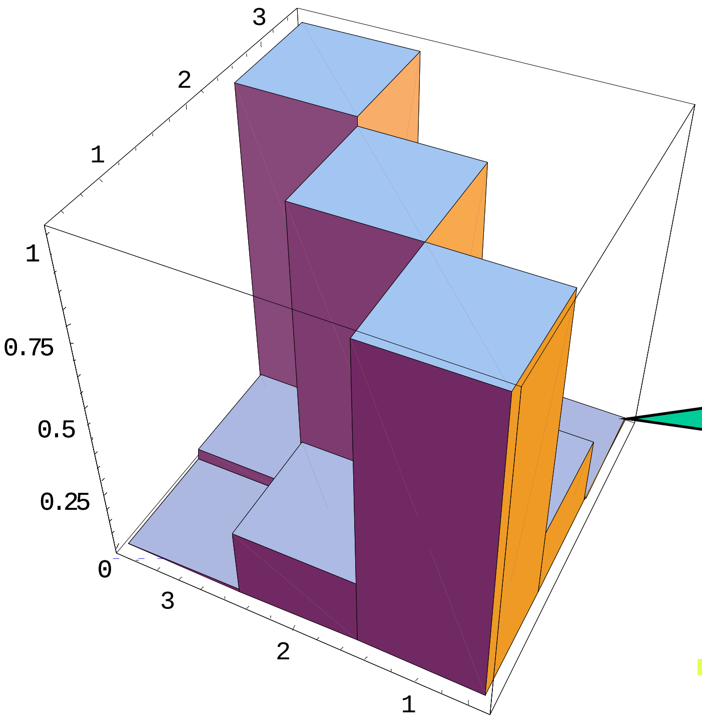
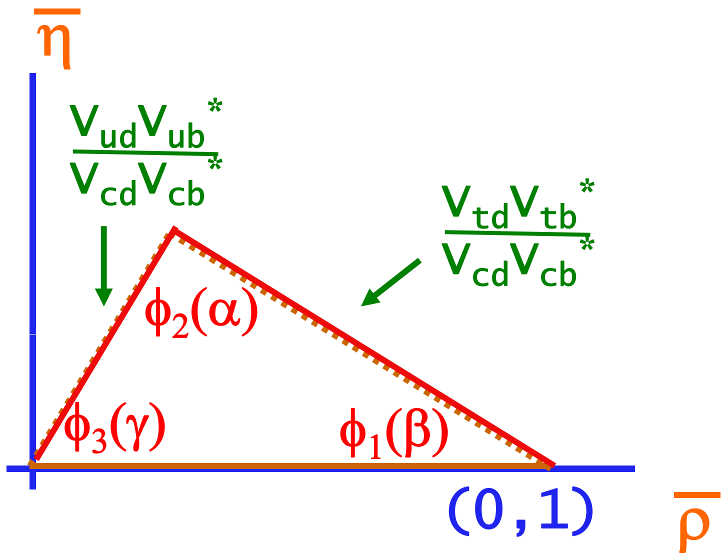
Unitary triangle: one of the sides is determined by V_{ub}

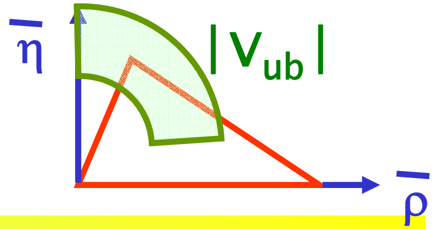
$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

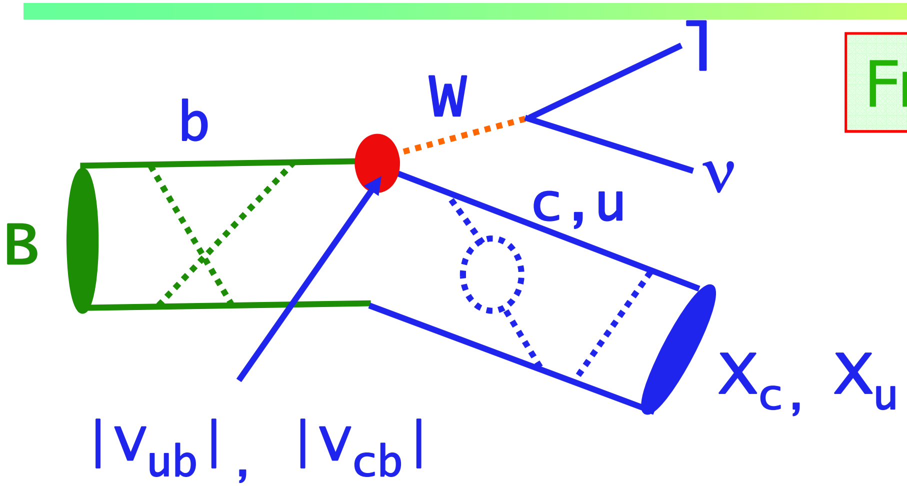
$$V = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$





$|V_{ub}|$ measurements





From semileptonic B decays

$b \to c l \nu$ background typically an order of magnitude larger.

Traditional inclusive method: fight the background from $b \to c l \nu$ decays by using only events with electron momentum above the $b \to c l \nu$ kinematic limit. Problem: extrapolation to the full phase space→ large theoretical uncertainty.

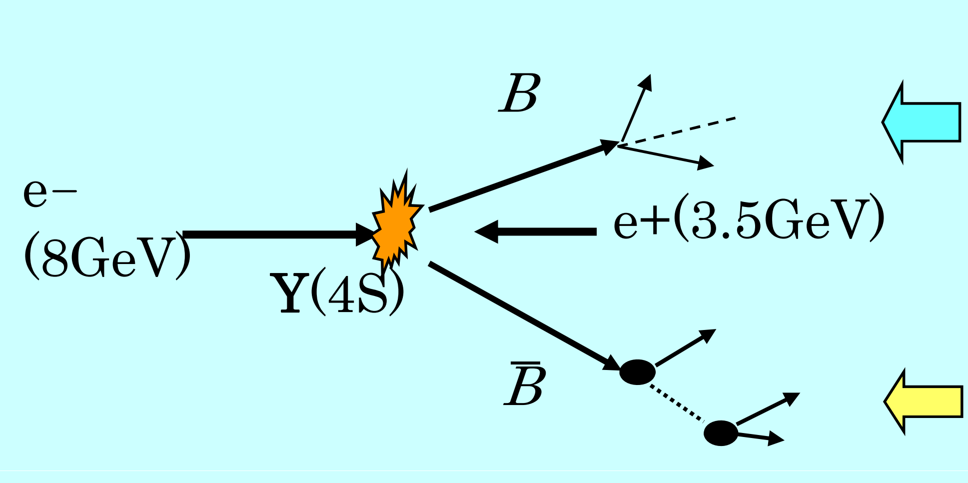
New method: fully reconstruct one of the B mesons, check the properties of the other (semileptonic decay, low mass of the hadronic system)

- Very good signal to noise
- Low yield (full reconstruction efficiency is 0.3-0.4%)

Full Reconstruction Method

Fully reconstruct one of the B's to

- Tag B flavor/charge
- Determine B momentum
- Exclude decay products of one B from further analysis



Decays of interest
$B \rightarrow X_u \, l \, \nu$,
$B \rightarrow K \, \nu \, \nu$
$B \rightarrow D\tau\nu$, $\tau\nu$

full reconstruction
$B \rightarrow D\pi$ etc. (0.1~0.3%)

→ Offline B meson beam!

Powerful tool for B decays with neutrinos

Fully reconstructed sample

Fully reconstructed sample

Clean environment but small sample: $\varepsilon_{reco} \approx 3 \cdot 10^{-3}$

Exclusive method: 180 decay channels

Reconstructed channels:

$B^0 \to D^{(*)-}\pi^+ \,/\, D^{(*)-}\rho^+ \,/\, D^{(*)-}a_1^+ \,/\, D^{(*)-} D_s^{(*)+}$

$B^+ \to D^{(*)0}\pi^+ \,/\, D^{(*)0}\rho^+ \,/\, D^{(*)0}a_1^+ \,/\, D^{(*)0} D_s^{(*)+}$

$D^{*0} \to D^0\pi^0$

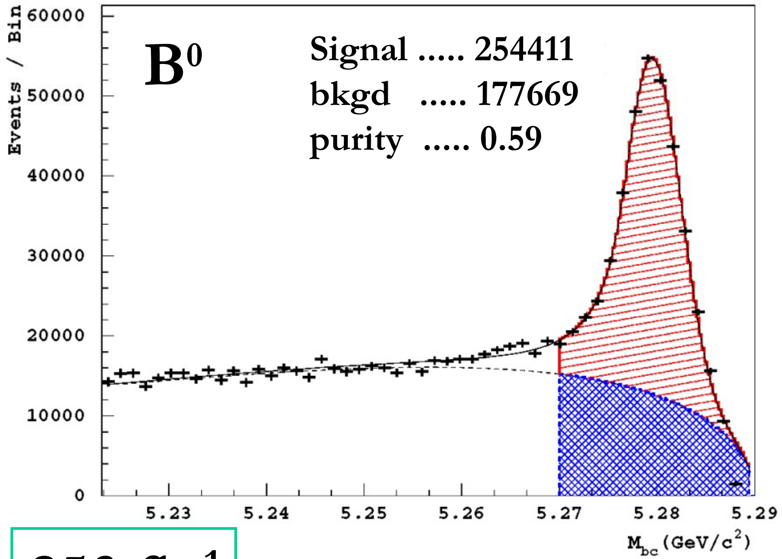
$D^* \to D^0\pi \,/\, D\pi^0$

$D_s^* \to D_s\gamma$

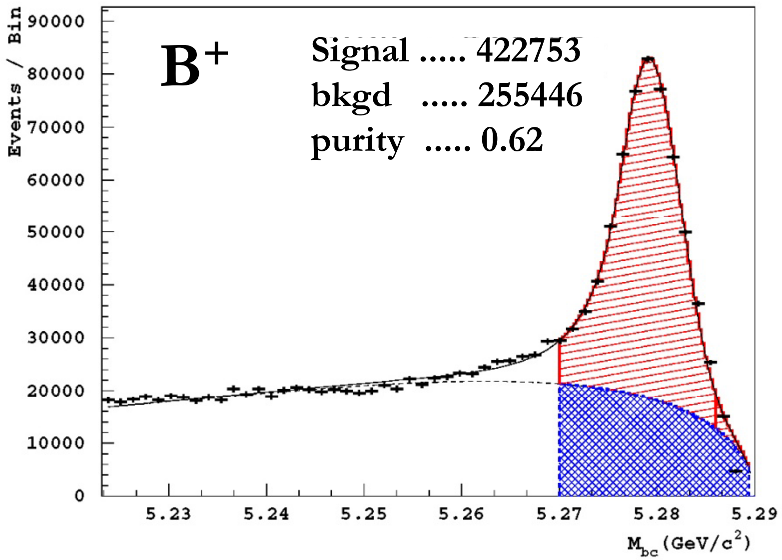
$D^0 \to K\pi / K\pi\pi^0 / K\pi\pi\pi / K_s\pi^0 / K_s\pi\pi / K_s\pi\pi\pi^0 / KK$

$D \to K\pi\pi / K\pi\pi\pi^0 / K_s\pi / K_s\pi\pi^0 / K_s\pi\pi\pi / KK\pi$

$D_s \to K_sK\pi / KK\pi$



253 fb^{-1}



M_x analysis

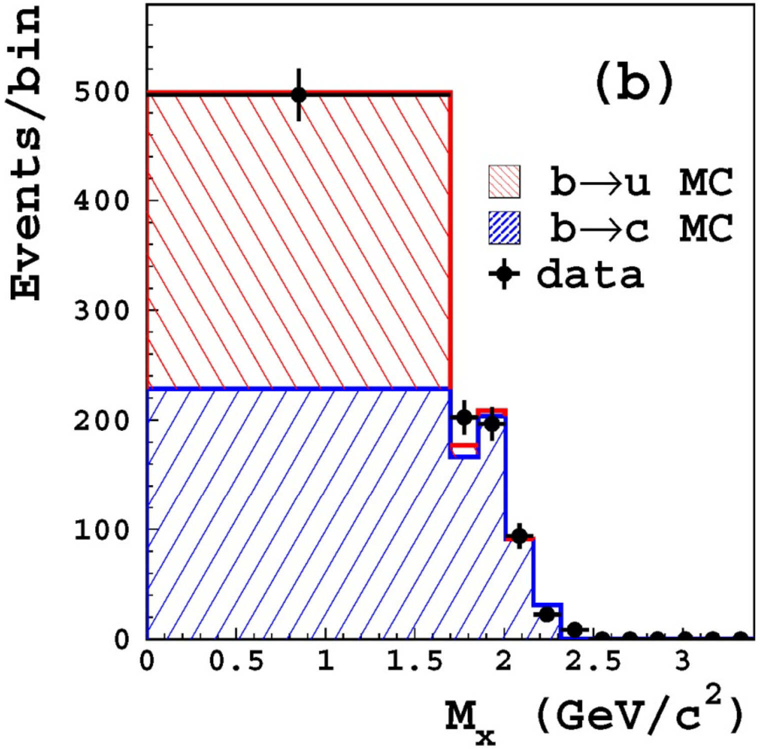
Use the mass of the hadronic system M_x as the discriminating variable against $b \to cl\nu$

M_x = mass of all hadrons from the B decay.

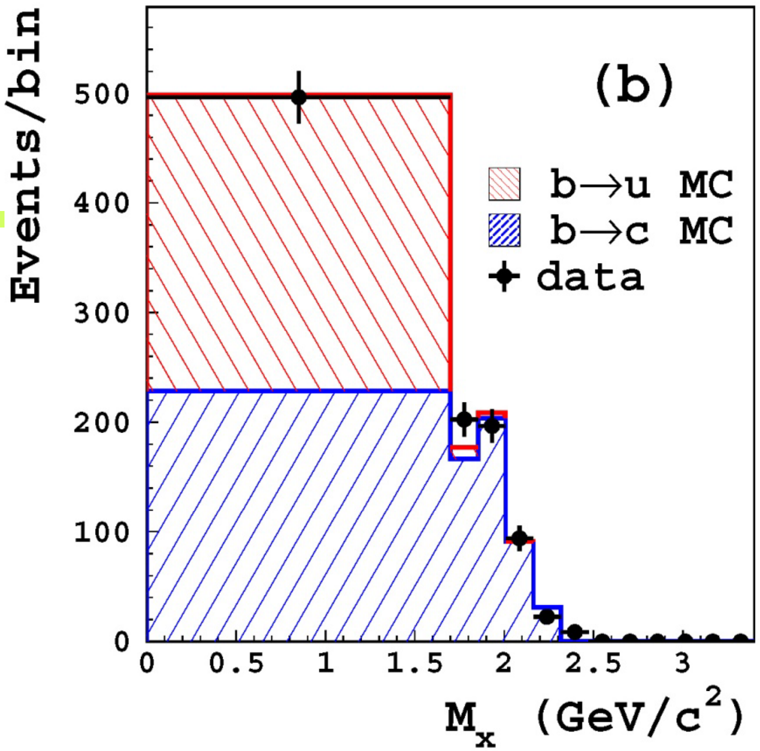
Expect:

- M_x for $b \to cl\nu$ to be above 1.8 GeV ($b \to cl\nu$ results in a D meson with >1.8 GeV)

- M_x for $b \to ul\nu$ to be mainly below 1.8 GeV ($B \to \pi l\nu$, $\rho l\nu$, $\omega l\nu$ …)



M_x analysis



M_x<1.7 GeV/c^2 / q^2>8 GeV^2/c^2

Total error on $|V_{ub}|$ 12%

253 fb^{-1}

$$|V_{ub}| = (4.93 \pm 0.25 \pm 0.22 \pm 0.15 \pm 0.13 \pm 0.46\ ^{+0.20}_{-0.22}) \times 10^{-3}$$

stat syst b→u b→c SF theo
model dep.

M_x<1.7 GeV/c^2 / no q^2 cut : total error on $|V_{ub}|$ 11%

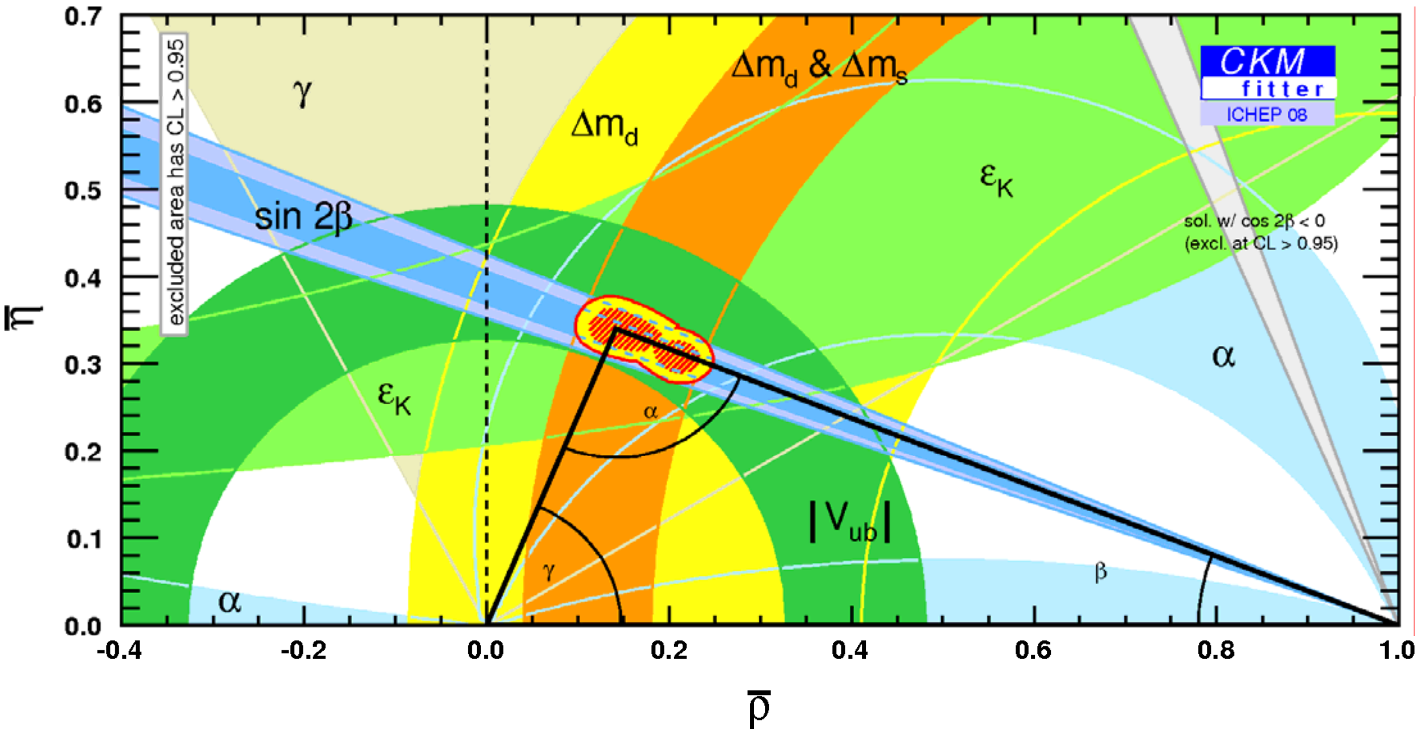
253 fb^{-1}

$$|V_{ub}| = (4.35 \pm 0.20 \pm 0.15 \pm 0.13 \pm 0.05 \pm 0.40\ ^{+0.13}_{-0.14}) \times 10^{-3}$$

stat syst b→u b→c SF theo
model dep.

All measurements combined...

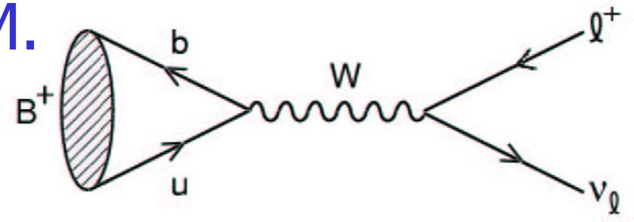
Constraints from measurements of angles and sides of the unitarity triangle →



→Remarkable agreement

Purely leptonic decay $B \to \tau \nu$

- Challenge: B decay with at least two neutrinos
- Proceeds via W annihilation in the SM.



- Branching fraction

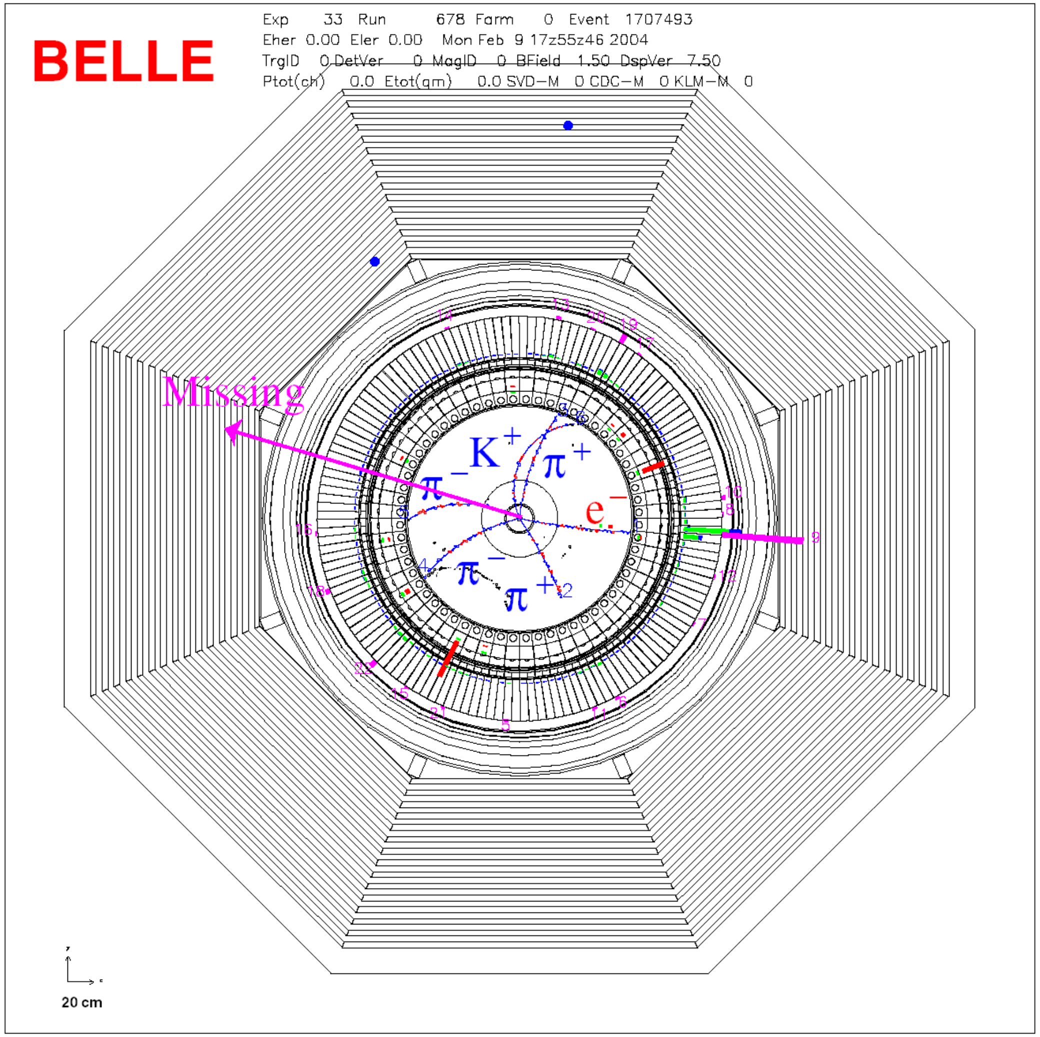
$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

- Provide information of $f_B|V_{ub}|$
  - $|V_{ub}|$ from $B \to X_u\, l\, \nu$ ➡ f_B ⟺ cf) Lattice
  - $Br(B \to \tau\nu)/\Delta m_d$ ➡ $|V_{ub}| / |V_{td}|$
- Limits on charged Higgs

Event candidate $B^- \rightarrow \tau^- \nu_\tau$

Again: fully reconstruct one of the B's

$$B^+ \to D^0 \pi^+$$
$$(\to K\pi^-\pi^+\pi^-)$$
$$B^- \to \tau(\to e\nu\bar{\nu})\nu$$



$B \rightarrow \tau \nu$

τ decay modes

$$\tau^- \rightarrow \mu^- \nu \bar{\nu}, e^- \nu \bar{\nu}$$

$$\tau^- \rightarrow \pi^- \nu, \pi^- \pi^0 \nu, \pi^- \pi^+ \pi^- \nu$$

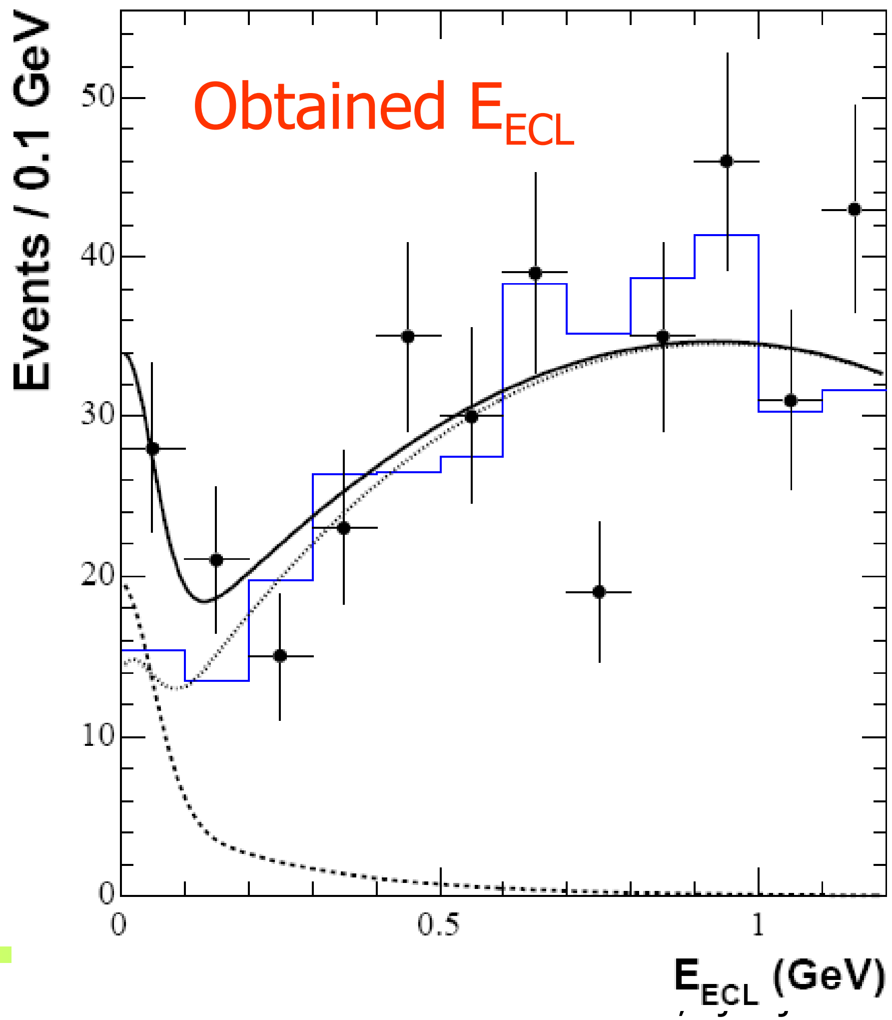
- Cover 81% of τ decays
- Efficiency 15.8%

Event selection

- Main discriminant: extra neutral ECL energy

Fit to $E_{residual}$ → $17.2^{+5.3}_{-4.7}$ signal events.

→3.5**σ** significance including systematics



$B \to \tau \nu_\tau$

$$BF(B^+ \to \tau^+ \nu_\tau) = (1.79^{+0.56+0.46}_{-0.49-0.51}) \times 10^{-4}$$

$$\Gamma^{SM}(B^+ \to \ell^+ \nu) = \frac{G_F^2}{8\pi} |V_{ub}|^2 f_B^2 m_B m_\ell^2 \left(1 - \frac{m_\ell^2}{m_B^2}\right)$$

→ Product of B meson decay constant f_B and CKM matrix element $|V_{ub}|$

$$f_B \times V_{ub} = \left(10.1^{+1.6+1.3}_{-1.4-1.4}\right) \times 10^{-4}\, GeV$$

Using $|V_{ub}| = (4.39 \pm 0.33) \times 10^{-3}$ from HFAG

$$f_B = 229^{+36+34}_{-31-37}\, MeV$$

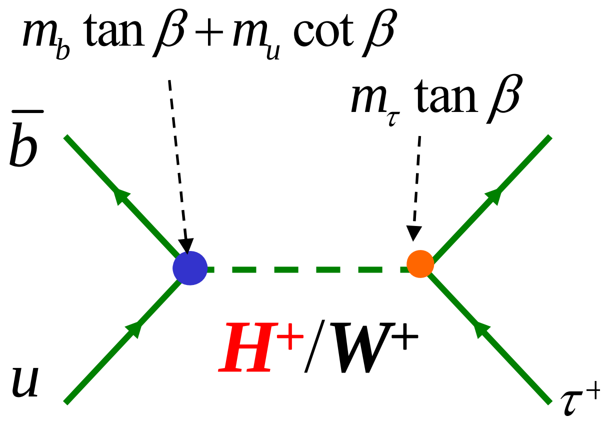
15%   15% = 13%(exp.) + 8%(V_{ub})

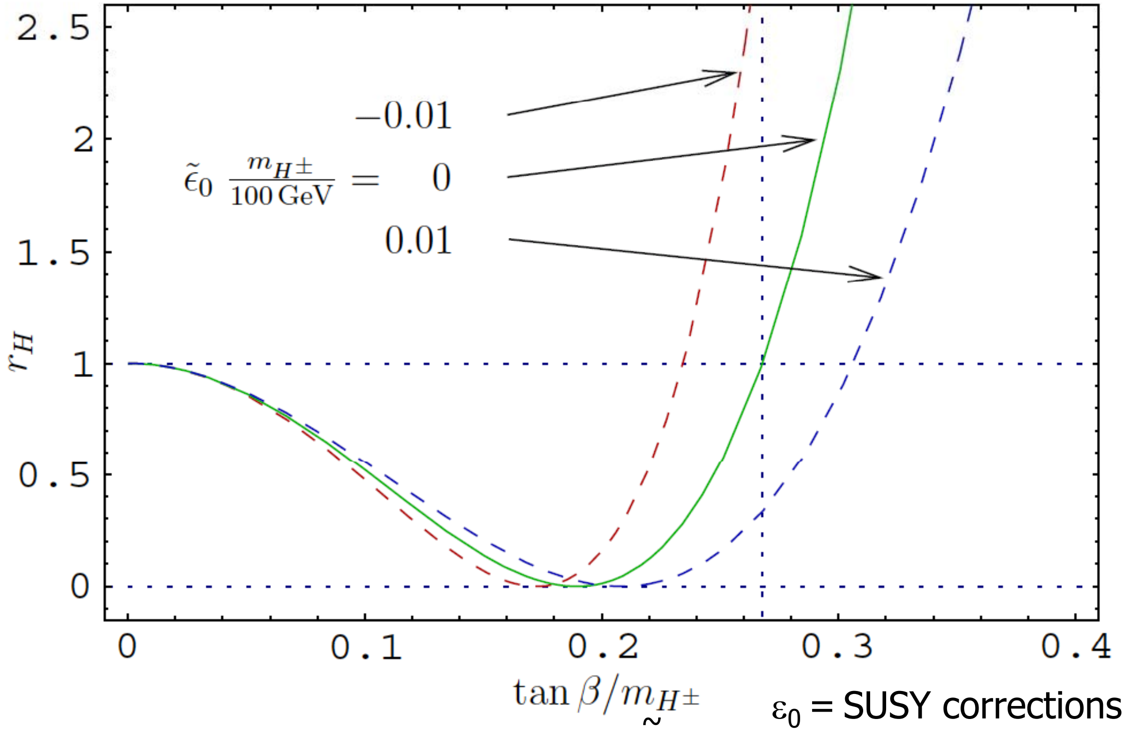
First measurement of f_B!

f_B = (216 ± 22) MeV from unquenched lattice calculation

[HPQCD, Phys. Rev. Lett. 95, 212001 (2005)]

Charged Higgs contribution to $B \to \tau\nu$





ε_0 = SUSY corrections to b Yukawa coupling

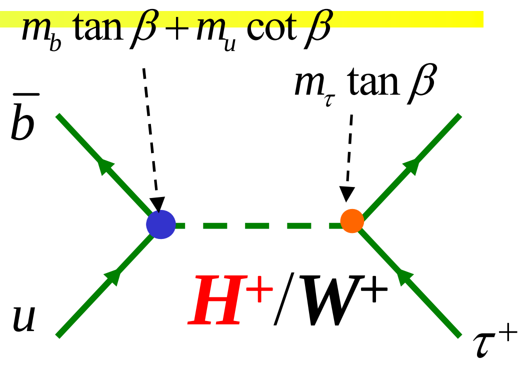
$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\mathrm{SM}} \times r_H,$$

$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

The interference is destructive in 2HDM (type II). $B > B_{SM}$ implies that H^+ contribution dominates

Phys. Rev. D **48**, 2342 (1993)

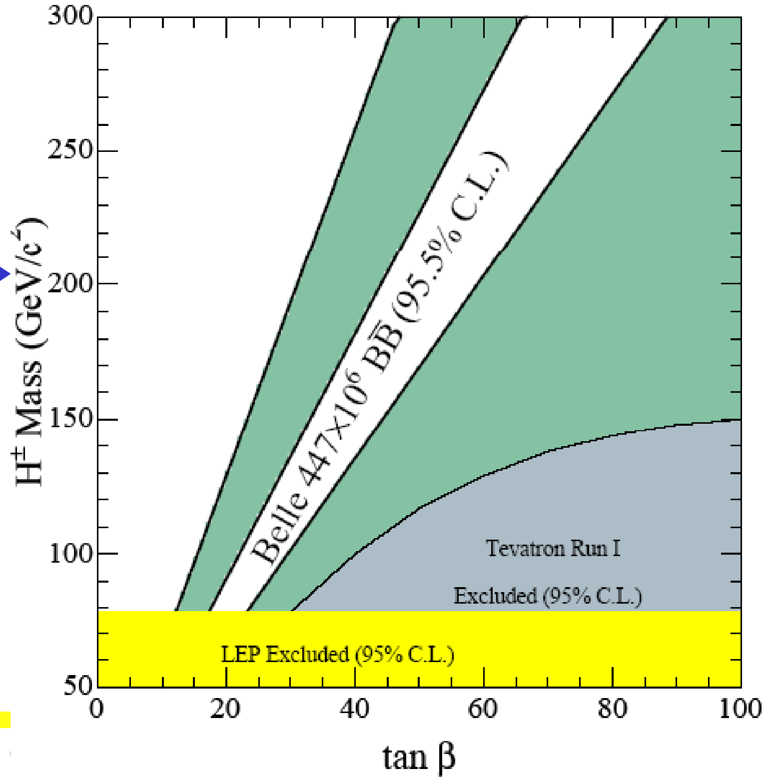
Charged Higgs limits from $B^- \to \tau^- \nu_\tau$

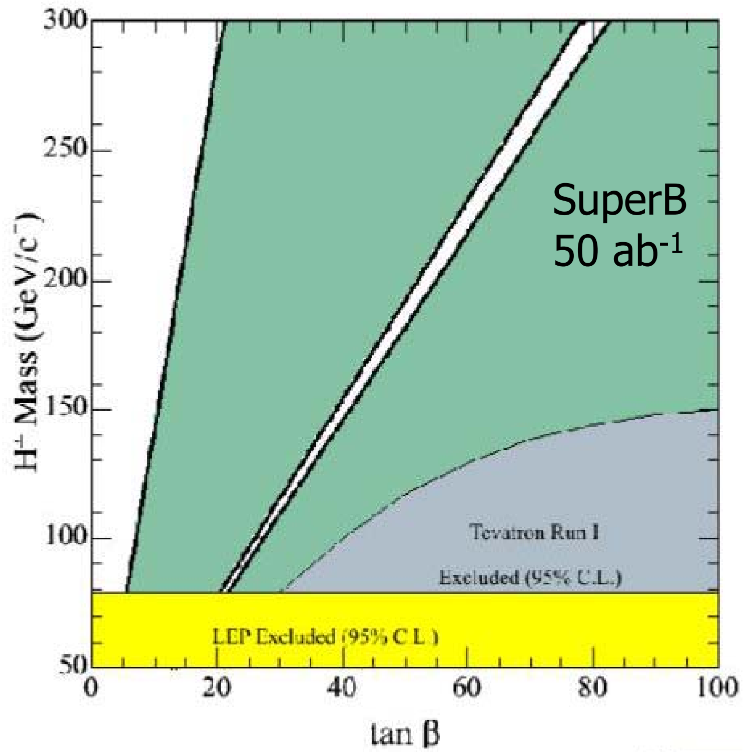


If the theoretical prediction is taken for $\mathbf{f_B}$

→ limit on charged Higgs mass vs. tanβ

$$r_H = \frac{BF(B \to \tau\nu)}{BF(B \to \tau\nu)_{SM}} = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$





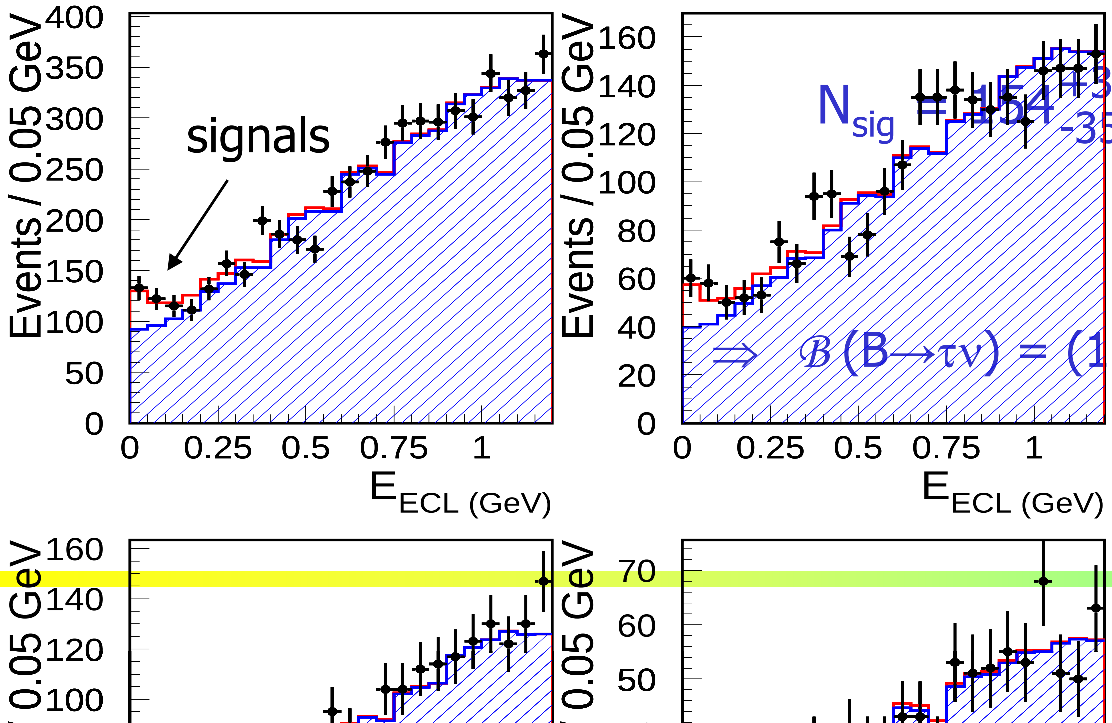
New Belle result on $B^+ \to \tau^+ \nu$

Method: Tag B on one side with the semileptonic decay $B \to D^{(*)} l \nu$

→ Neutrino not reconstructed in the tagging B decay sequence → more background than in fully reconstructed hadronic decays

Again look for τ signature with "extra" energy in the ECAL

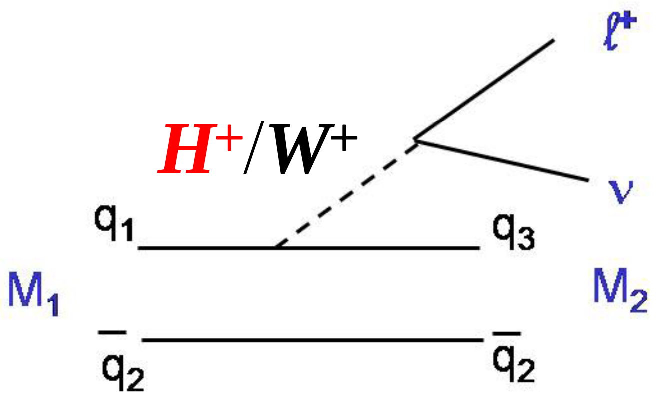
657 M $B\bar{B}$ with $D^{(*)} l$ **n** tag

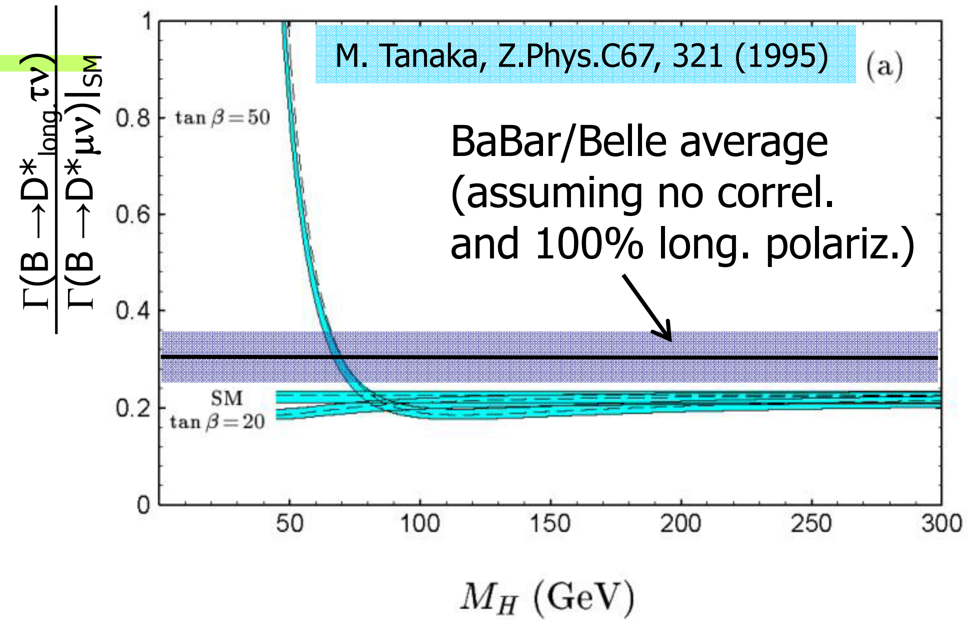


$N_{sig} = 154^{+36}_{-35}$ (stat) $^{+20}_{-22}$ (syst)

$\Rightarrow \mathcal{B}(B \to \tau\nu) = (1.65 \;^{+0.38}_{-0.37}\,^{+0.35}_{-0.37})\; 10^{-4}$

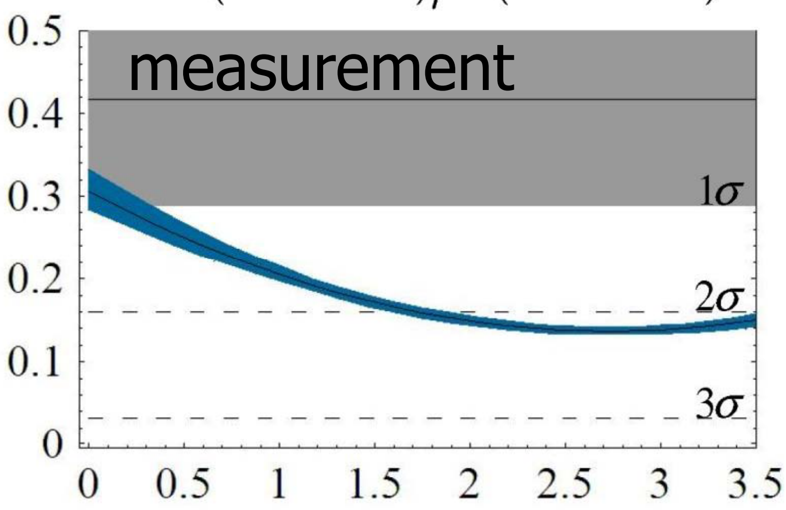
Charged Higgs limits from $B^- \to D^{(*)} \tau^- \nu_\tau$



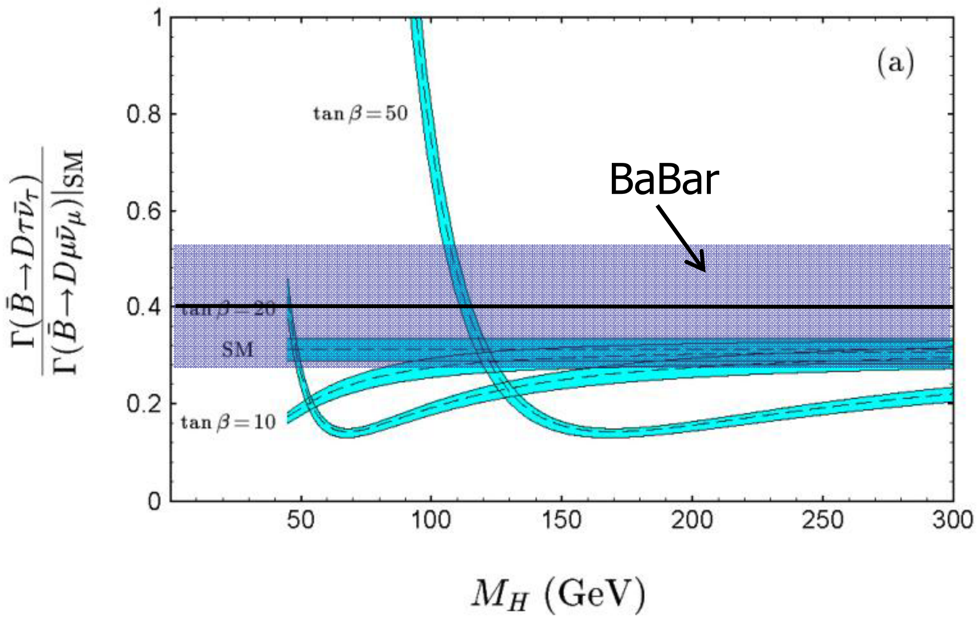


U. Nierste et al., PRD78, 015006 (2008)

$$R \equiv \mathcal{B}(B \to D\tau\nu)/\mathcal{B}(B \to D\ell\nu)$$

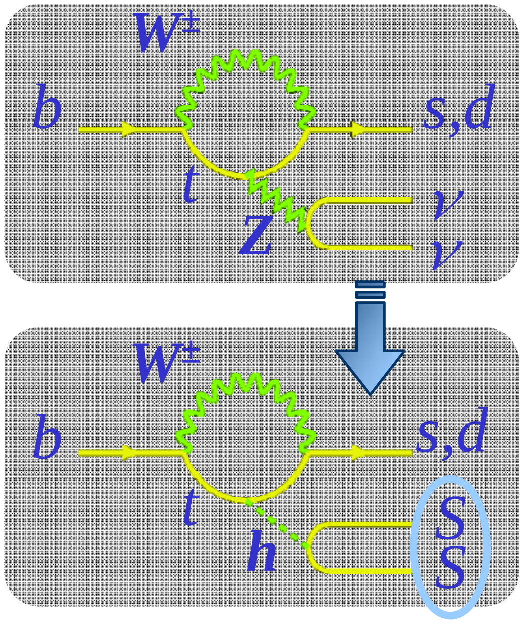


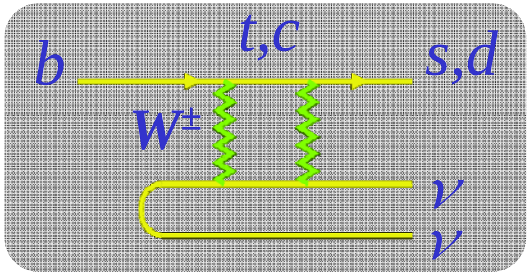
$m_B^2/m_H^2 \tan^2\beta$ (in 2HDM-II)



$B \to K^{(*)} \nu\nu$

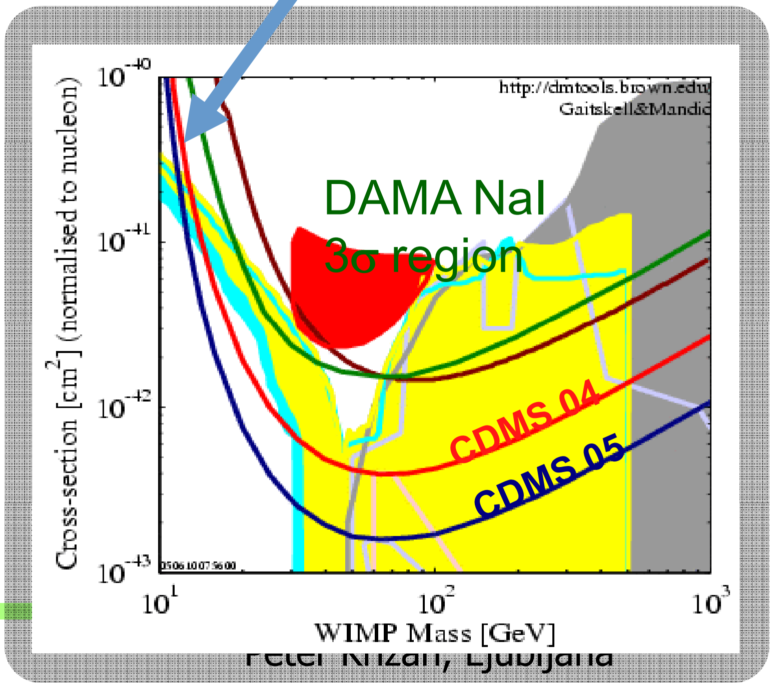
- Proceed through electroweak penguin + box diagram.
- Sensitive to New Physics in the loop diagram.
- Theoretically clean: no long distance contributions.
- May be sensitive to light dark matter (C. Bird, PRL 93, 201803 (2004))



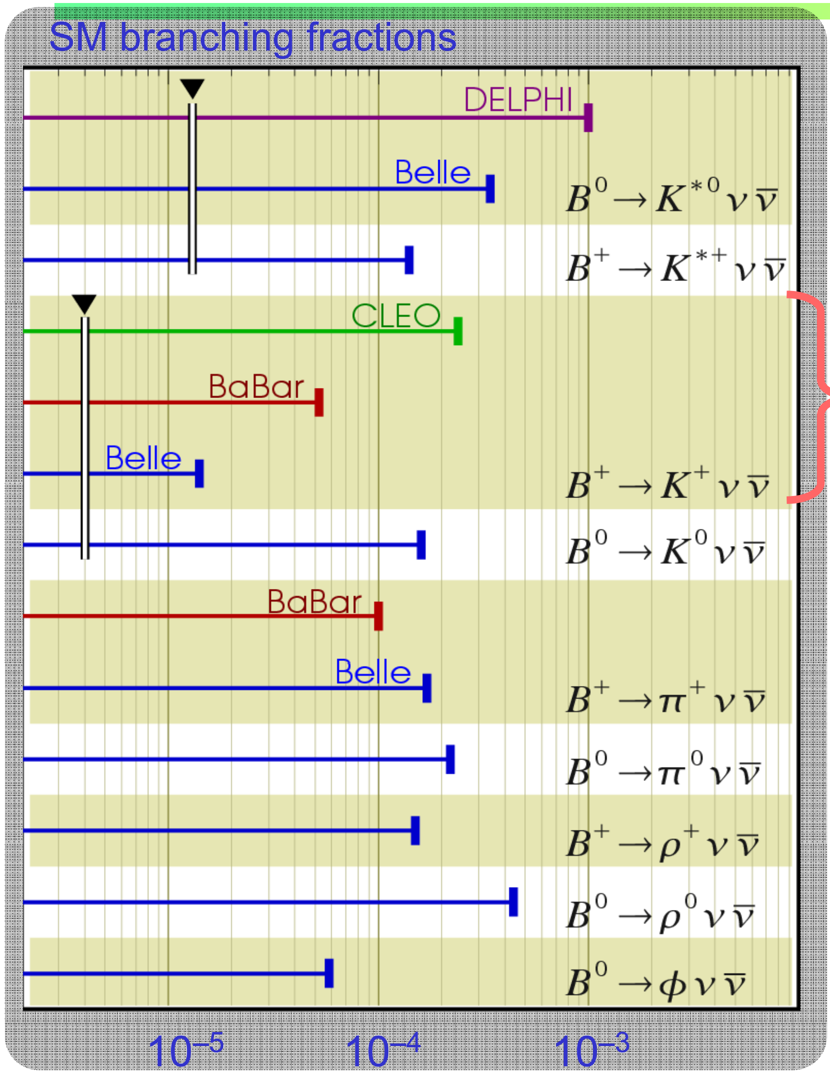


$b \to s$ + Missing E may be enhanced by this extra diagram.

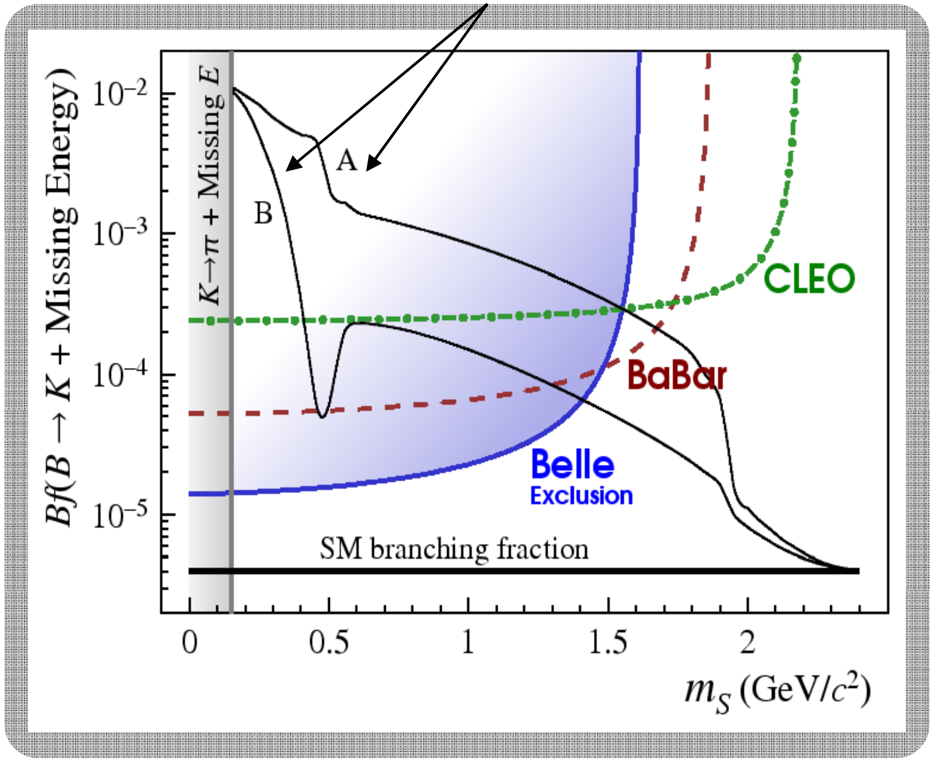
No sensitivity to light dark matter (M<10 GeV) in direct searches



$B \to K^{(*)}\nu\nu$: present limits



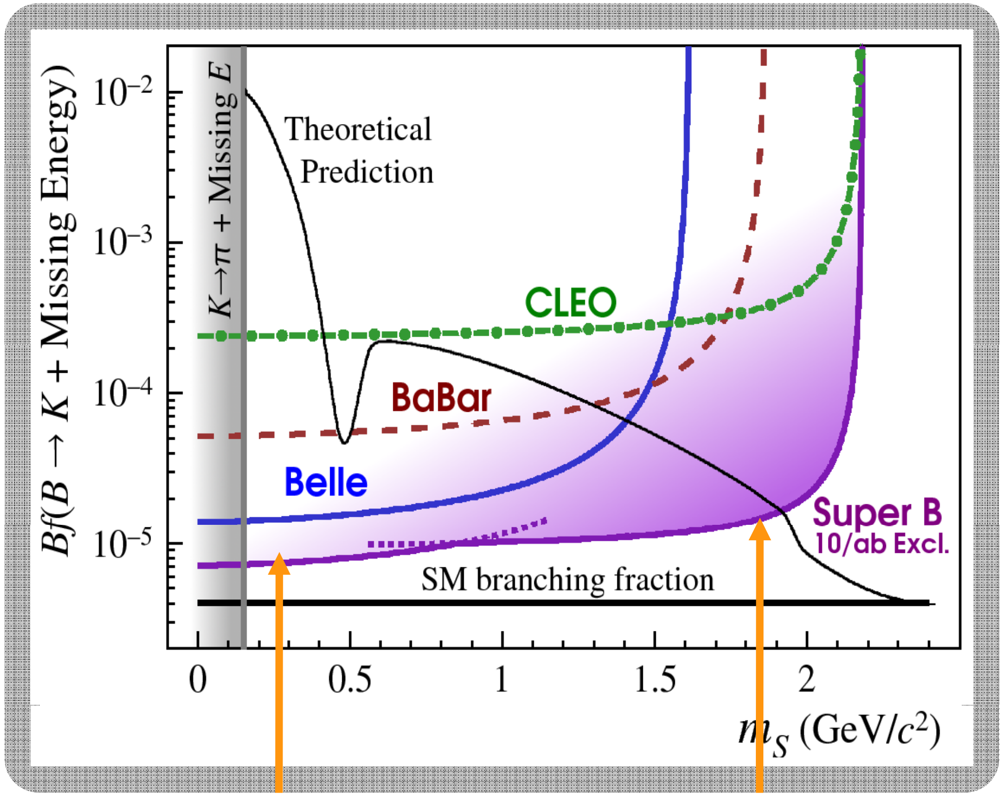
- Limit on light dark matter based on the $K^+\nu\nu$ limits (using theory predictions, C. Bird, PRL 93, 201803 (2004)



- Limit depends on P*(K) momentum cut

$B \to K^{(*)} \nu\nu$: prospects for 10/ab

- Assuming no changes in the analysis & detector:

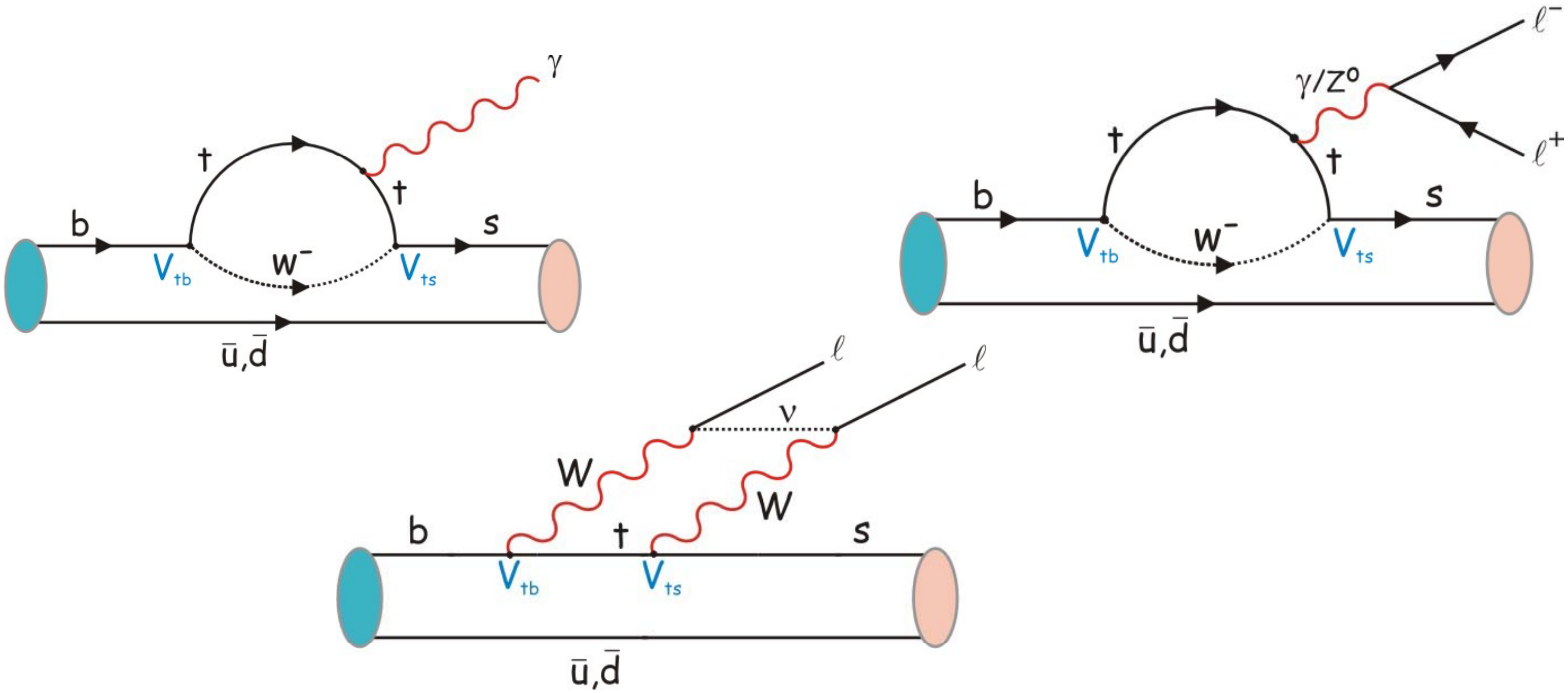


with the same $P^*(K)$ threshold (1.6 GeV)

with a lower $P^*(K)$ threshold (0.7 GeV)

Why FCNC decays?

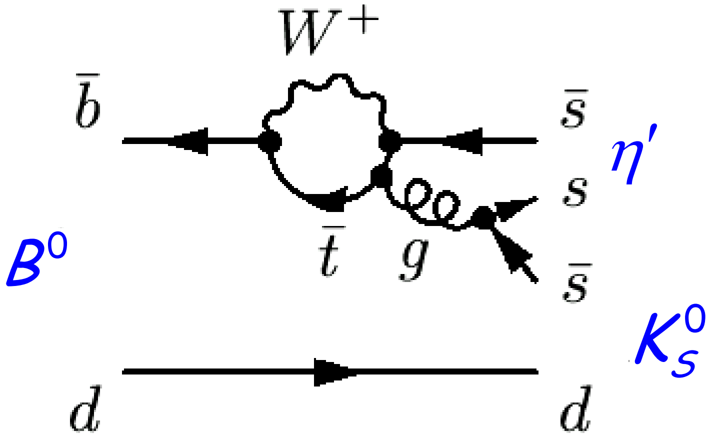
Flavour changing neutral current (FCNC) processes (like b→s, b→d) are fobidden at the tree level in the Standard Model. Proceed only at low rate via higher-order loop diagrams. Ideal place to search for new physics.



How can New Physics contribute to b→s?

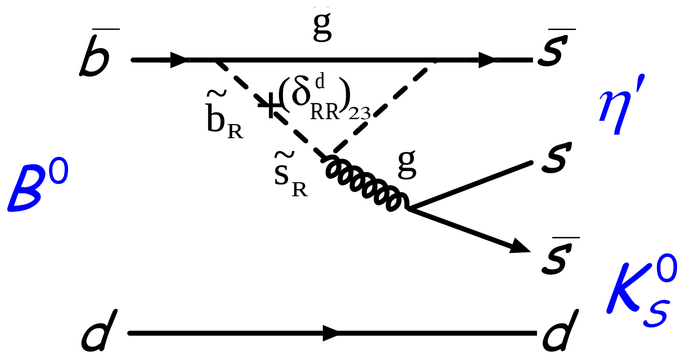
For example in the process:

$B^0 \to \eta' K^0$



Ordinary penguin diagram with a t quark in the loop

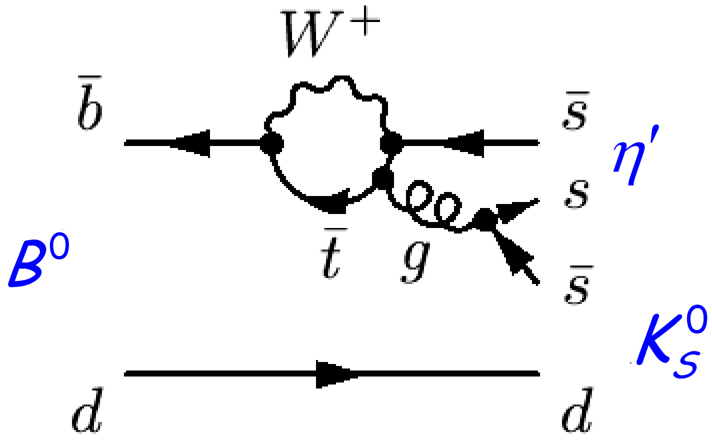
Diagram with supersymmetric particles



Searching for new physics phases in CP violation measurements in b→s decays

Prediction in SM:

$B^0 \to \eta' K^0$



$$a_f = -\mathrm{Im}(\lambda_f)\sin(\Delta m t)$$

$$\mathrm{Im}(\lambda_f) = \xi_f \sin 2\phi_1$$

The same value as in the decay $B^0 \to J/\psi\, K_S$!

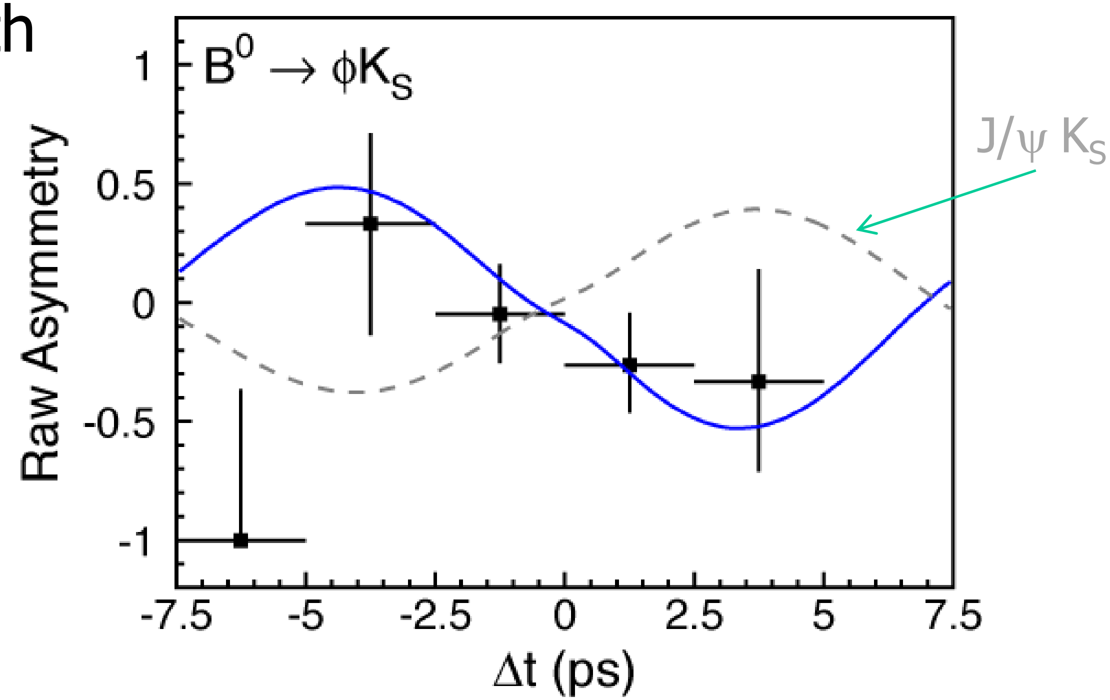
This is only true if there are no other particles in the loop! In general the parameter can assume a different value $\sin 2\phi_1^{eff}$

Result of 2003 (140/fb): surprise!

Measurement: points with error bars.

Standard Model predictions: dashed

Result of the unbinned likelihood fit: blue curve

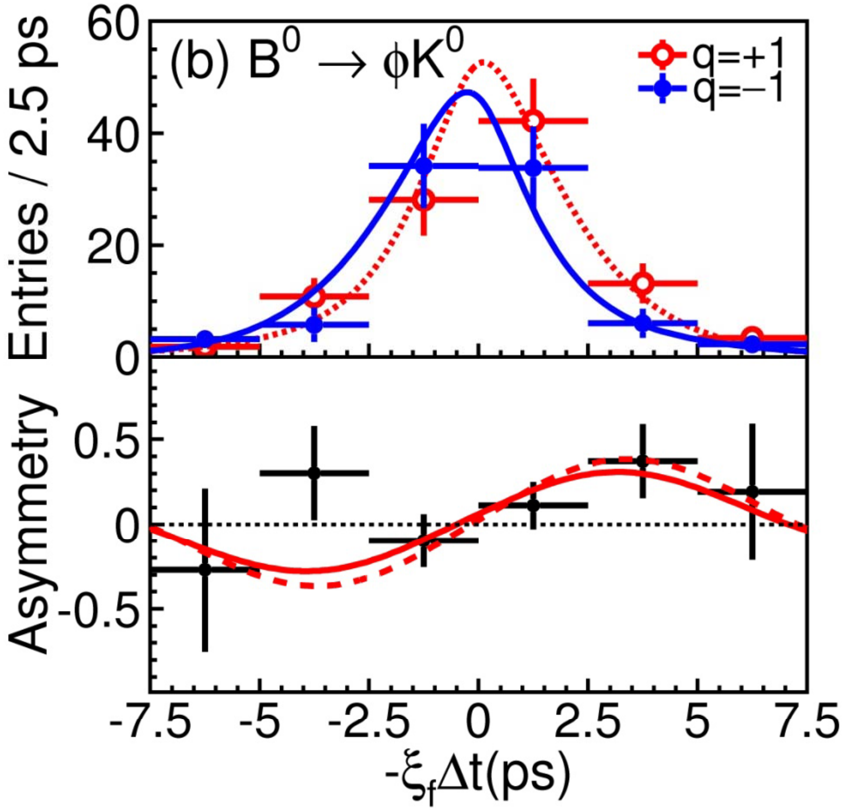


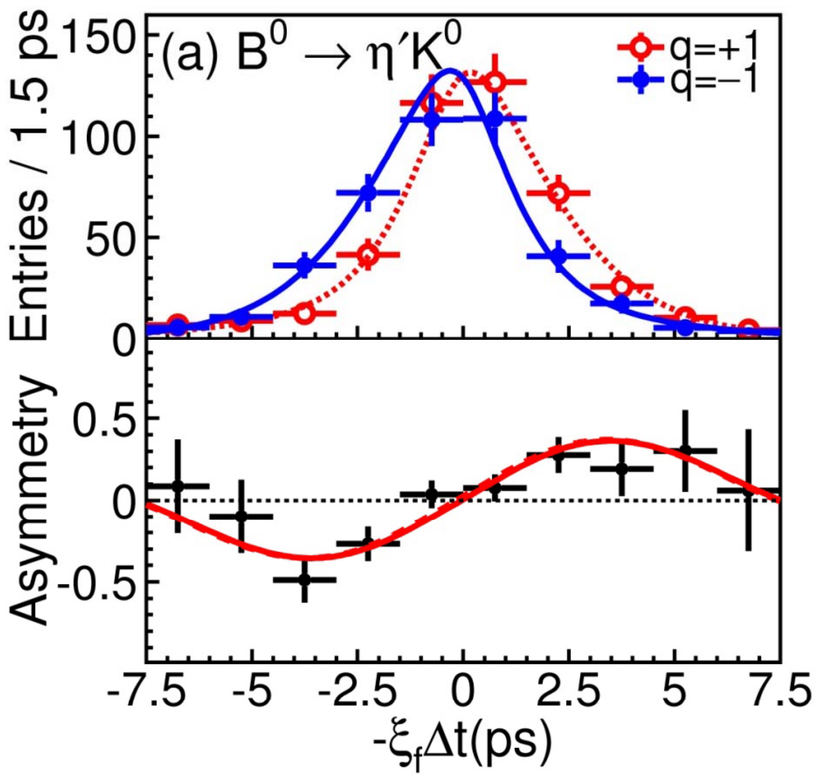
Measure: $S=-0.96\pm0.50$, expect $S= \sin 2\phi_1=+0.731 \pm 0.056$

not conclusive → needed more data

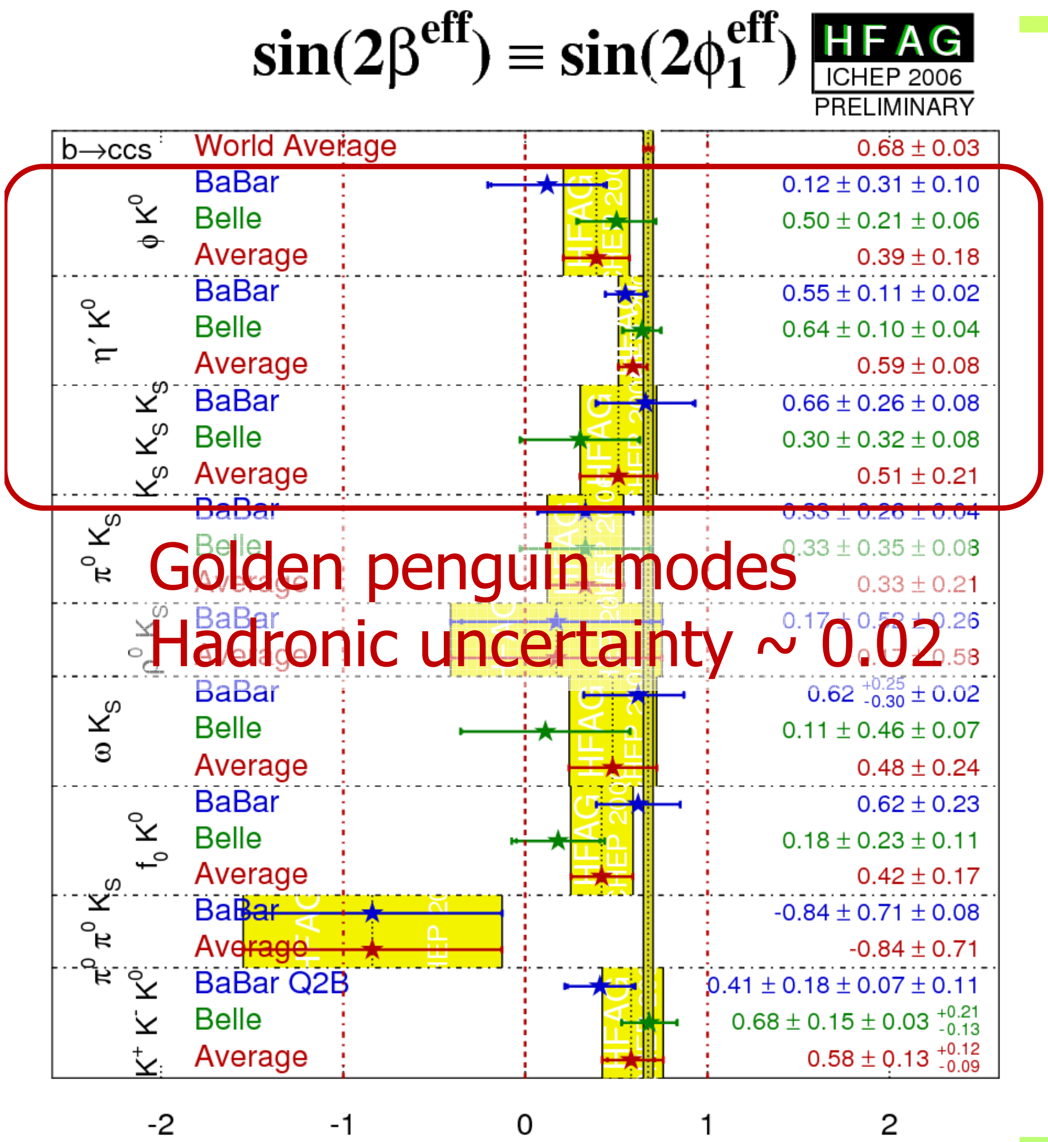
... with more data ...

$B \rightarrow \phi K_S$ $B \rightarrow \eta' K_S$





Search for NP: $b \to s q\bar{q}$



ICHEP08

BaBar
Belle
Naïve average

0.26±0.25±0.04
$0.67\pm^{0.25}_{0.27}\pm0.07$
0.45±0.18

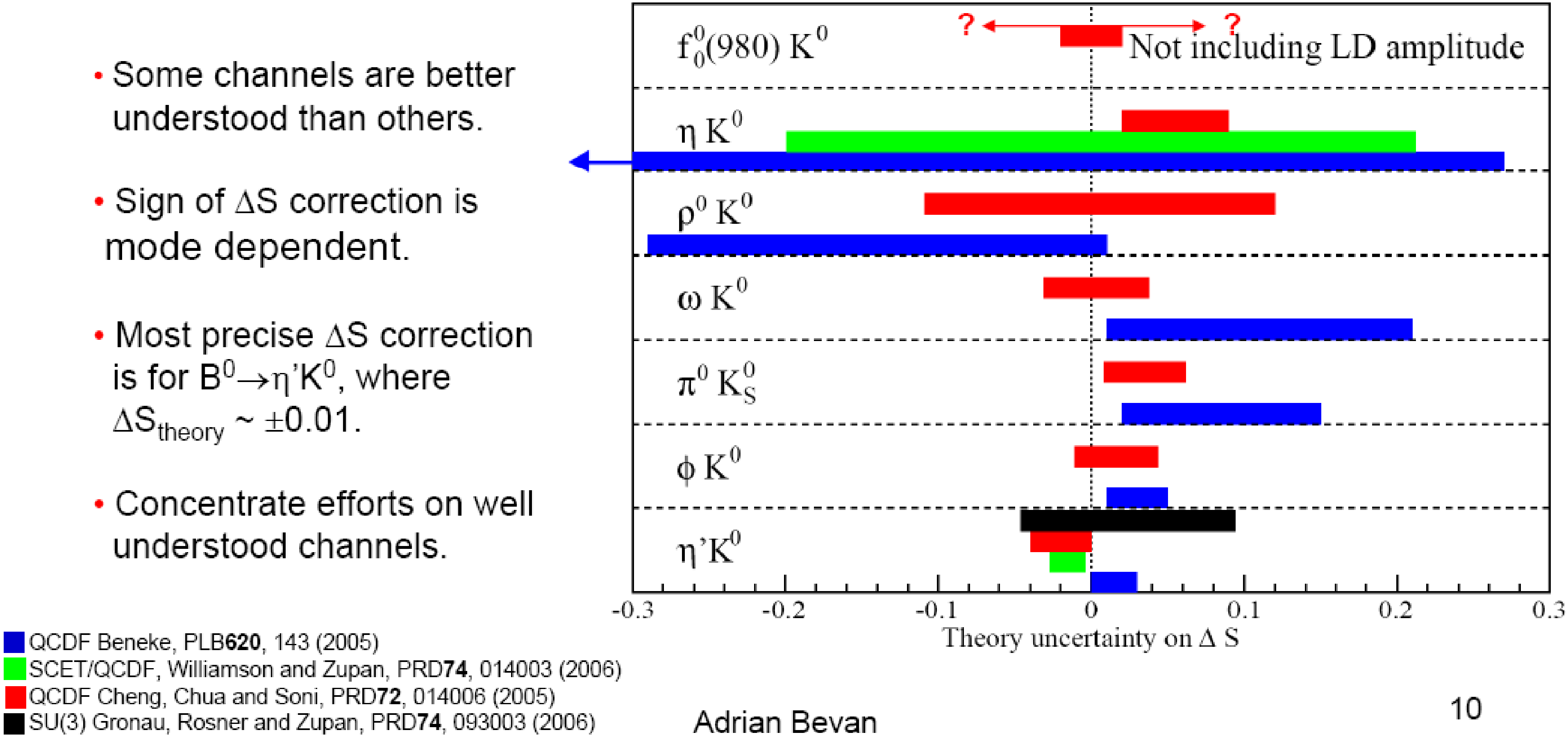
0.57±0.08±0.02
0.64±0.10±0.04
0.60±0.07

0.71±0.24±0.04
0.30±0.32±0.08
0.57±0.20

Need much more data to clarify the issue

- To find NP we need to understand the SM contributions to a process.
  - Leading order term is expected to be the same as a SM weak phase.
  - Higher order terms including re-scattering, suppressed amplitudes, final state radiation and so on can modify our expectations.

- Some channels are better understood than others.
- Sign of ΔS correction is mode dependent.
- Most precise ΔS correction is for $B^0 \to \eta' K^0$, where $\Delta S_{theory} \sim \pm 0.01$.
- Concentrate efforts on well understood channels.



CP asymmetry in time integrated rates ('direct CP', also for charged B)

$$a_f = \frac{\Gamma(B \to f) - \Gamma(\overline{B} \to \overline{f})}{\Gamma(B \to f) + \Gamma(\overline{B}^- \to \overline{f})} = \frac{1 - |\overline{A}/A|^2}{1 + |\overline{A}/A|^2}$$

Need $|\overline{A}/A| \neq 1$: how do we get there?

$$A_f = \sum_i A_i e^{i(\delta_i + \varphi_i)}$$

$$\overline{A}_{\overline{f}} = \sum_i A_i e^{i(\delta_i - \varphi_i)}$$

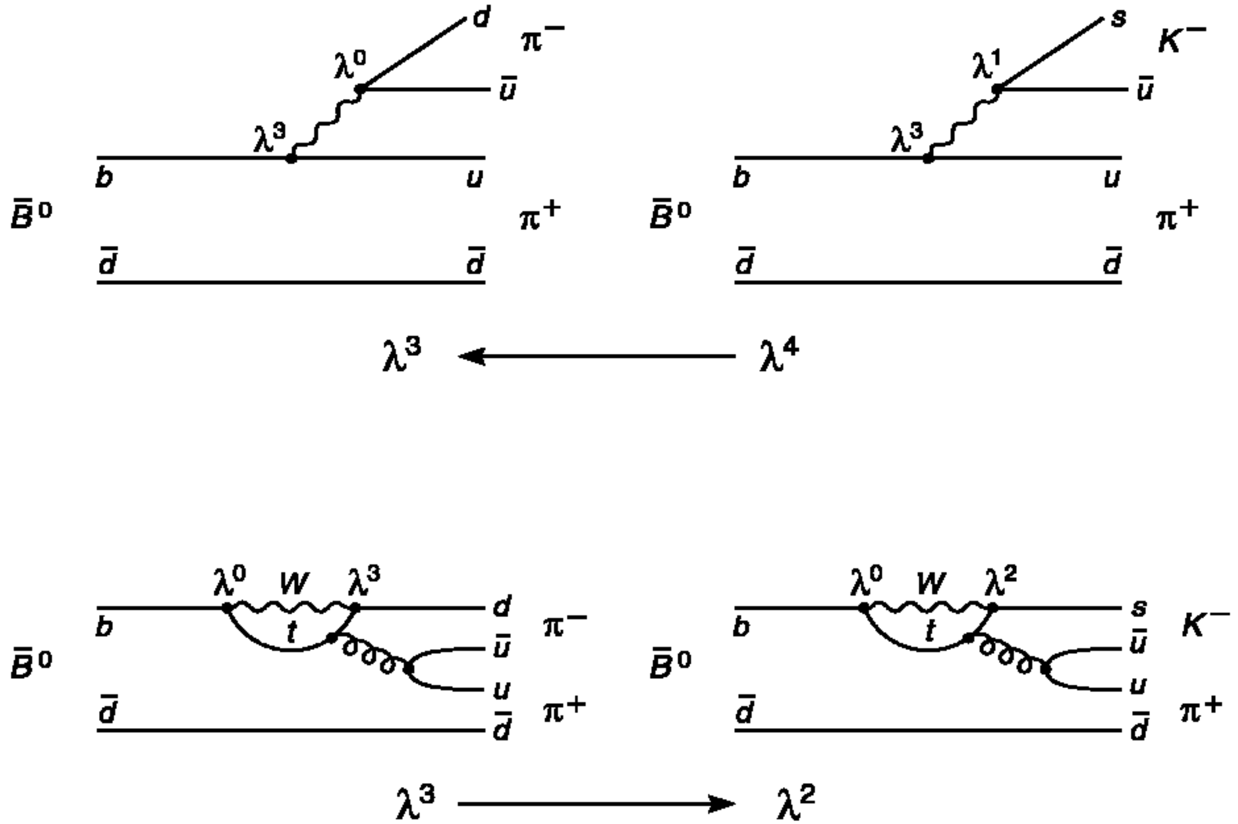
In general, A is a sum of amplitudes with strong phases δ_i and weak phases ϕ_i. The amplitudes for anti-particles have the same strong phases and opposite weak phases →

$$\left|A_f\right|^2 - \left|\overline{A}_{\overline{f}}\right|^2 = \sum_{i,j} A_i A_j \sin(\varphi_i - \varphi_j)\sin(\delta_i - \delta_j)$$

→ Need at least two interfering amplitudes with different weak and strong phases.

Diagrams for B→ ππ, Kπ decays

ππ

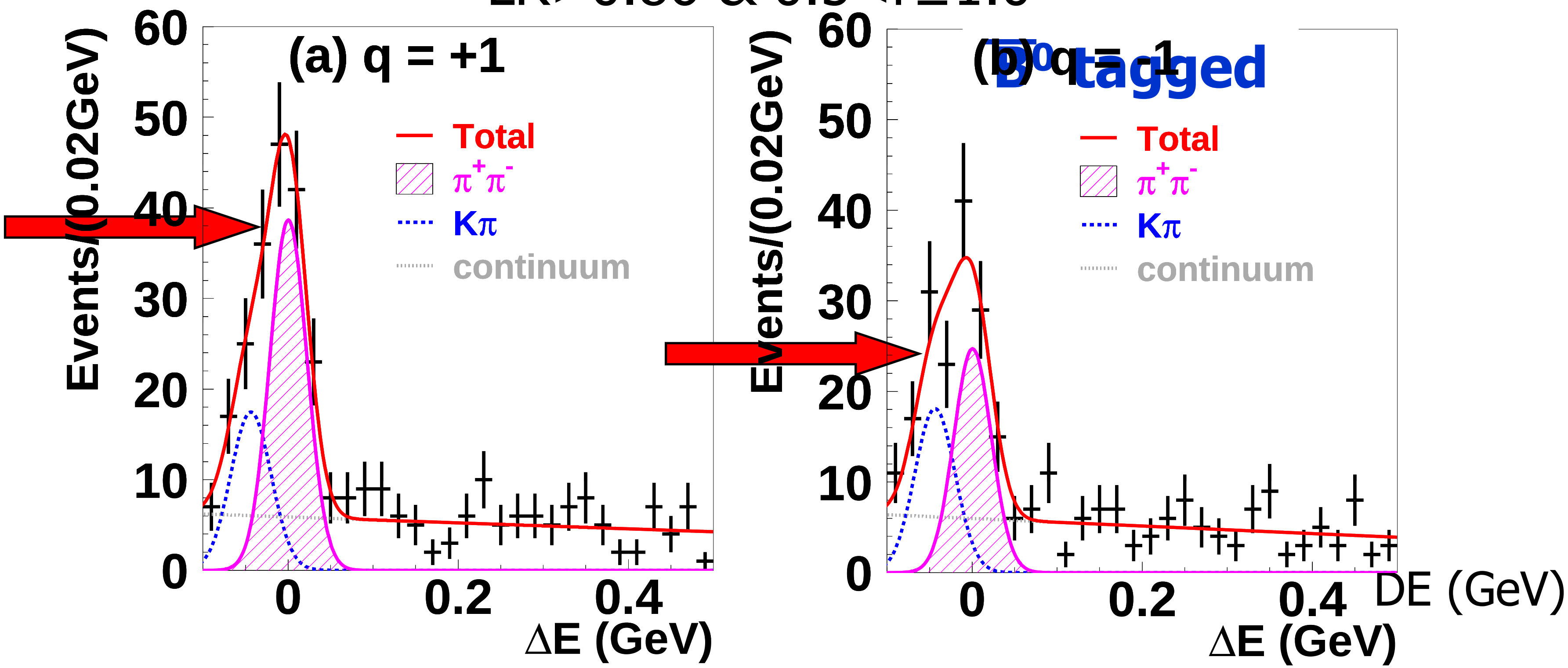


Kπ

- Penguin amplitudes are sizeable in both decays

Direct CP violation in $\pi^+\pi^-$

LR>0.86 & 0.5<r≤1.0



Visible indication of direct CP violation.

Counting experiment consistent with the time-dependent fit (see lecture 1).

A difference in the direct violation of CP symmetry in B^+ and B^0 decays

CP asymmetry

$$\mathcal{A}_f = \frac{N(\bar{B} \to \bar{f}) - N(B \to f)}{N(\bar{B} \to \bar{f}) + N(B \to f)}$$

Difference between B^+ and B^0 decays

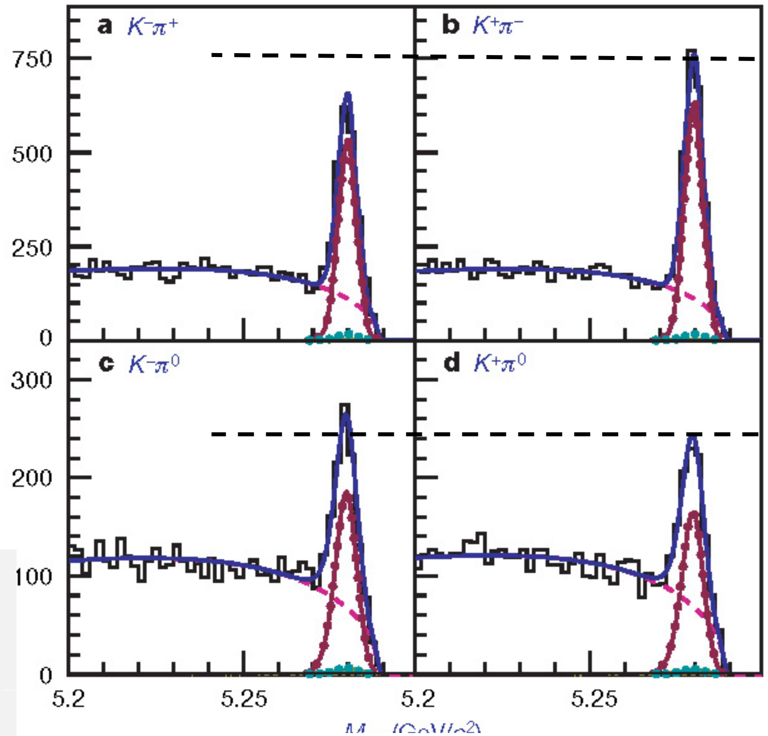
In SM expect $\mathcal{A}_{K^\pm\pi^\mp} \approx \mathcal{A}_{K^\pm\pi^0}$

Measure:

$$\mathcal{A}_{K^\pm\pi^\mp} = -0.094 \pm 0.018 \pm 0.008$$

$$\mathcal{A}_{K^\pm\pi^0} = +0.07 \pm 0.03 \pm 0.01$$

$$\Delta\mathcal{A} = +0.164 \pm 0.037$$

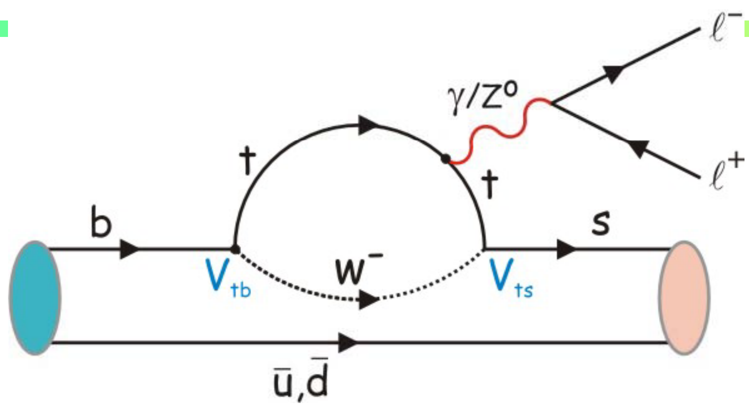


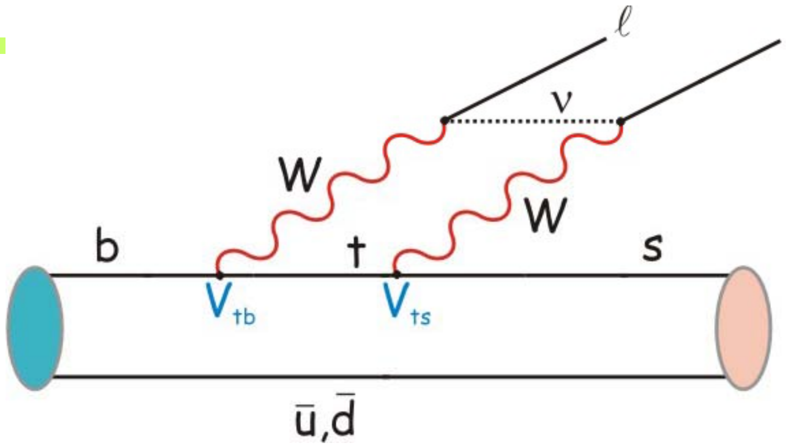
A problem for a SM explanation
(in particular when combined with other measurements)
A hint for new sources of CP violation?

~1 in 10^5 B mesons decays in this decay mode

Belle, Nature 452, 332 (2008)

Another FCNC decay: $B \rightarrow K^{*}\, l^{+}\, l^{-}$





$b \rightarrow s\, l^{+}l^{-}$ was first measured in $B \rightarrow K\, l^{+}l^{-}$ by Belle (2001).

Important for further searches for the physics beyond SM

Particularly sensitive: backward-forward asymmetry in $K^{*}\, l^{+}l$

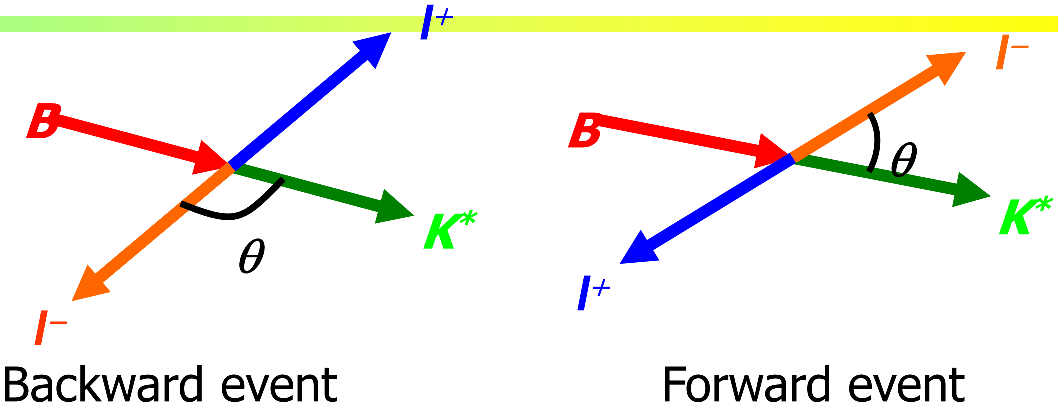
$$A_{FB} \propto \Re\left[C_{10}^{*}\left(sC_{9}^{eff}(s) + r(s)C_{7}\right)\right]$$

C_i : Wilson coefficients, abs. value of C_7 from $b \rightarrow s\gamma$

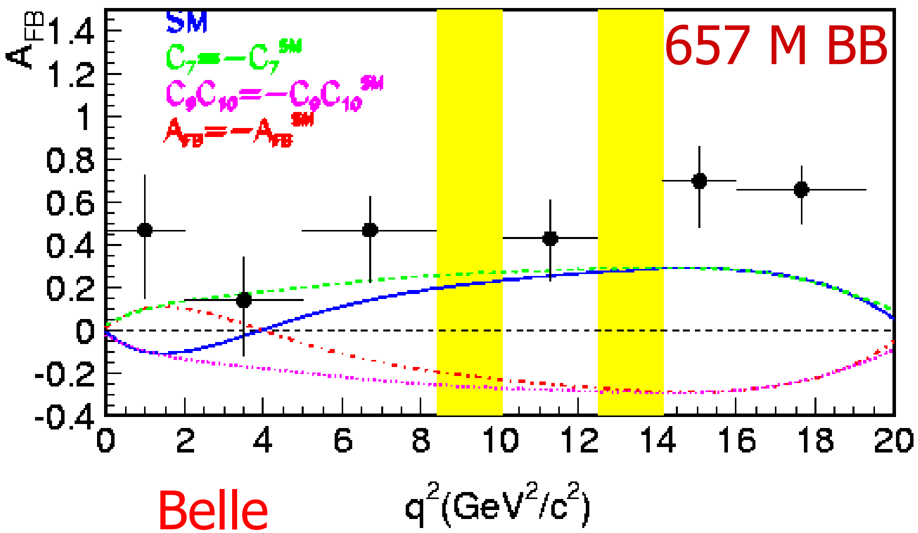
s=lepton pair mass squared

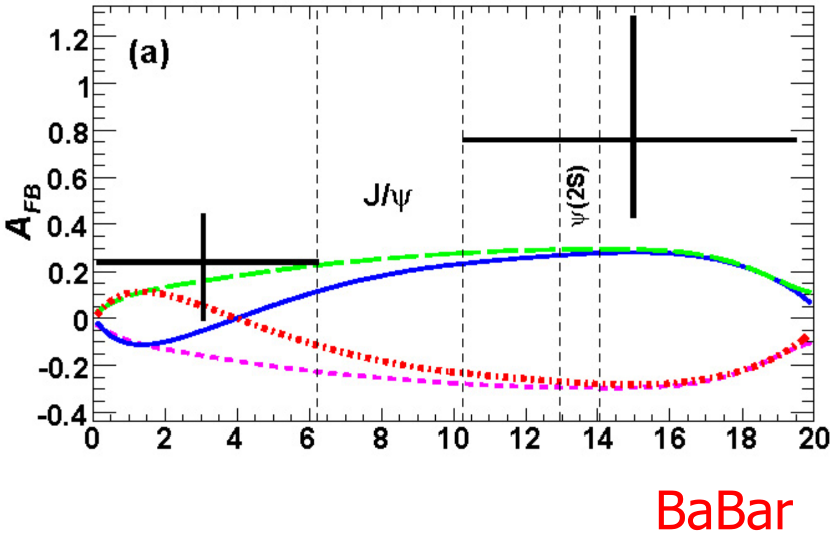
Backward-forward asymmetry in $K^* l^+ l$

$$A_{FB} \propto \Re\left[C_{10}^{*} \left(s C_9^{eff}(s) + r(s) C_7 \right) \right]$$



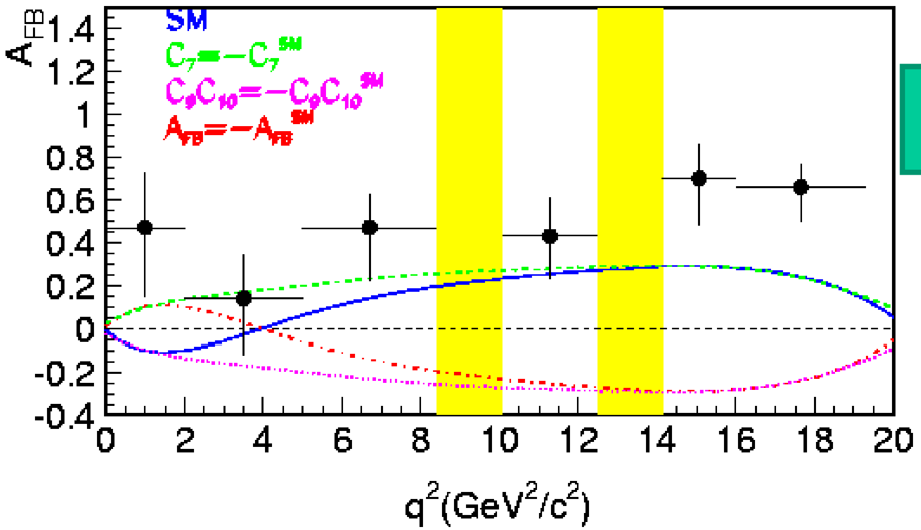
[γ* and Z* contributions in B→K* l l interfere and give rise to forward-backward asymmetries c.f. $e^+e^- \to \mu^+ \mu^-$]

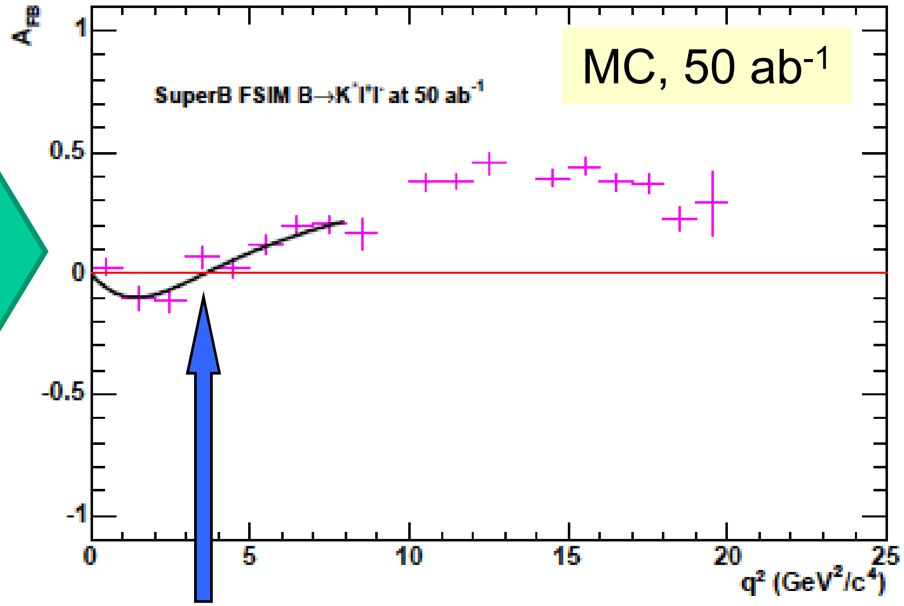




$A_{FB}(B \rightarrow K^* l^+ l^-)[q^2]$ at a Super B Factory

657 M BB





- Zero-crossing q^2 for A_{FB} will be determined with a 5% error with 50ab^{-1}.

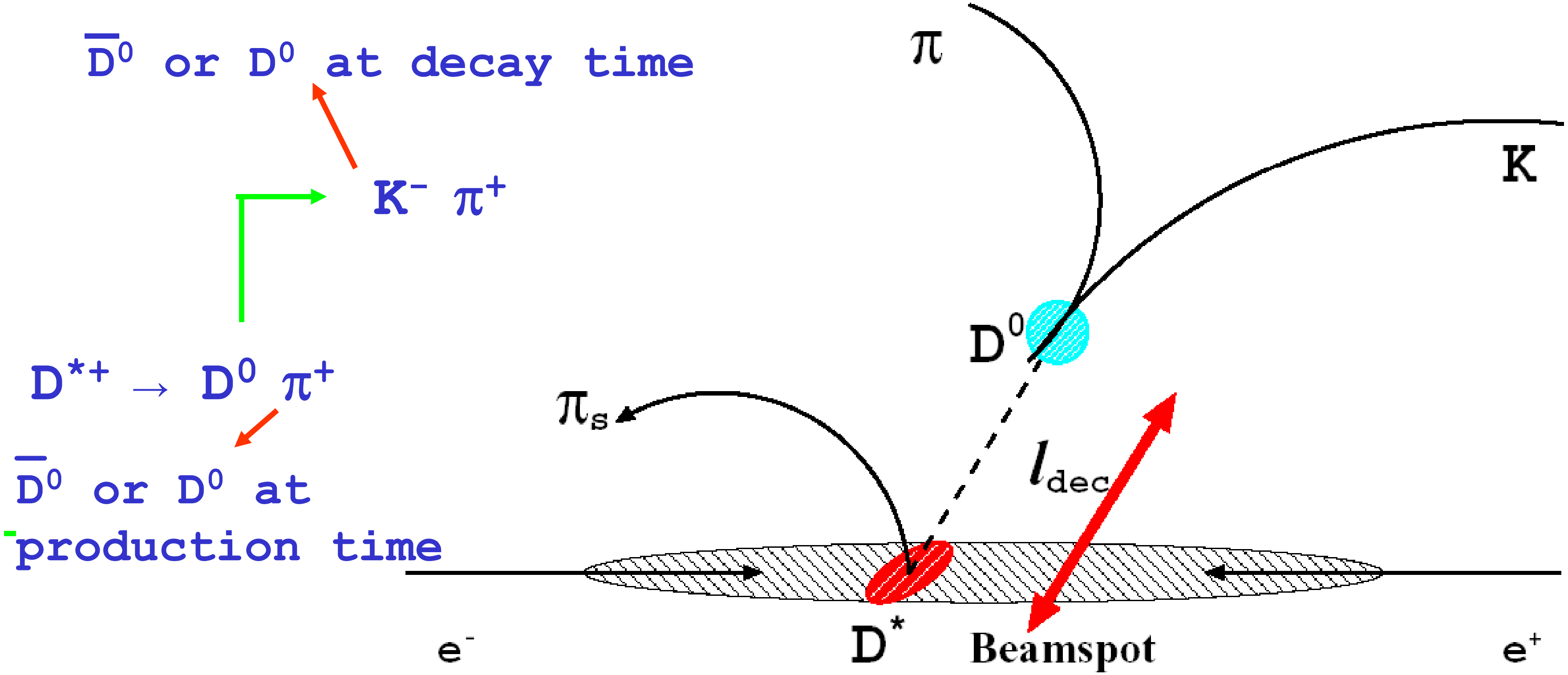
Strong competition from LHCb and ATLAS/CMS

Experimental methods in D^0 mixing searches

The method: investigate D decays in the decay sequence:

$D^{*+} \to D^0\pi^+$, $D^0 \to$ specific final states

Used for tagging the initial flavour and for background reduction



$p_{cms}(D^*) > 2.5$ GeV/c eliminates D meson production from $b \to c$

D^0 mixing in K^+K^-, $\pi^+\pi^-$

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

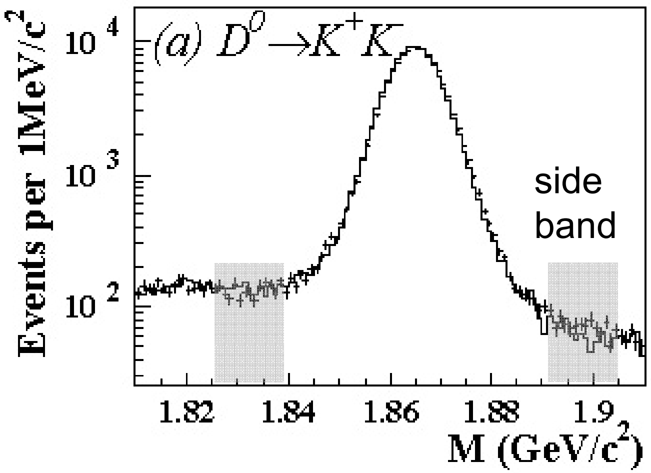
$$\left| D_{1,2} \right\rangle = p \left| D^0 \right\rangle \pm q \left| \overline{D}^0 \right\rangle$$

CP even final state;
in the limit of no CPV: CP|D_1> = |D_1>
$\Rightarrow$ measure $1/\Gamma_1$

$$y_{CP} \equiv \frac{\tau(K^-\pi^+)}{\tau(K^-K^+)} - 1 = y\cos\varphi - \frac{1}{2} A_M x \sin\varphi \underset{no\ CPV}{=} y$$

S. Bergman et al., PLB486, 418 (2000)

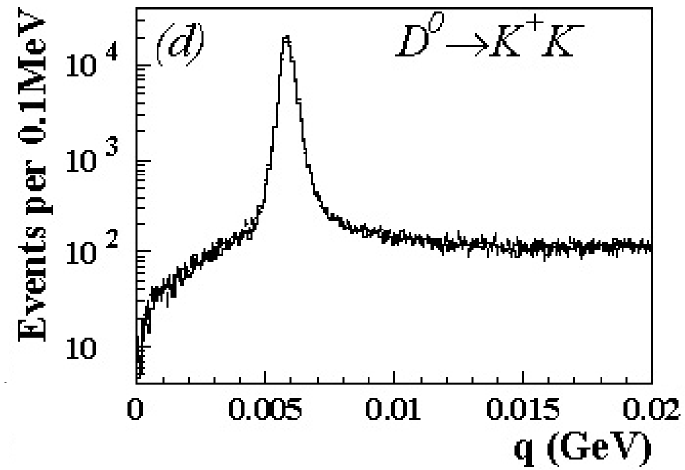
A_M, ϕ: CPV in mixing and interference



Signal: $D^0 \to K^+K^- / \pi^+\pi^-$ from D^*

M, Q, σ_t selection optimized in MC

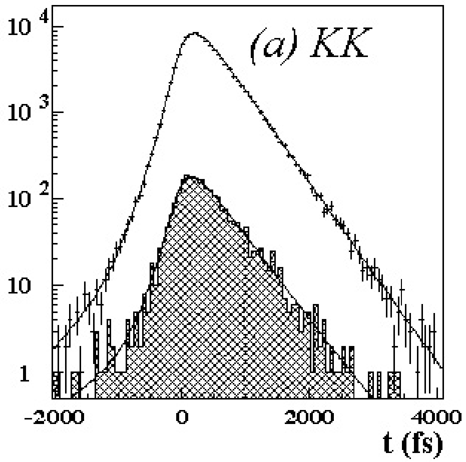
	K^+K^-	$K^-\pi^+$	$\pi^+\pi^-$
N_{sig}	111×10^3	1.22×10^6	49×10^3
purity	98%	99%	92%



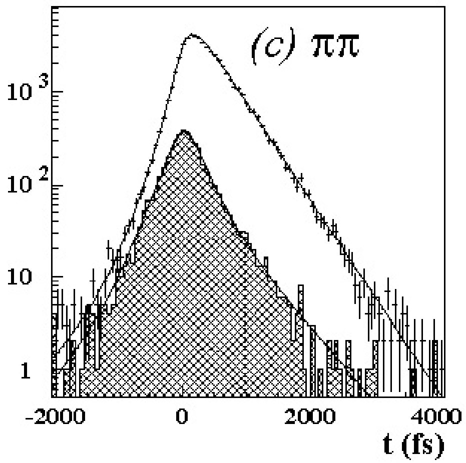
PRL 98, 211803 (2007), 540fb^{-1}

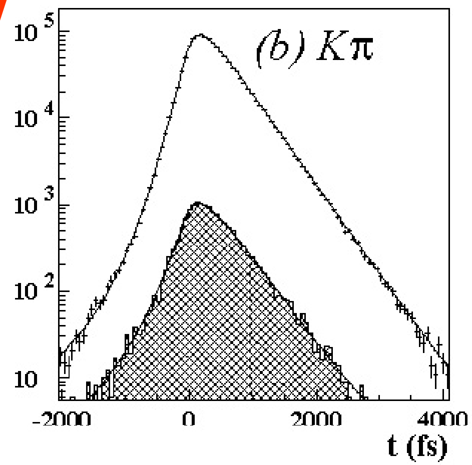
D^0 mixing in K^+K^-, $\pi^+\pi^-$

Decay time distributions for KK, ππ, Kπ

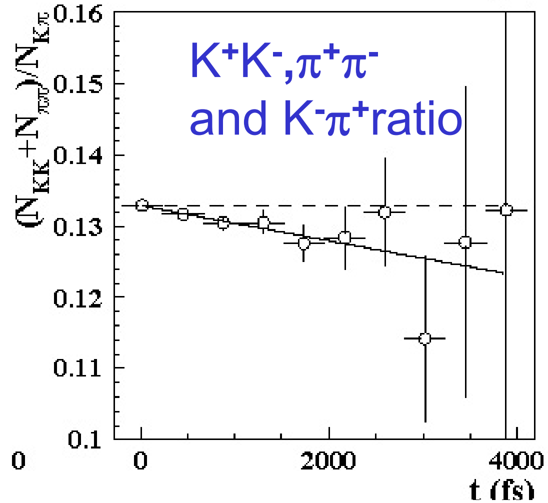


+





Difference of lifetimes
visually observable
in the ratio of the distributions →



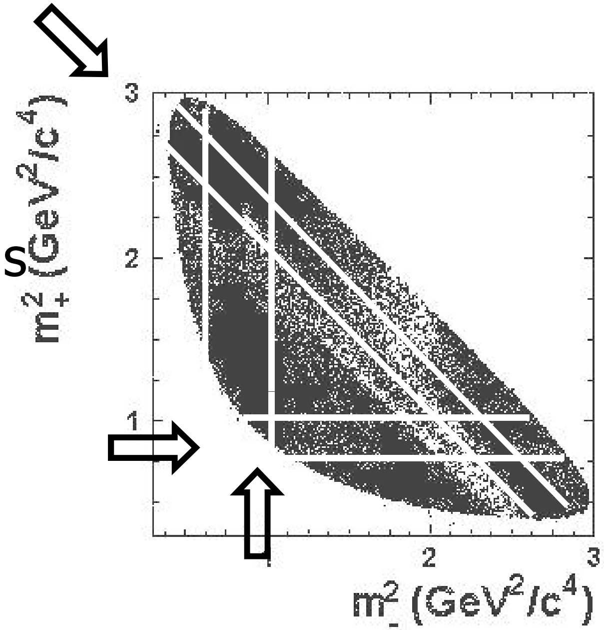
Real fit:

$$y_{CP} = (1.31 \pm 0.32 \pm 0.25)\ \%$$

evidence for D^0 mixing
(regardless of possible CPV)

→ y_{CP} is on the high side of SM expectations

D^0 mixing in $K_S\,\pi^+\pi^-$



time-dependent Dalitz plot analysis

different decays identified through Dalitz plot analysis

CF: $D^0 \to K^{*-}\pi^+$

DCS: $D^0 \to K^{*+}\pi^-$

CP: $D^0 \to \rho^0 K_S$

time-dependence:

$m_\pm^2 = m^2(K_S\,\pi^\pm)$: Dalitz variables

$$\mathcal{M}(m_-^2, m_+^2, t) \equiv \left\langle K_S \pi^+ \pi^- \middle| D^0(t) \right\rangle =$$

$$= \frac{1}{2}\mathcal{A}(m_-^2, m_+^2)\left[e^{-i\lambda_1 t} + e^{-i\lambda_2 t}\right] + \frac{1}{2}\frac{q}{p}\overline{\mathcal{A}}(m_-^2, m_+^2)\left[e^{-i\lambda_1 t} - e^{-i\lambda_2 t}\right]$$

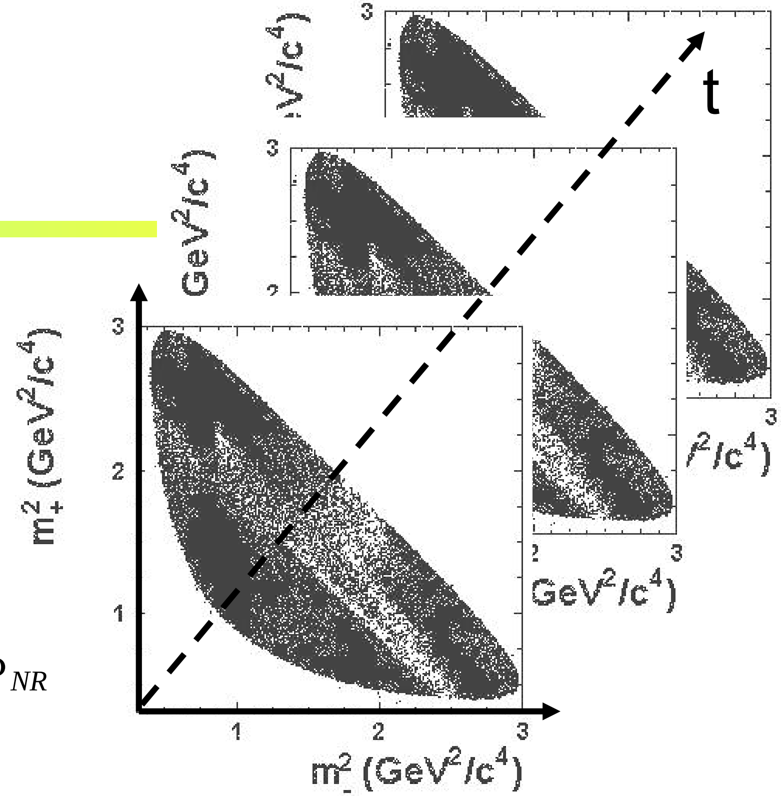
$\langle f \mid D^0 \rangle$ $\qquad$ $\langle f \mid \overline{D}^0 \rangle$

$\lambda_{1,2} = m_{1,2} - i\Gamma_{1,2}/2 = f(x,y)$

analogous for $\overline{\mathcal{M}} = \langle f \mid \overline{D}^0(t) \rangle$

Rate: terms with $\cos(x\Gamma t)\exp(-\Gamma t)$, $\sin(x\Gamma t)\exp(-\Gamma t)$, $\exp(-(1\pm y)\Gamma t)$ → sensitive to x and y

D^0 mixing in $K_S\ \pi^+\pi^-$



Signal

N_{sig}= (534.4±0.8)x10^3
P ≈ 95%

Dalitz model

$$\mathcal{A}(m_-^2, m_+^2) = \sum a_r\ e^{i\Phi_r} B(m_-^2, m_+^2) + a_{NR}\ e^{i\Phi_{NR}}$$

18 resonant BW terms + non-resonant contribution

Fit $\left|\mathcal{M}(m_-^2, m_+^2, t)\right|^2$ to the data distribution ⇒ x, y

$x = (0.80 \pm 0.29 \pm ^{0.13}_{0.16})\%$
$y = (0.33 \pm 0.24 \pm ^{0.10}_{0.14})\%$

Search for CP violation in the D^0 system

Relevant CKM elements of the 2x2 submatrix:

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

phase: $\sim \frac{2\eta A^2\lambda^5}{\lambda} \sim O(10^{-3})$

CPV in D^0 very small, $\leq 10^{-3}$;
parameterization:

$$\frac{q}{p} \neq 1; \ \frac{q}{p} \equiv (1+\frac{A_M}{2})e^{i\varphi}; \ A_M, \varphi \neq 0$$

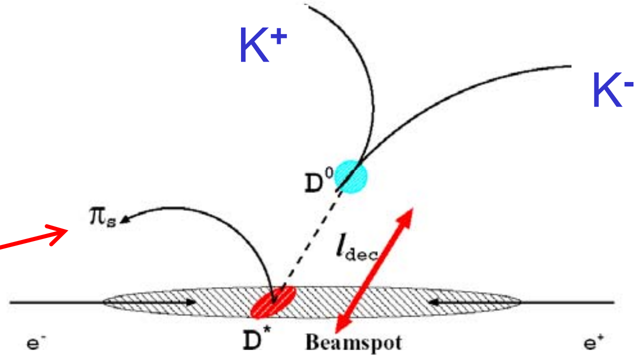
$D^0 \rightarrow K^+\pi^-, K^+K^- / \pi^+\pi^-, K_S\,\pi^+\pi^-$
t evolution depends also on CPV parameters

- x, y at upper limit of SM expectation → search for CPV
- at current level of sensitivity: positive signal clear indication of NP

Search for CP violation

CPV in $D^0 \to K^+K^- / \pi^+\pi^-$

Tag the D meson flavour (D or D-bar) by D* charge (=charge of the 'slow' pion), $D^{*+} \to \pi^+ D^0$



$$y_{CP} \equiv \frac{\tau(K^-\pi^+)}{\tau(K^-K^+)} - 1 = y\cos\varphi - \frac{1}{2} A_M x \sin\varphi$$

$$A_\Gamma = \frac{\tau(\overline{D}^0 \to K^-K^+) - \tau(D^0 \to K^-K^+)}{\tau(\overline{D}^0 \to K^-K^+) + \tau(D^0 \to K^-K^+)} = \frac{1}{2} A_M y\cos\varphi - x\sin\varphi$$

$A_\Gamma = (0.01 \pm 0.30 \pm 0.15)$ **%**

indirect CPV

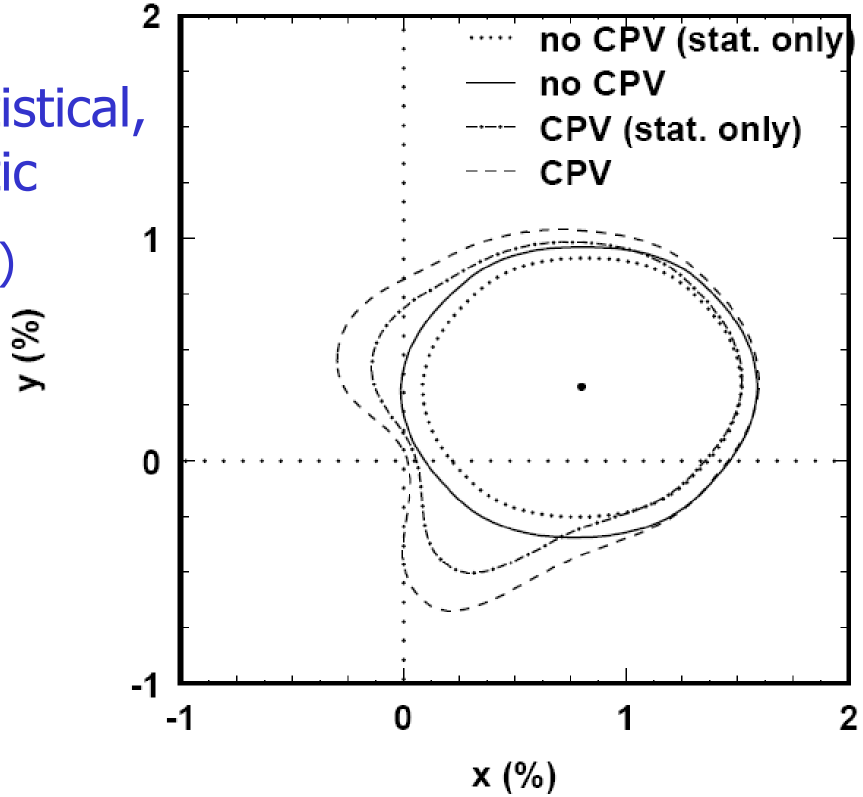
Search for CP violation - continued

CPV in $D^0 \to K_S \pi^+\pi^-$

95% C.L. contours for (x, y):

•CPV allowed: dash-dotted: statistical, dashed: statistical and systematic

(No CPV assumed: dotted and solid)



Dalitz plot fit separately for D^0 and $\overline{D}^0$:

•Fit parameters consistent for both samples → no direct CPV

•Parameters |q/p| and ϕ=arg(q/p) consistent with CP conservation

Fit assuming no direct CPV →
Parameters of CPV in mixing and interf. in mixing and decay:

$|q/p| = 0.95 \pm^{0.22}_{0.20}$
$\phi = \arg(q/p) = (-2\pm^{10}_{11})^0$

D^0 mixing

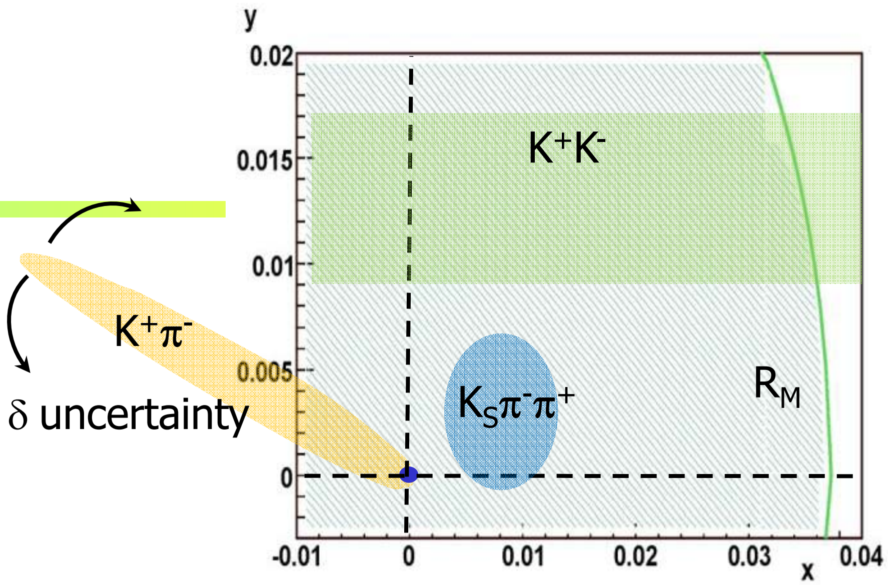
Average of results

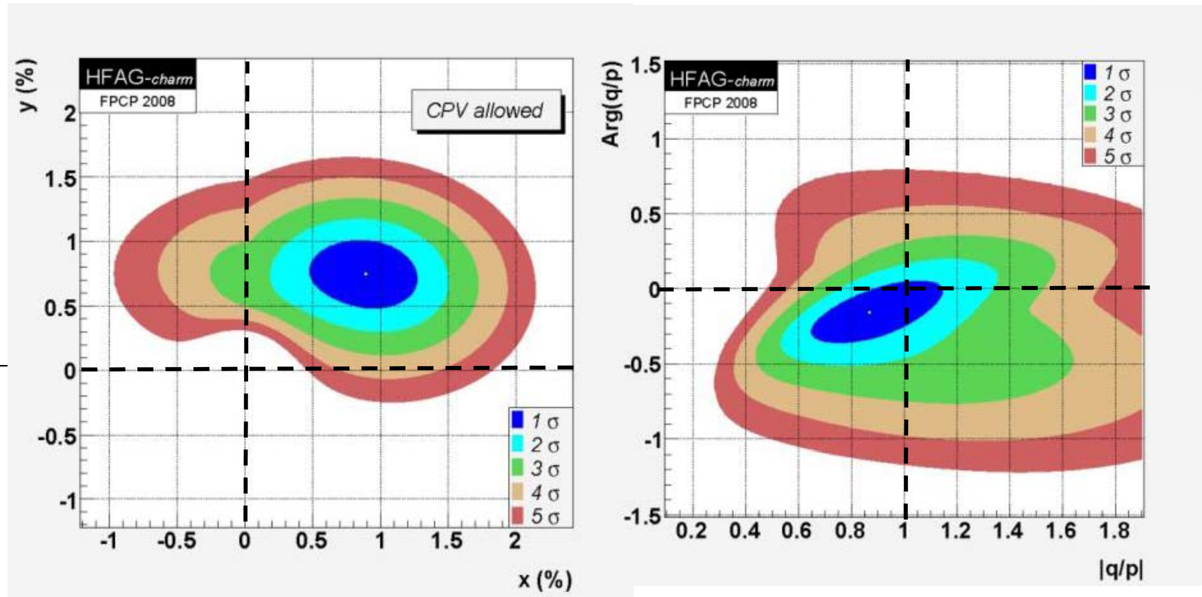
χ^2 fit including correlations among measured quantities

Parameter	CPV-allowed
x (%)	$0.89^{+0.26}_{-0.27}$
y (%)	$0.75^{+0.17}_{-0.18}$
δ (°)	$21.9^{+11.3}_{-12.4}$
R_D (%)	0.3348 ± 0.0086
A_D (%)	-2.0 ± 2.4
$\|q/p\|$	$0.87^{+0.18}_{-0.15}$
ϕ (°)	$-9.1^{+8.1}_{-7.8}$
$\delta_{K\pi\pi}$ (°)	$33.0^{+25.9}_{-26.6}$

CPV (A_D, $|q/p|$, ϕ)

χ^2/n.d.f.= 23.5/18





(x,y)≠(0,0): 6.7σ;
CP even state heavier and shorter lived;
no CPV within 1σ

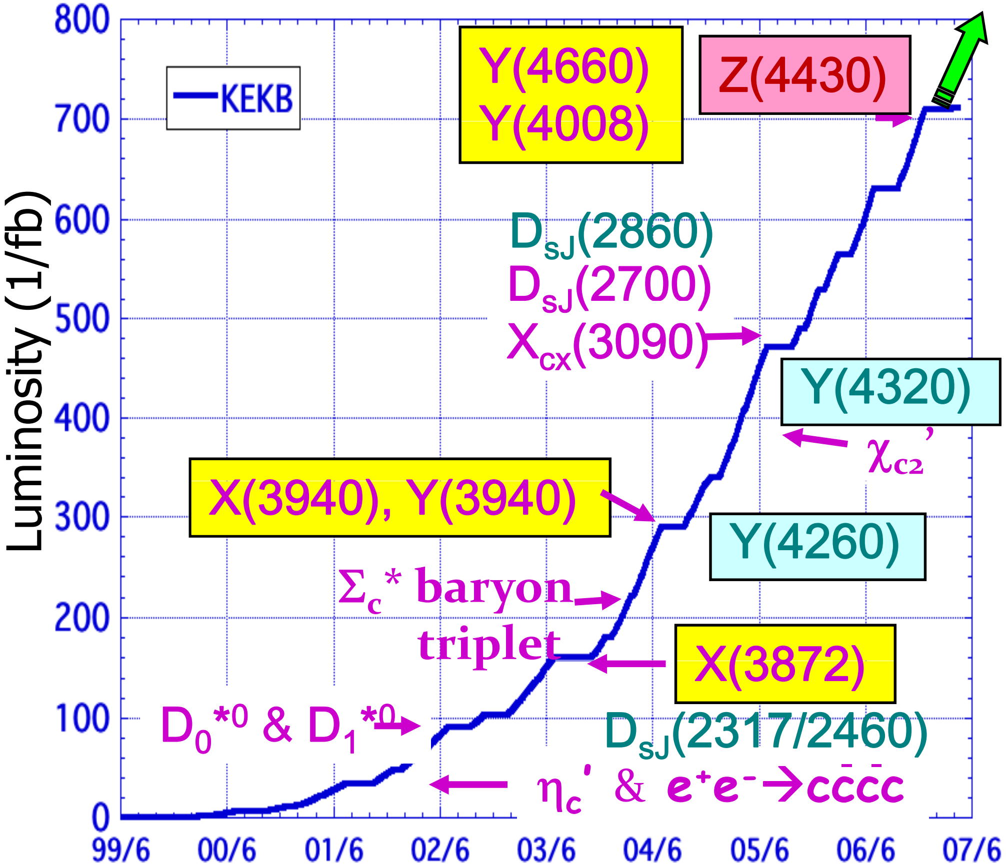
$x(D^0) \approx 0.01$; $x(K^0) \approx 1$; $x(B_d) \approx 0.8$; $x(B_s) \approx 25$

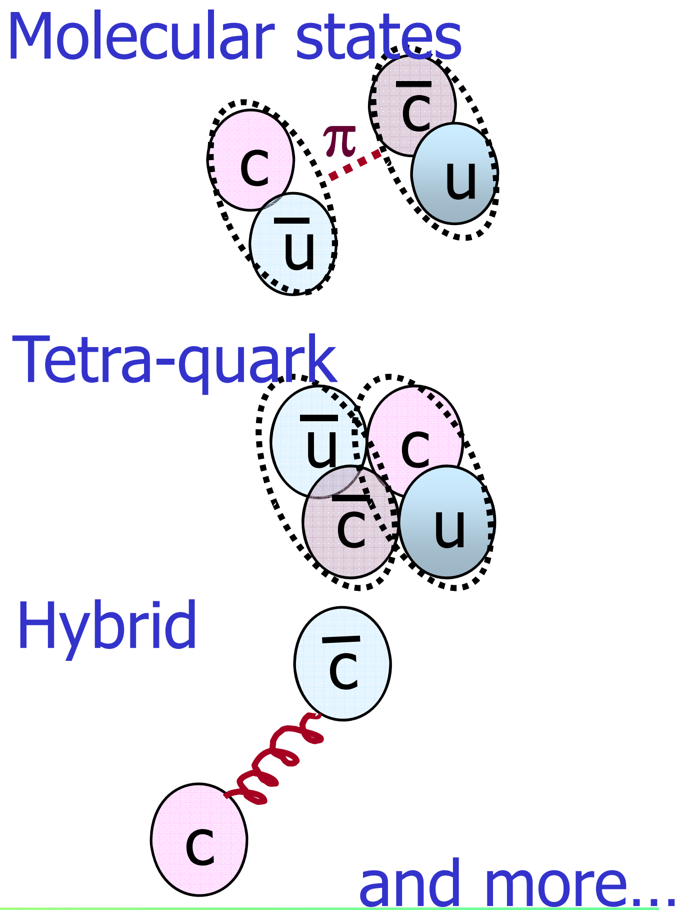
B factories: a success story

- Measurements of CKM matrix elements and angles of the unitarity triangle
- Observation of direct CP violation in B decays
- Measurements of rare decay modes (e.g., $B \rightarrow \tau\nu$, $D\tau\nu$) by fully reconstructing the other B meson
- Observation of D mixing
- CP violation in $b \rightarrow s$ transitions: probe for new sources if CPV
- Forward-backward asymmetry (A_{FB}) in $b \rightarrow s l^+ l^-$ has become a powerfull tool to search for physics beyond SM.
- Observation of new hadrons

New hadrons at B-factories

Discoveries of many new hadrons at B-factories have shed light on new class of hadrons beyond the ordinary mesons.





Back-up slides

Model-indep. check of NP

- A_{cp} $(K\pi)$ sum rule

M. Gronau, PLB 627, 82 (2005);

D. Atwood & A. Soni, Phys. Rev. D 58, 036005(1998).

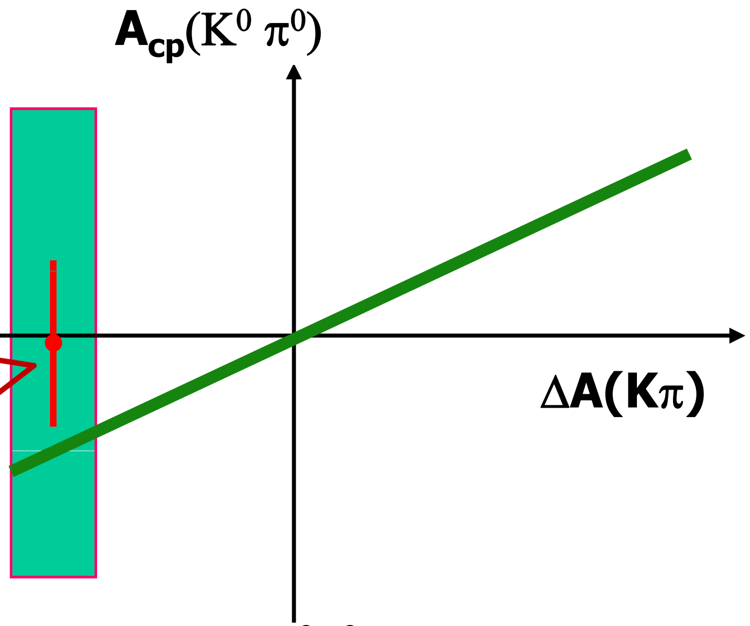
$$\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = \mathcal{A}_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + \mathcal{A}_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

$B^0 \to K^0 \pi^0$ New

BaBar: $A = -0.13 \pm 0.13 \pm 0.03$

BELLE: $A = +0.14 \pm 0.13 \pm 0.06$

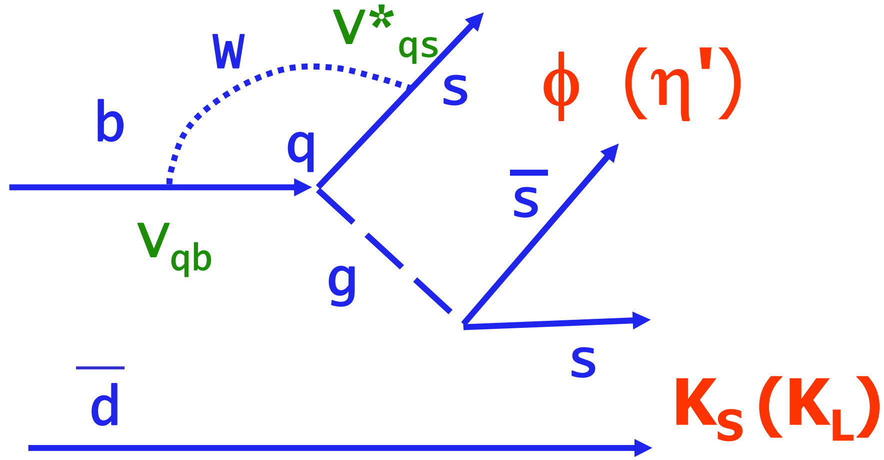
HFAG AVG: -0.01 ± 0.10



Sum rule predicts $A_{cp}(K^0\pi^0) = -0.151 \pm 0.043$

b→sss decays

Pure penguin diagrams



$$A(s\bar{s}s) = V_{cb}V_{cs}^{*}(P_s^c - P_s^t) + V_{ub}V_{us}^{*}(P_s^u - P_s^t).$$

$V_{cb}V_{cs}^* = A\lambda^2$ $\quad$ $V_{ub}V_{us}^* = A\lambda^4(\rho - i\eta)$

First term dominates →

λ same as for $J/\psi K_S$

$$\lambda_{\phi K_S} = \eta_{\phi K_S}\left(\frac{V_{tb}^{*}V_{td}}{V_{tb}V_{td}^{*}}\right)\left(\frac{V_{cd}^{*}V_{cb}}{V_{cd}V_{cb}^{*}}\right)$$

$$\mathrm{Im}(\lambda_{\phi K_S}) = \sin 2\phi_1 = \sin 2\beta$$