The other window on New Physics: CP violation at the B factories

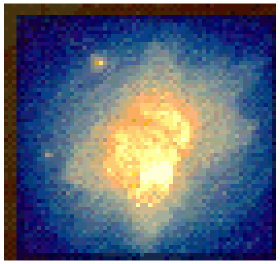
“How would you like to live in Looking-glass House?”
L. Carroll

Gabriella Sciolla
M.I.T.

Outline:

- The physics of CP violation
  - What is CP and why is it interesting?
- CPV in the B system
  - CPV in the Standard Model and the Unitarity Triangle
- Constraining the Unitarity Triangle at the B factories
  - Measurements of angles and sides
- Conclusion
  - Summary & Prospects

The matter dominated Universe



The Big Bang model predicts:

- matter and anti-matter produced in equal amounts
- matter and anti-matter annihilated into pure energy

But this goes against experimental evidence:

- The Universe exists
- It is made of (almost) only matter

How is this possible?

A. Sakharov's 3 conditions (1967):

- Baryon number non conservation
- Thermal non equilibrium
- C and CP violation

The CP symmetry

$$CP = C \times P$$

C: Charge Conjugation
Particle → Anti-particle

P: Parity
Inverts space coordinates

Is Nature CP symmetric?

Interaction	*C*	*P*	*T*	*CP*	*CPT*
Strong	✔	✔	✔	✔	✔
Electromagnetic	✔	✔	✔	✔	✔
Weak	✘	✘	?	?	✔

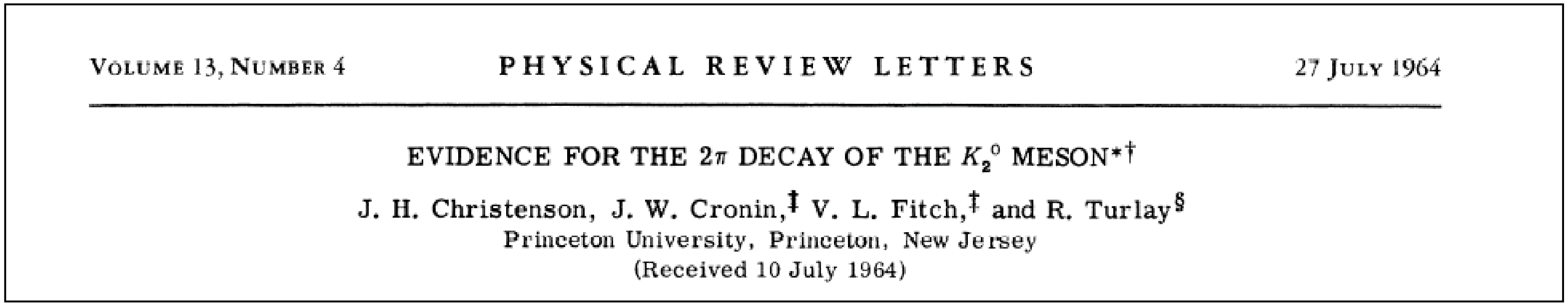
Wu et al., 1957

but CP was expected to be conserved

$$CP|\overline{\nu}\rangle_L = |\nu\rangle_R$$

CP violation in K decays

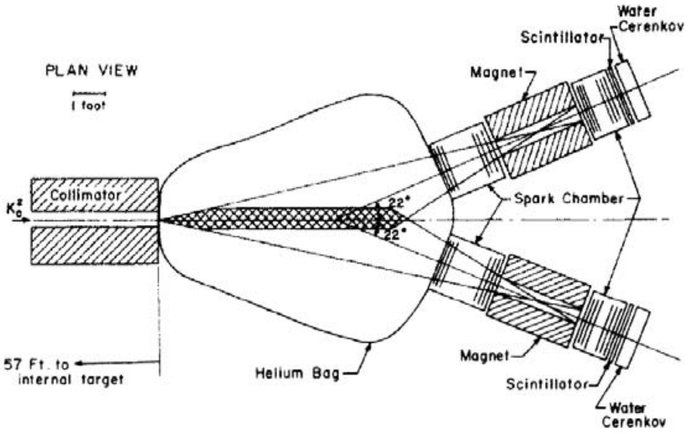
In 1964 Fitch and Cronin discovered CP violation in the decays of K_L mesons: $K_L \rightarrow \pi^+\pi^-$

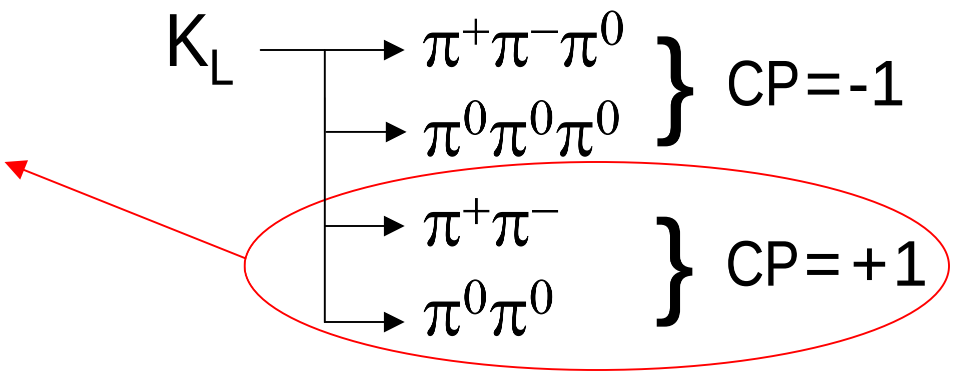


VOLUME 13, NUMBER 4 PHYSICAL REVIEW LETTERS 27 JULY 1964

EVIDENCE FOR THE 2π DECAY OF THE K_2^0 MESON*†

J. H. Christenson, J. W. Cronin,‡ V. L. Fitch,‡ and R. Turlay§
Princeton University, Princeton, New Jersey
(Received 10 July 1964)





$K_L \rightarrow \pi^+\pi^-\pi^0$, $\pi^0\pi^0\pi^0$ } CP=-1

$K_L \rightarrow \pi^+\pi^-$, $\pi^0\pi^0$ } CP=+1

CP violation in the Standard Model

In 1973 the Kobayashi-Maskawa mechanism explained CPV and predicted the existence of third quark family.

CP violation originates from a complex phase in the quark mixing matrix (CKM matrix).

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\bar{\rho}-\boxed{i\bar{\eta}}) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-\boxed{i\bar{\eta}}) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^6)$$

Pros and Cons of CKM

Pros:

- ✓ Elegant and simple explanation of CPV in SM
- ✓ It is very predictive: only one CPV phase
- ✓ It accommodates all experimental results
  - Indirect CP violation in $K \rightarrow \pi\pi$ and $K_L \rightarrow \pi l \nu$
  - Direct CP violation in $K \rightarrow \pi\pi$
  - CP violation in the B system

Cons:

- ☹ n_B/n_γ predicted by CKM « observed value
  - ...by orders of magnitude!

→ New sources of CPV must exist besides CKM!

CPV as a probe for New Physics:

Any extension of SM provides new sources of CP violation

Standard Model or New Physics?

Measure CP violation in channels theoretically very well understood and look for deviations w.r.t. Standard Model prediction

What can we learn from kaons?

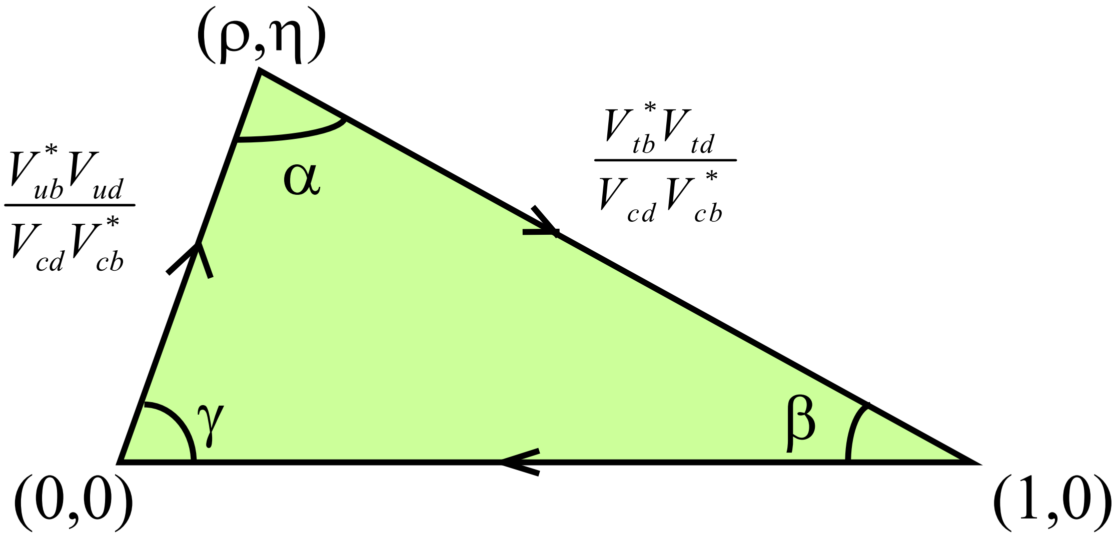
- Experimental results very hard to interpret theoretically:
  - Loose constraints from ε_K measurement
  - No constraints from ε'/ε yet...
- ...or clear theory but very hard to reach experimentally:
  - $BF(K_L \rightarrow \pi^0 \nu \bar{\nu}) \sim 10^{-11}$!

Can B mesons do better?

The Unitarity Triangle

Unitarity of CKM implies: $V^\dagger V = 1$ → 6 unitarity conditions

Of particular interest: $\boxed{\mathbf{V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0}}$



All sides are ~ O(1) → possible to measure both sides and angles!

- CP asymmetries in B meson decays measure α, β and γ
- Sides from B mixing, rare B decays, Semileptonic B decays

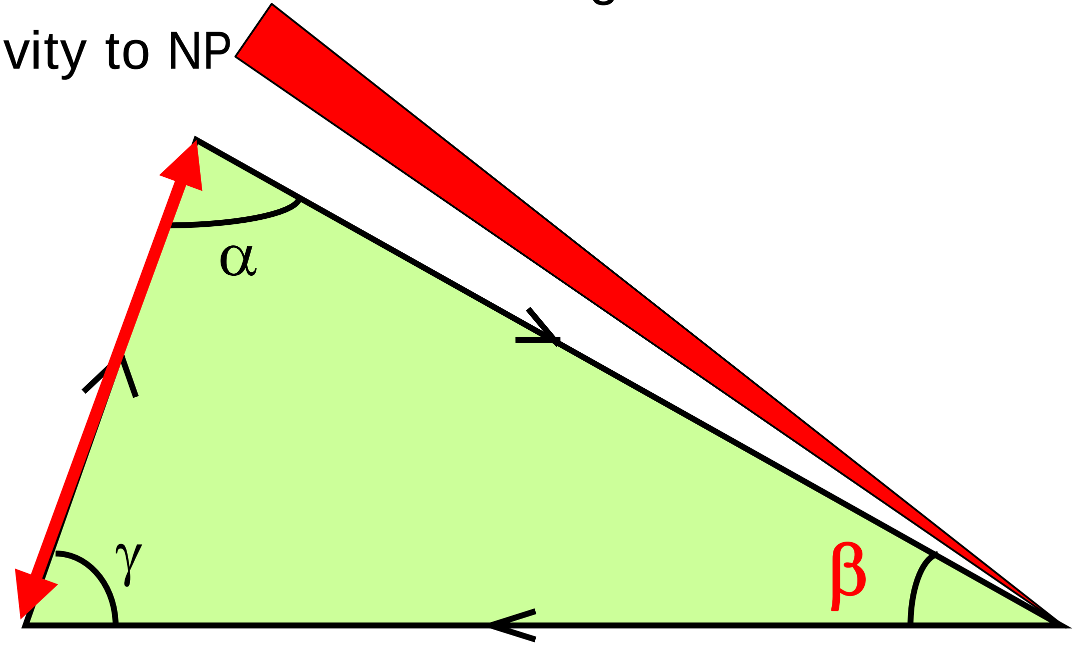
Redundancy, redundancy, redundancy!

3 ways to look for New Physics:

a) Sides vs angles

b) Measurement of same angle using channels with different sensitivity to NP

c) Measurement of same sides using channels with different sensitivity to NP



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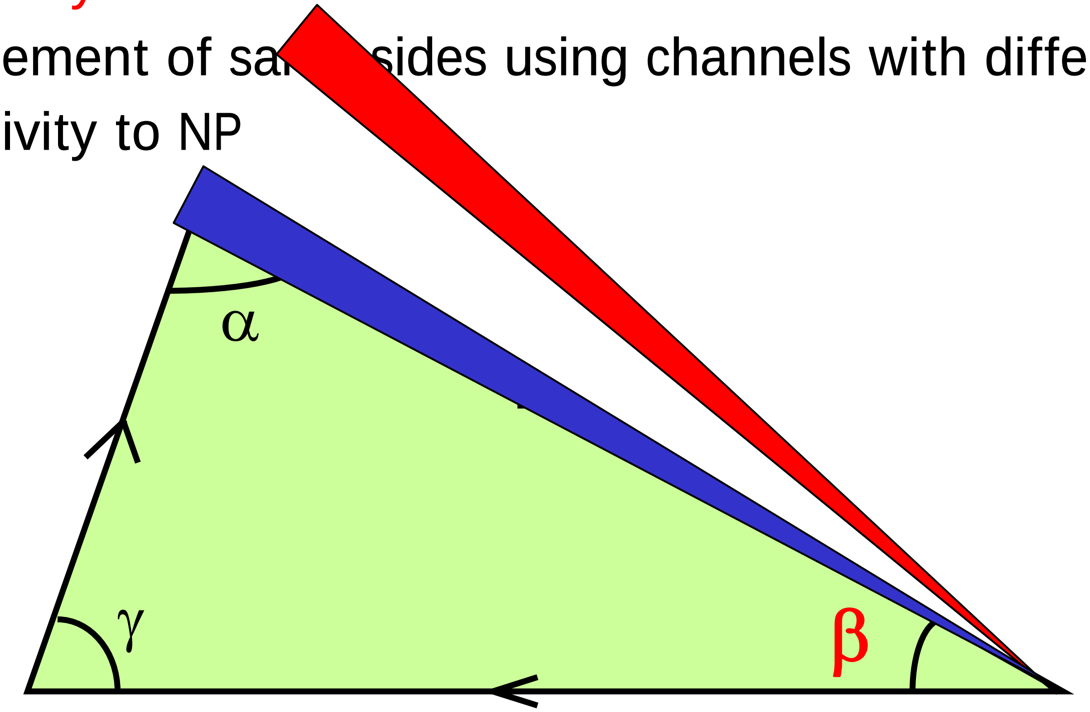

Redundancy, redundancy, redundancy!

3 ways to look for New Physics:

a) Sides vs angles

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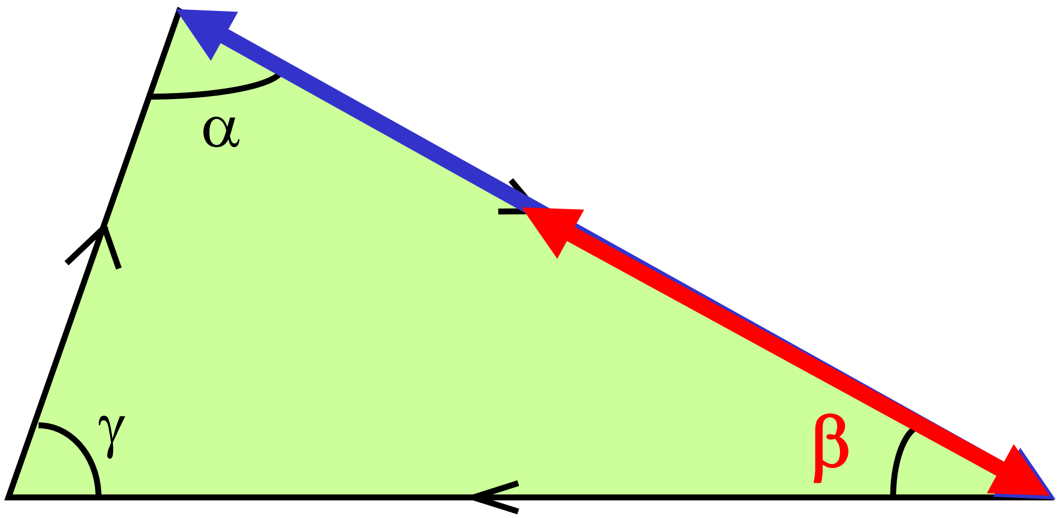


How to measure the angles?

Time dependent CP asymmetry in B^0 decays.

$$A_{CP}(t) = \frac{N(\overline{B}^0(t) \to f_{CP}) - N(B^0(t) \to f_{CP})}{N(\overline{B}^0(t) \to f_{CP}) + N(B^0(t) \to f_{CP})}$$

Questions:

- How is $A_{CP}(t)$ related to the UT angles? ←
- How can we measure $A_{CP}(t)$?

The B^0 system

The B^0 system:

	B mesons
Flavor eigenstates	B^0 and $\overline{B}^0$
Mass eigenstates	B_H and B_L

$$|B_L\rangle = p\,|B^0\rangle + q\,|\overline{B}^0\rangle$$
$$|B_H\rangle = p\,|B^0\rangle - q\,|\overline{B}^0\rangle$$

$$(p^2 + q^2 = 1)$$

The K^0 system:

	K mesons
Flavor eigenstates	K^0 and $\overline{K}^0$
Mass eigenstates	K_S and K_L

$$|K_S\rangle = p'\,|K^0\rangle + q'\,|\overline{K}^0\rangle$$
$$|K_L\rangle = p'\,|K^0\rangle - q'\,|\overline{K}^0\rangle$$

Time evolution of B^0

- Starting from pure B^0($\overline{B}^0$) state, and after time *t*

$$|B^0(t)\rangle = e^{-im_B t} e^{-\Gamma t}\left\{\cos\frac{\Delta m\, t}{2}|B^0\rangle - i\frac{q}{p}\sin\frac{\Delta m\, t}{2}|\overline{B}^0\rangle\right\}$$

$$|\overline{B}^0(t)\rangle = e^{-im_B t} e^{-\Gamma t}\left\{-i\frac{p}{q}\sin\frac{\Delta m\, t}{2}|B^0\rangle + \cos\frac{\Delta m\, t}{2}|\overline{B}^0\rangle\right\}$$

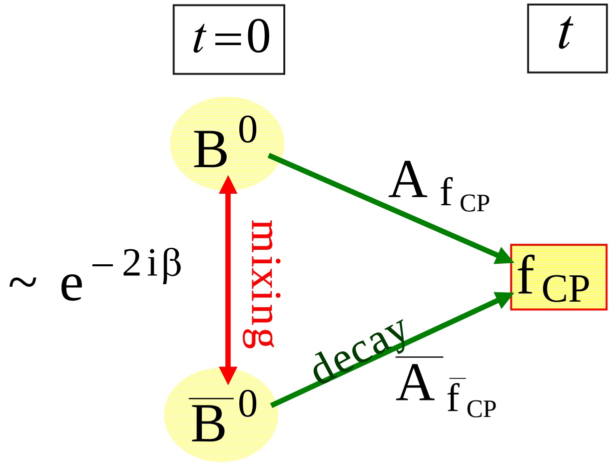
- Interested in Prob(B^0(t)→f) and Prob($\overline{B}^0$(t)→f) :
  - Calculate amplitudes

$$\langle f|\mathcal{H}|B^0(t)\rangle \quad \text{and} \quad \langle f|\mathcal{H}|\overline{B}^0(t)\rangle$$

  - Use

$$A_f = \langle f|\mathcal{H}|B^0\rangle \quad \overline{A}_f = \langle f|\mathcal{H}|\overline{B}^0\rangle$$

  - Take square to get decay rates...



CP violation in interference between mixing and decays in B^0

Time dependent CP asymmetry for $B^0 \rightarrow f_{CP}$:

$$\boxed{A_{CP}(t) = \frac{N(\overline{B}^0(t) \to f_{CP}) - N(B^0(t) \to f_{CP})}{N(\overline{B}^0(t) \to f_{CP}) + N(B^0(t) \to f_{CP})} = S_f \sin(\Delta m t) - C_f \cos(\Delta m t)}$$

where

$$S_f = \frac{2\,\mathrm{Im}\,\lambda_f}{1+|\lambda_f|^2} \qquad C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} \qquad \lambda_f = \frac{q}{p}\cdot\frac{\overline{A}_f}{A_f}$$

For B^0 $\left|\frac{q}{p}\right| \sim 1$, so when only 1 diagram contributes to the final state: $|\lambda|=1$

$$\boxed{A_{CP}(t) = -\eta_f \,\mathrm{Im}\lambda \sin(\Delta m t)}$$

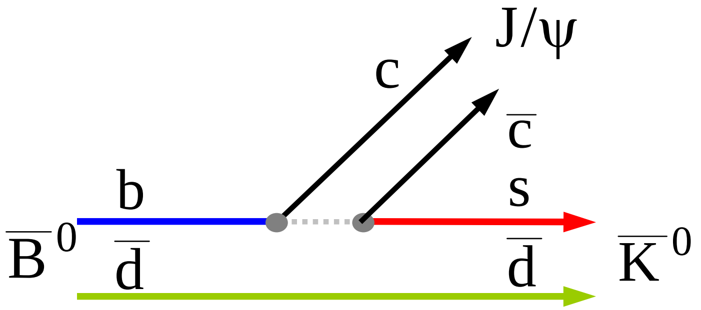
(CP violation in interference between mixing and decays in B^0)

CP violation in B^0 decays: $\sin 2\beta$

For some lucky modes, Imλ is directly and simply related to the angles of the Unitarity Triangle.

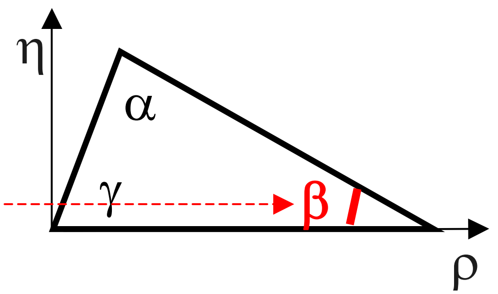
Example:

$B^0 \rightarrow J/\Psi K_S$: the "golden mode"



$$\lambda = \left(\frac{V_{tb}^{*}V_{td}}{V_{tb}V_{td}^{*}}\right)\left(\frac{\cancel{V_{cs}^{*}}V_{cb}}{\cancel{V_{cs}}V_{cb}^{*}}\right)\left(\frac{V_{cd}^{*}\cancel{V_{cs}}}{V_{cd}\cancel{V_{cs}^{*}}}\right)$$

$$\boxed{A_{CP}(t) = \sin 2\beta \ \sin\Delta m t}$$



How to measure the angles?

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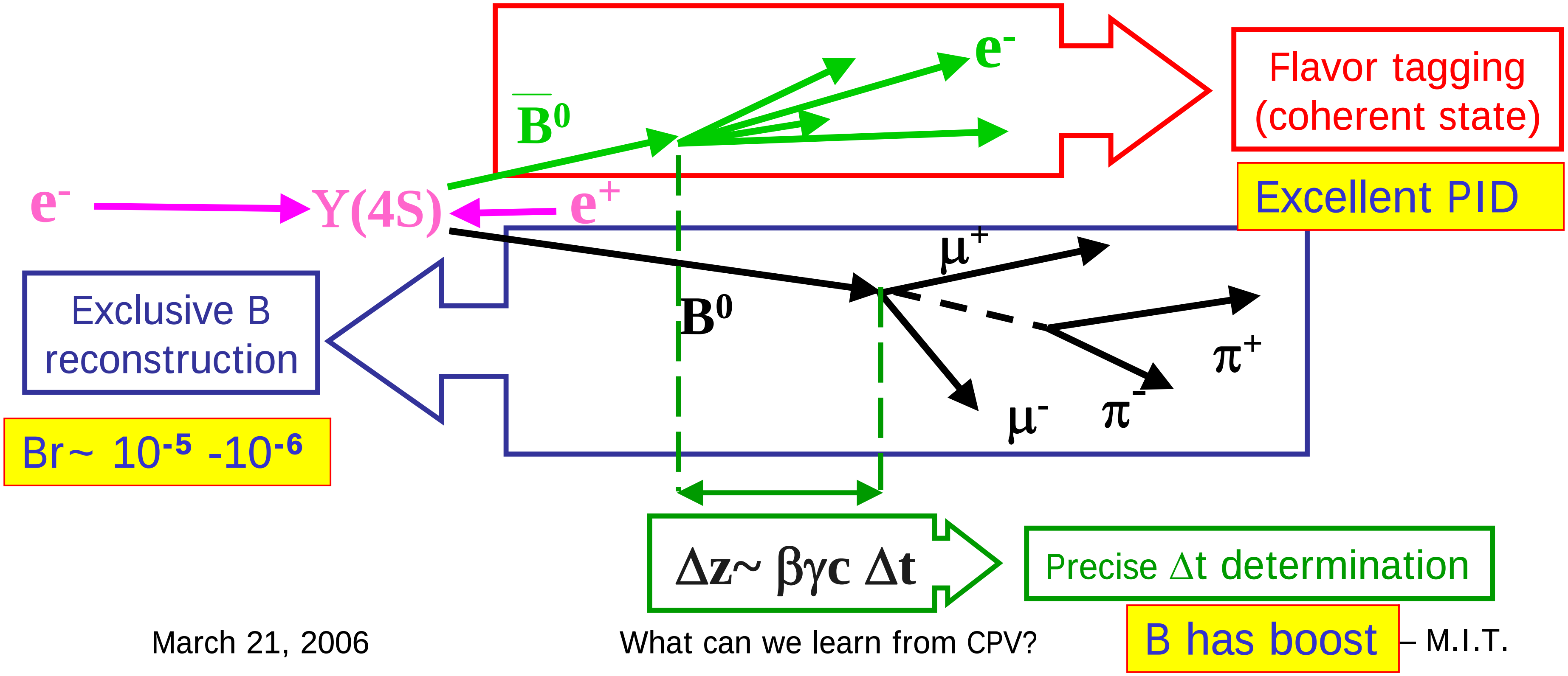
Questions:

- How is $A_{CP}(t)$ related to the UT angles? ✓
- How can we measure $A_{CP}(t)$? ←

How to measure the CP asymmetry

$$A_{CP}(t)=\frac{N(\overline{B}^0(t)\rightarrow f_{CP})-N(B^0(t)\rightarrow f_{CP})}{N(\overline{B}^0(t)\rightarrow f_{CP})+N(B^0(t)\rightarrow f_{CP})}$$



Flavor tagging
(coherent state)

Excellent PID

Exclusive B
reconstruction

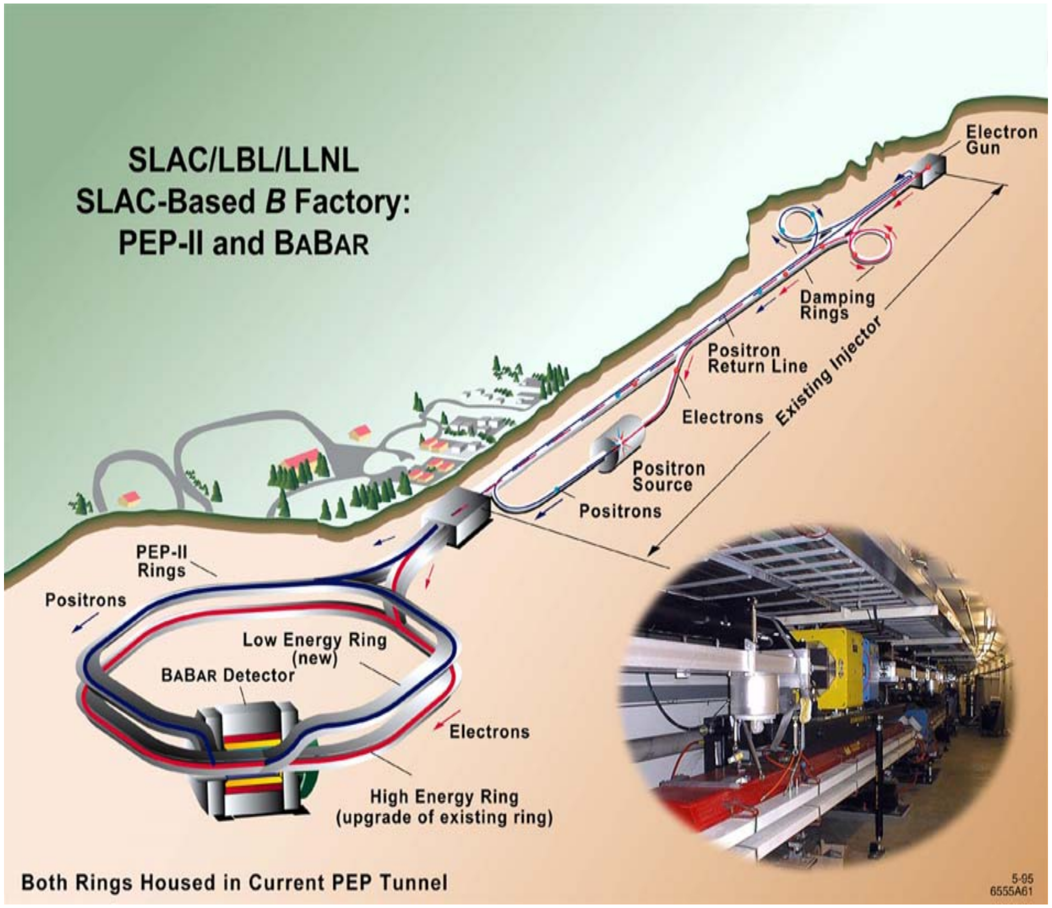
Br~ 10^{-5} -10^{-6}

$\Delta z \sim \beta\gamma c\, \Delta t$

Precise Δt determination

B has boost

The B factories: PEP-II and KEK-B

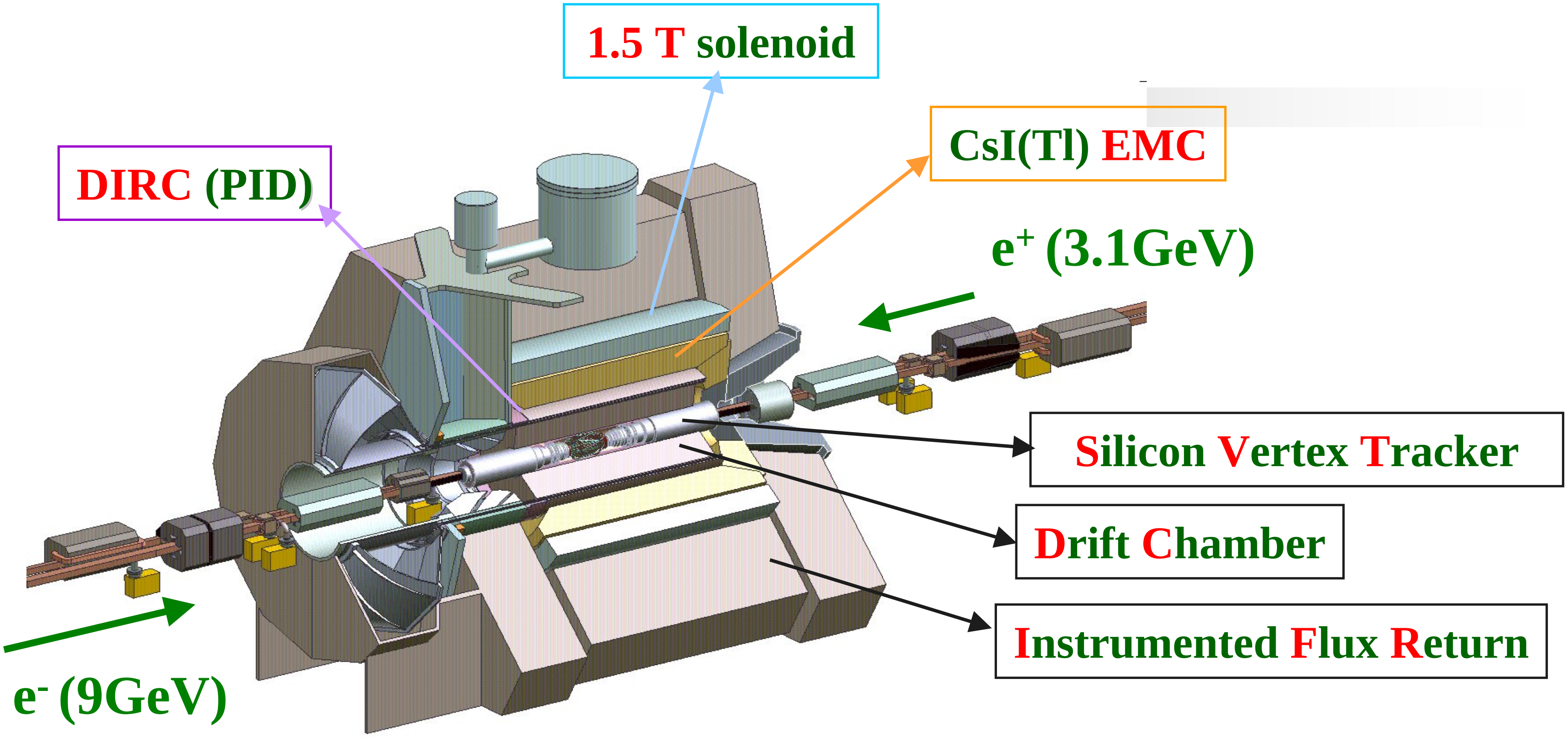


- Asymmetric beams
  - 9.0 GeV e^- beam
  - 3.1 GeV e^+ beam
- Currents: 1-2 A
- Peak Luminosity:
  - Design: 3 x 10^{33} $cm^{-2}s^{-1}$
  - Achieved: 12 x 10^{33} $cm^{-2}s^{-1}$
- Integrated Luminosity

  >400 fb^{-1}
  - Belle: ~600 fb^{-1}

>1 ab^{-1} in total !

The BABAR Detector



1.5 T solenoid

DIRC (PID)

CsI(Tl) EMC

e^+ (3.1GeV)

Silicon Vertex Tracker

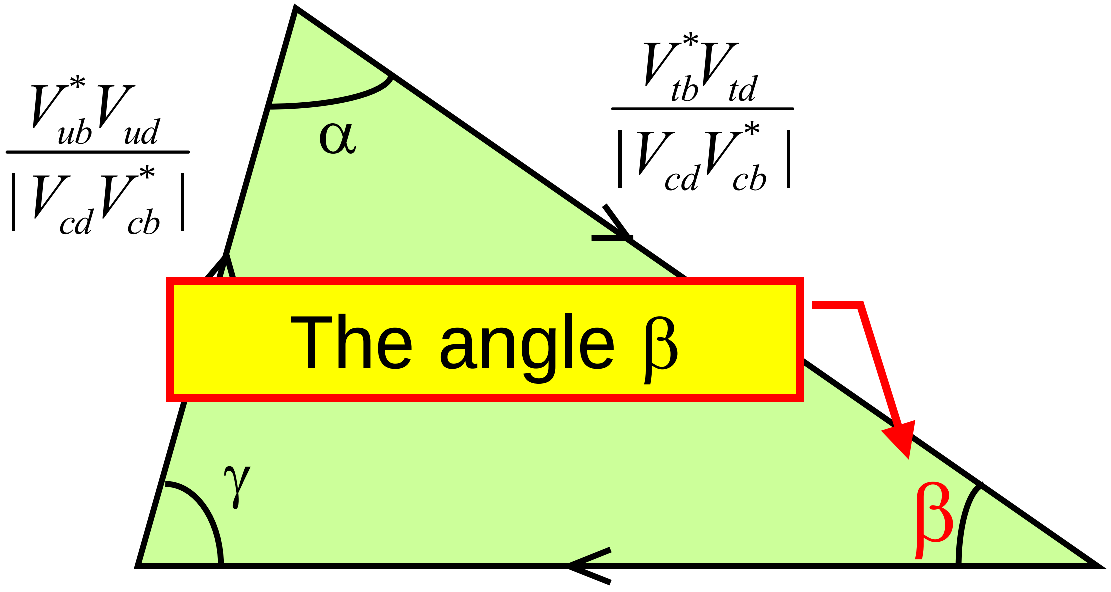
Drift Chamber

Instrumented Flux Return

e^- (9GeV)

- SVT: 97% efficiency, 15μm z resolution
- Tracking: $\sigma(p_T)/p_T = 0.13\%\ p_T \oplus 0.45\%$
- DIRC: K-π separation: > 4.2σ @ p=3 GeV/c
- EMC: $\sigma_E/E = 2.3\%\ E^{-1/4} \oplus 1.9\%$

The measurements



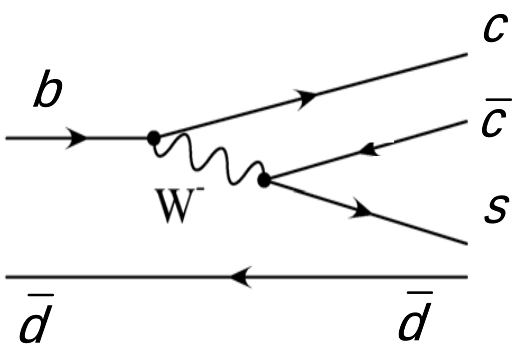
The angle β

BaBar 2006 (347M BB)

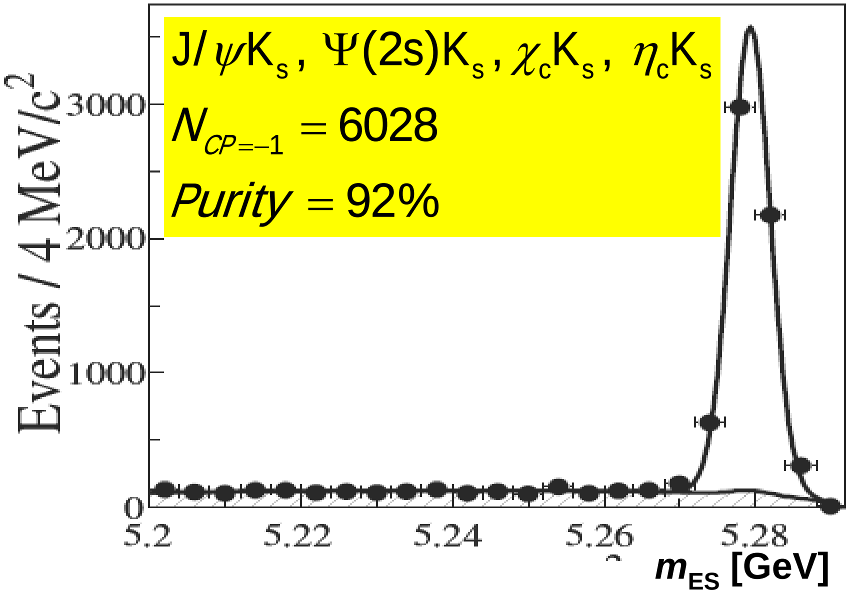
The golden mode for sin2β:

$B^0 \rightarrow$ charmonium K^0

- Theoretically clean
- Experimentally clean
- Relatively large BF (~10^{-4})



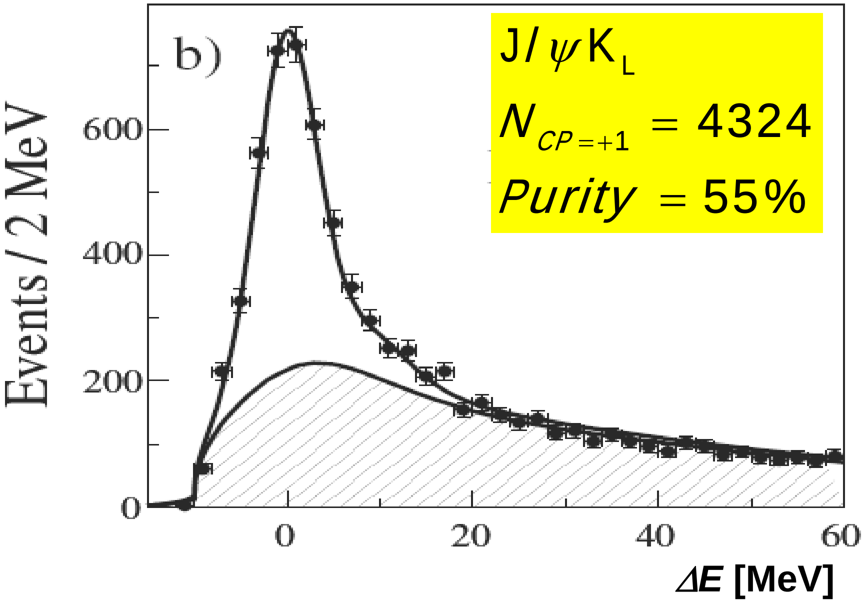
CP sample:



$J/\psi K_s$, $\Psi(2s)K_s$, $\chi_c K_s$, $\eta_c K_s$

$N_{CP=-1} = 6028$

$Purity = 92\%$

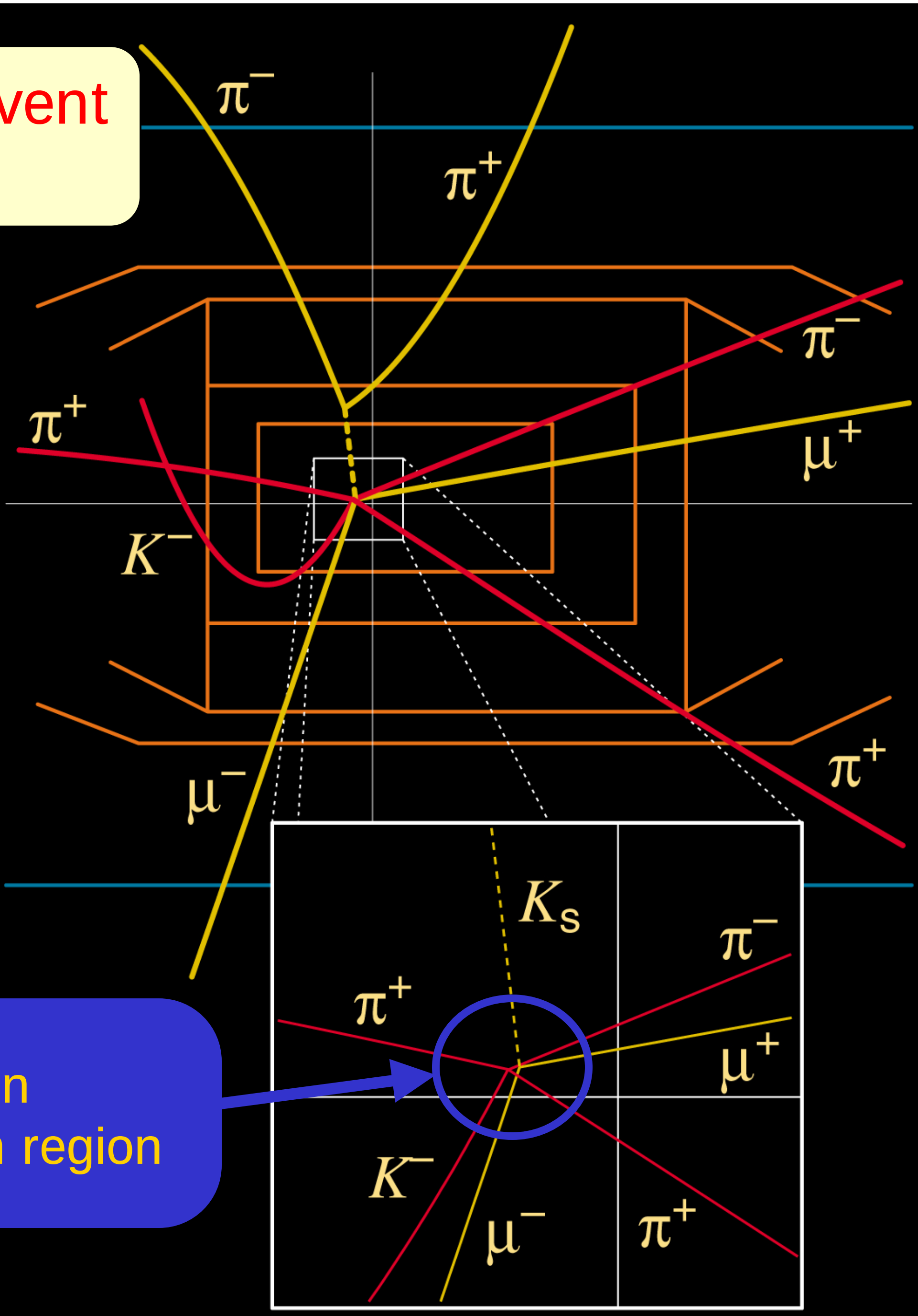


$J/\psi K_L$

$N_{CP=+1} = 4324$

$Purity = 55\%$

Gold plated event at BaBar



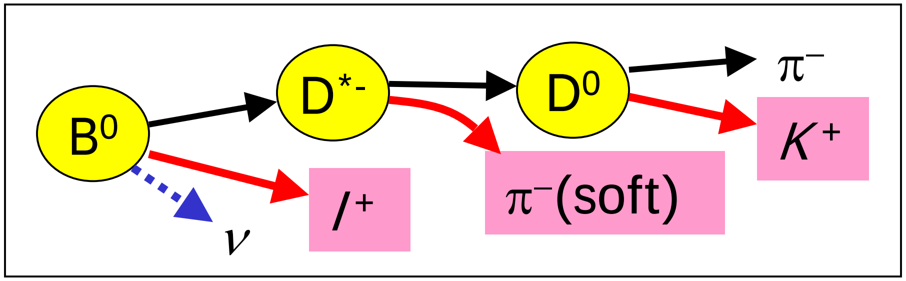
$B^0 \rightarrow J/\Psi\ K_S$

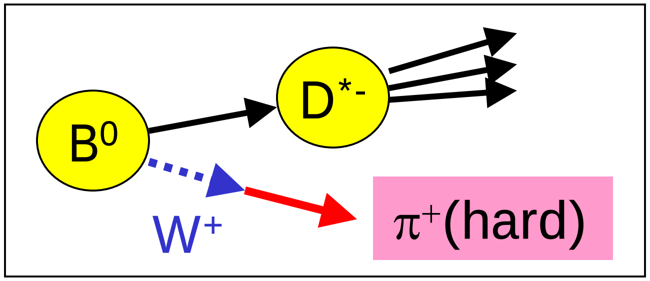
$\bar{B}^0 \rightarrow K^- X$

Zoom on interaction region

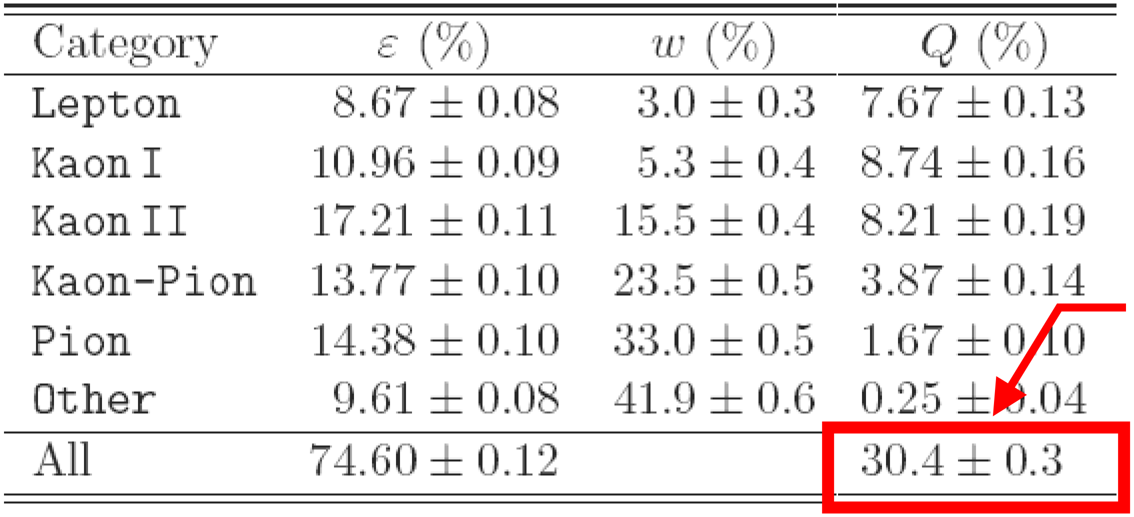
B flavor tagging

The principle:





Information combined in a NN-based algorithm



Category	ε (%)	w (%)	Q (%)
Lepton	8.67 ± 0.08	3.0 ± 0.3	7.67 ± 0.13
Kaon I	10.96 ± 0.09	5.3 ± 0.4	8.74 ± 0.16
Kaon II	17.21 ± 0.11	15.5 ± 0.4	8.21 ± 0.19
Kaon-Pion	13.77 ± 0.10	23.5 ± 0.5	3.87 ± 0.14
Pion	14.38 ± 0.10	33.0 ± 0.5	1.67 ± 0.10
Other	9.61 ± 0.08	41.9 ± 0.6	0.25 ± 0.04
All	74.60 ± 0.12		$\boxed{30.4 \pm 0.3}$

$Q=\varepsilon_{tag}(1-2w)^2$

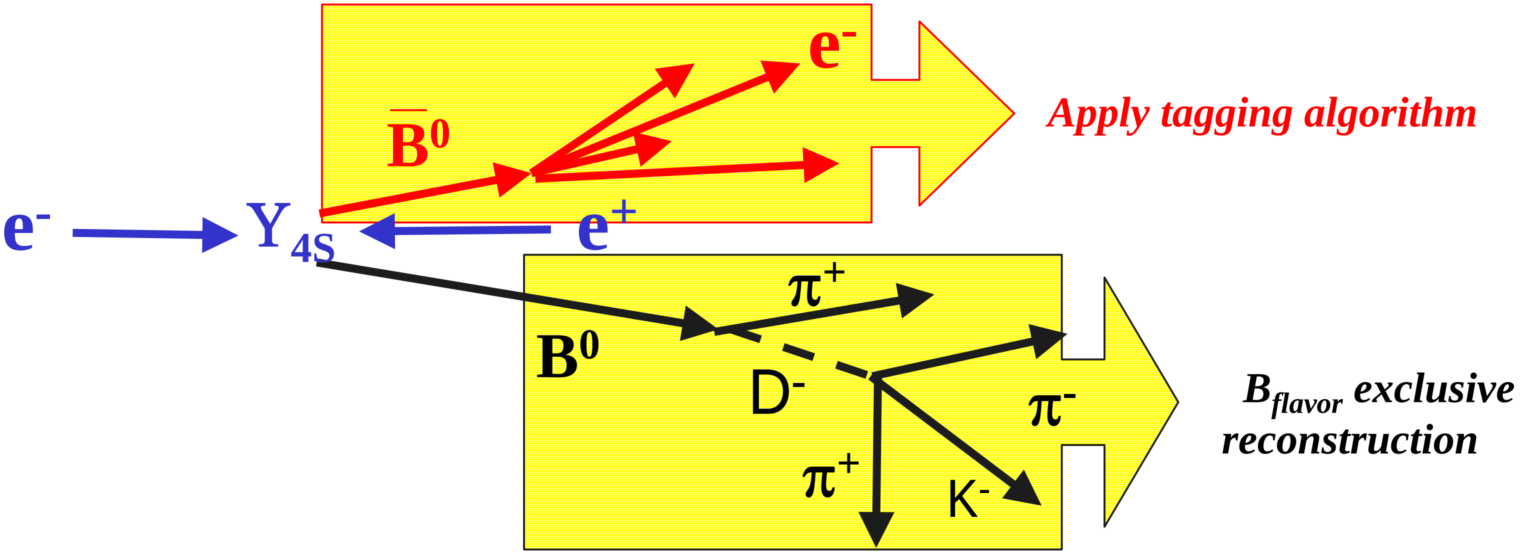
The importance of tagging

Flavor tagging is a crucial ingredient in CP measurements since

$$\sigma(\sin 2\beta) \propto 1/\sqrt{Q}$$

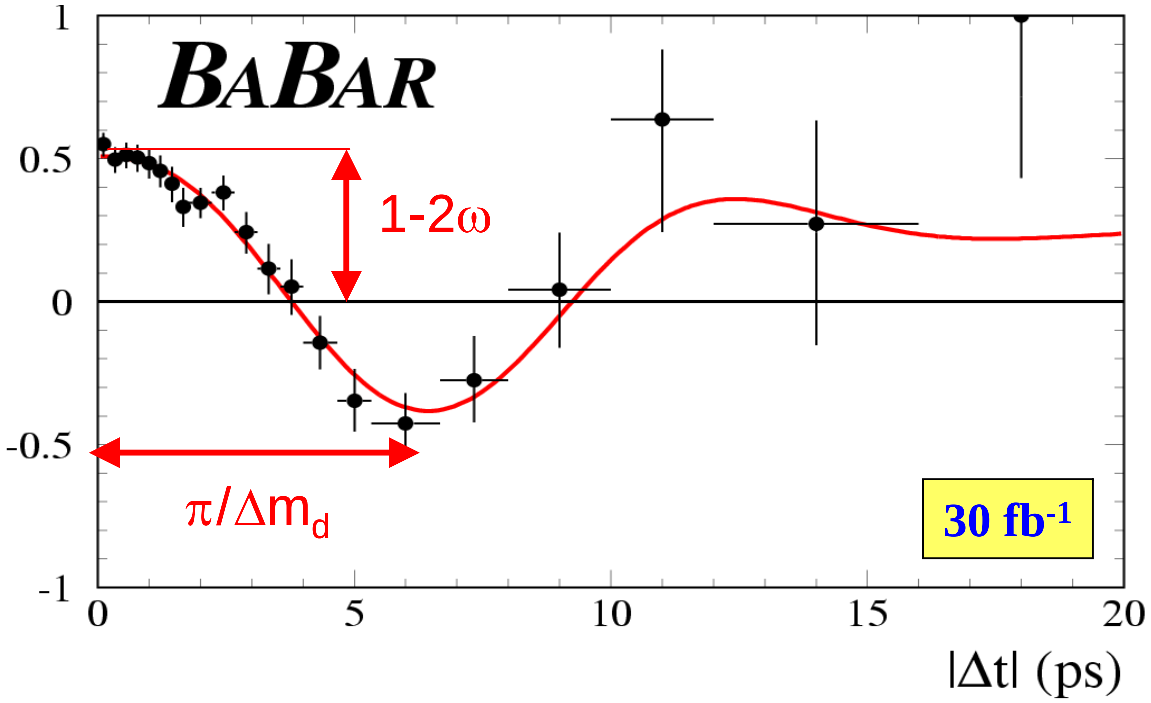
$$A_{CP}^{obs}(t) = (1-2\omega)A_{CP}(t)$$

→Extract tagging purity and efficiency directly from data in time dependent B^0 mixing measurement



Time dependent mixing fit

$$A^{mixing}(t) = \frac{N^{mixed}(t) - N^{unmixed}(t)}{N^{mixed}(t) + N^{unmixed}(t)} \propto (1-2\omega)\cos(\Delta m t)$$



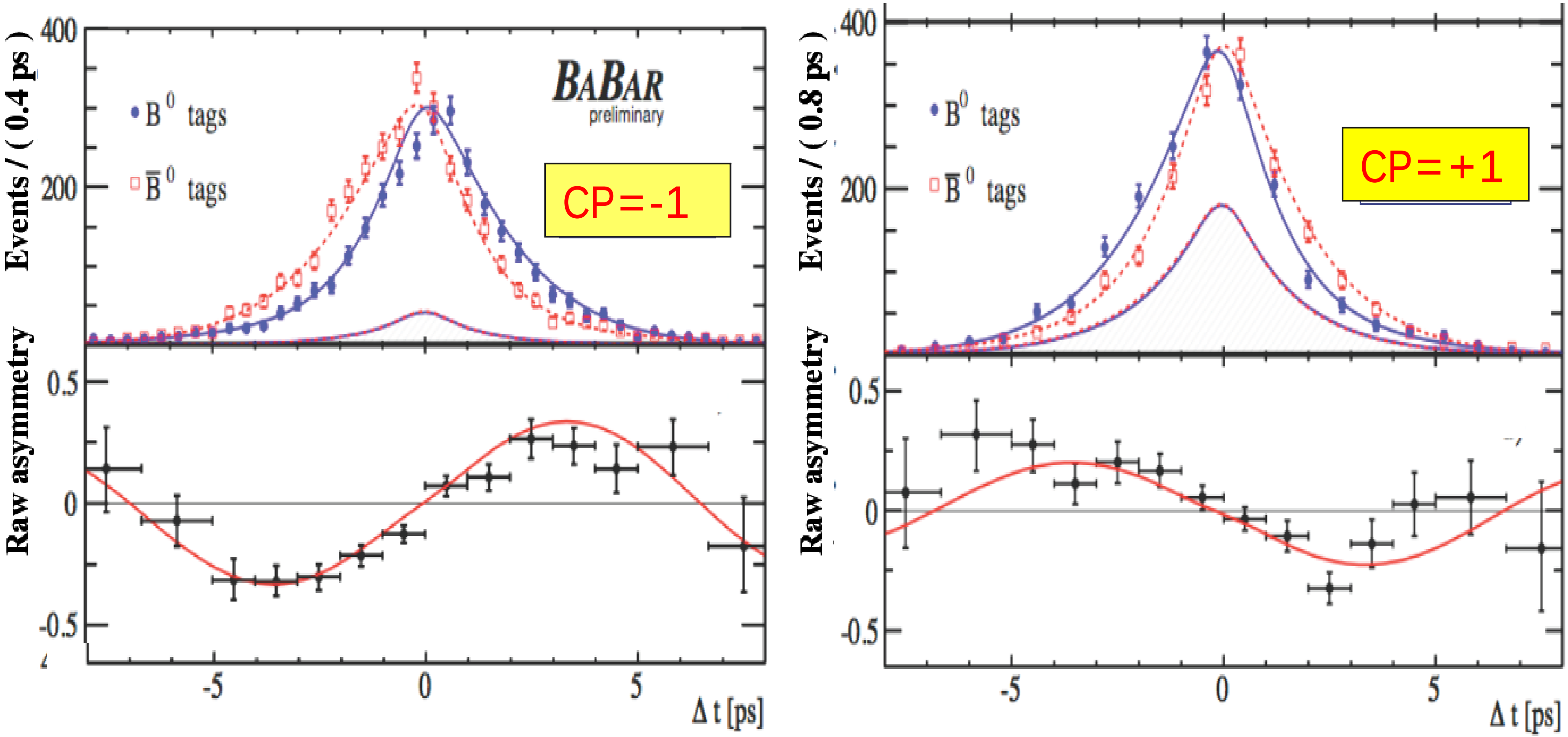
$$\Delta m_d = 0.516 \pm 0.016_{(stat)} \pm 0.010_{(syst)} \text{ h ps}^{-1}$$

hep-ex/0607107 (BaBar 2006)

The golden mode for sin2β:

CP fit in B→ charmonium K^0

Unbinned maximum likelihood fit to Δt distribution



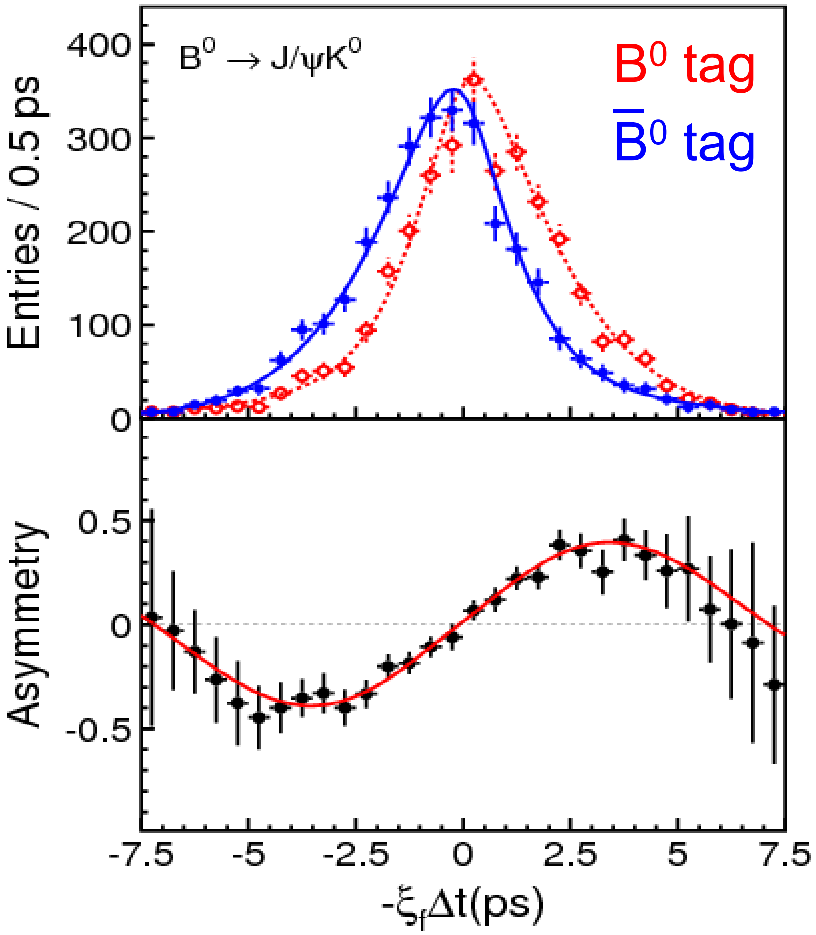
$$\boxed{\sin(2\beta) = 0.710 \pm 0.034_{stat} \pm 0.019_{syst}}$$

Belle 2006

The golden mode for sin2β:

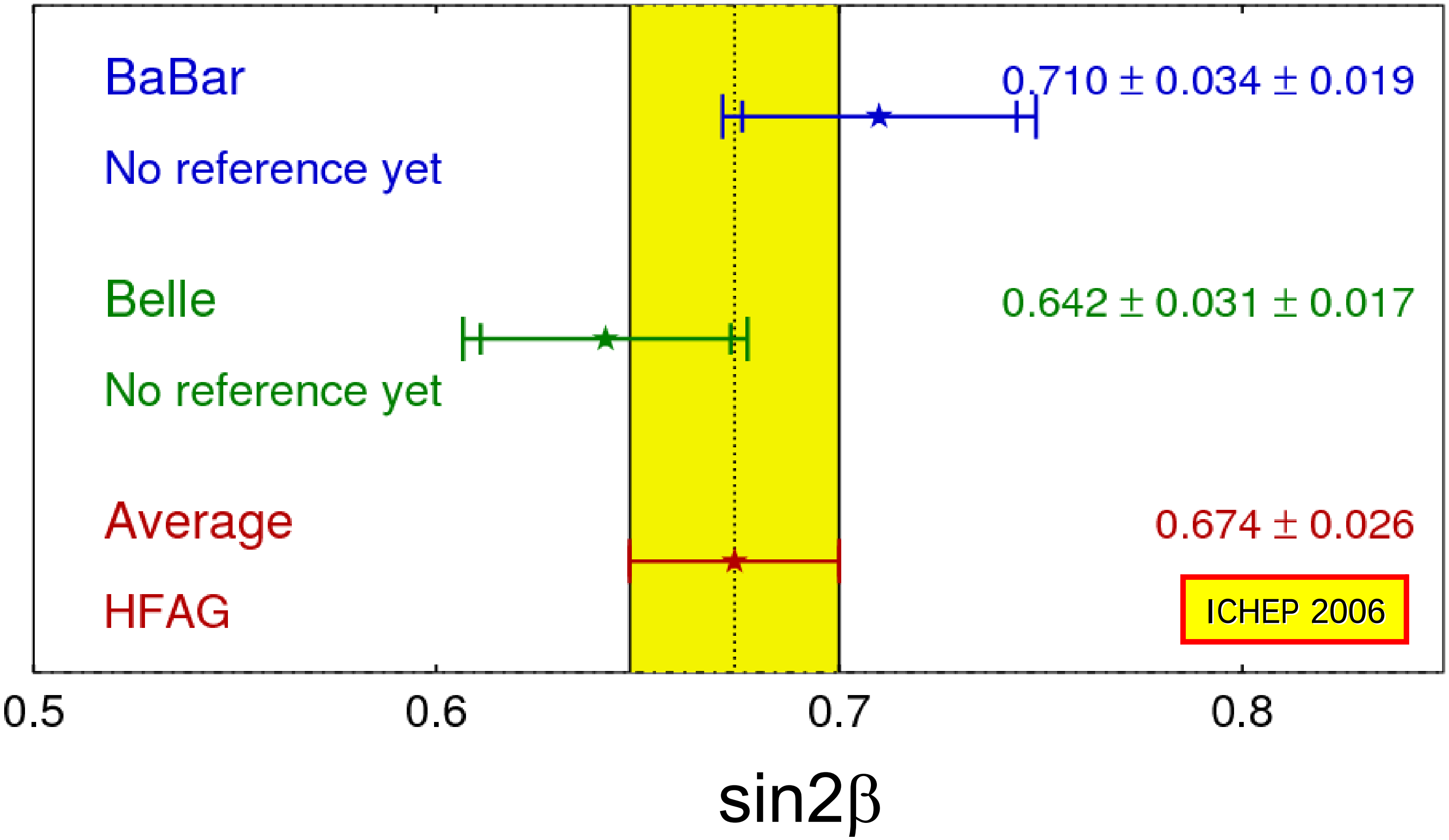
Belle's B→ charmonium K^0

532 M $B\bar{B}$ pairs



$$\sin(2\beta) = 0.642 \pm 0.031_{stat} \pm 0.017_{syst}$$

How well do we know sin(2β)?



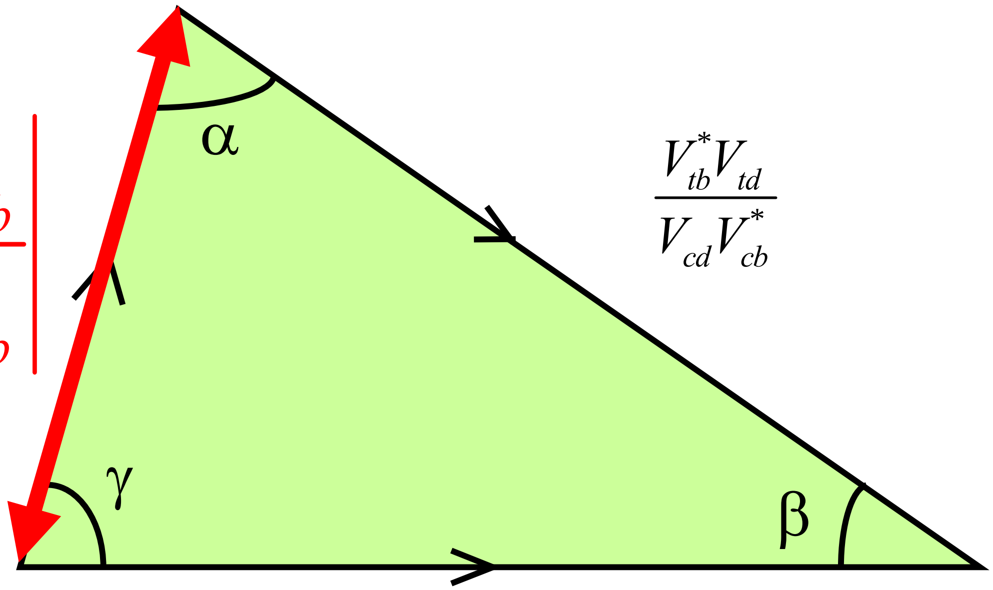
How to look for New Physics

- Beautiful measurement:
  - Error on sin2β is 0.026!
  - Error on $\beta < 1$ degree!

- But by itself is useless! To test the SM we need to compare it with other measurements:
  - Opposite side in the UT
  - Independent measurement of sin2β using channels mediated by other Feynman diagrams

The left side: R_b

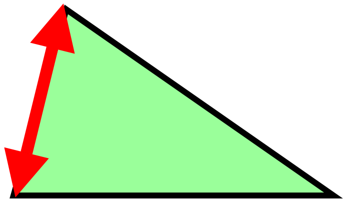
$$R_b \propto \left|\frac{V_{ub}}{V_{cb}}\right|$$



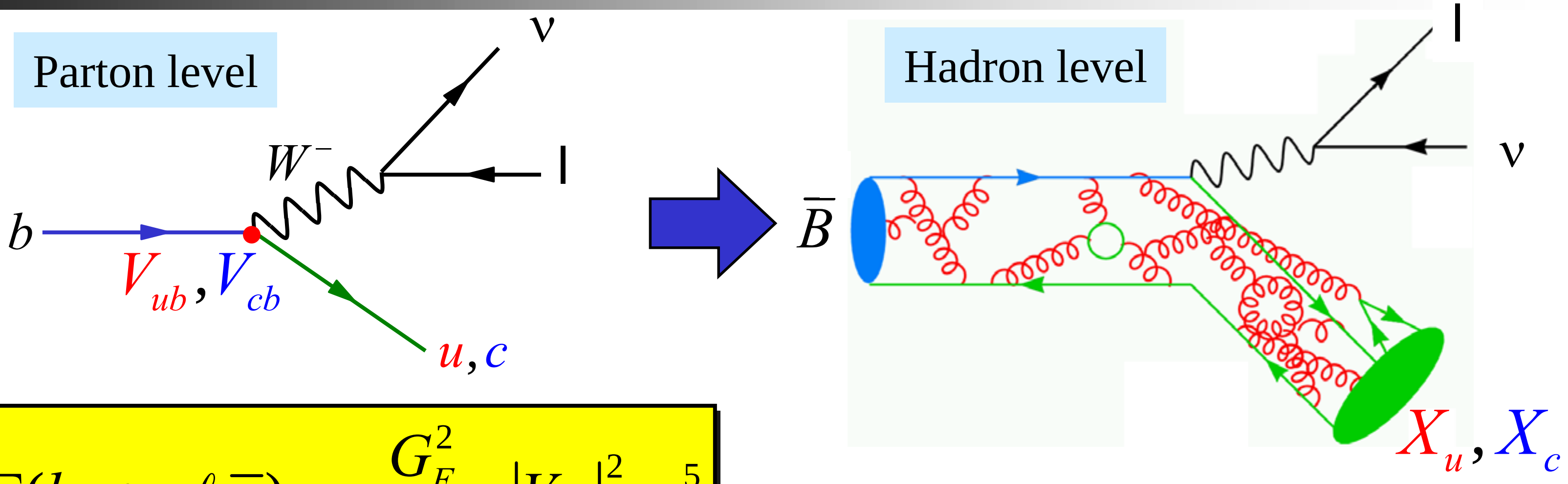
NB: β is the best measured quantity in the Unitarity Triangle

$$\boxed{\beta = 21.2 \pm 1.0 \text{ degrees}}$$

→ precise measurement of R_b is needed for accurate tests of SM



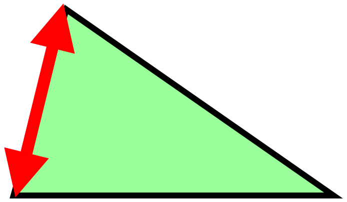
Semileptonic B Decays

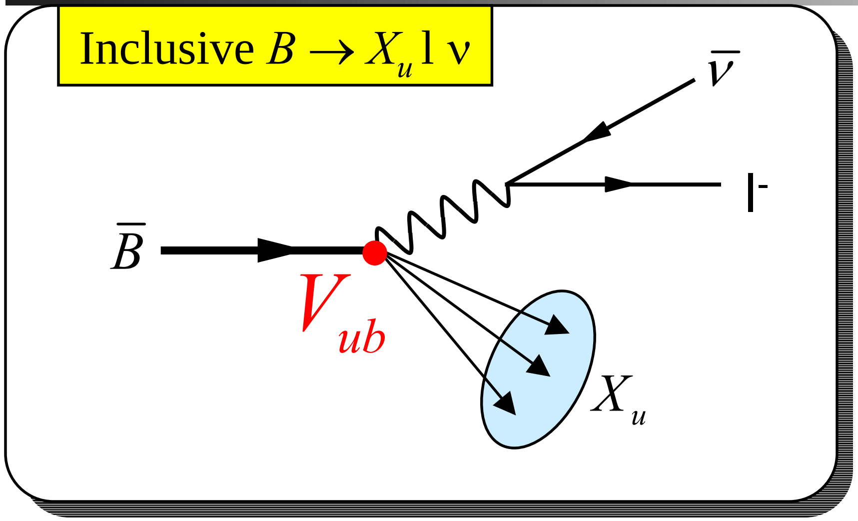


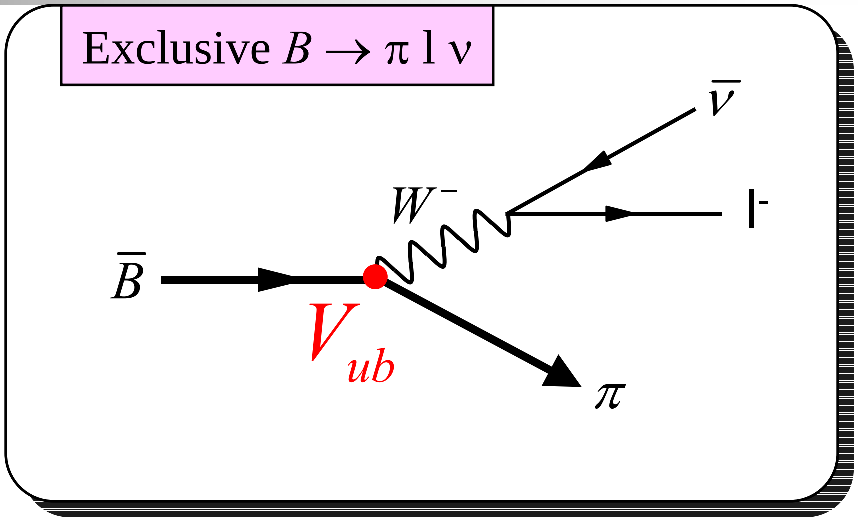
$$\boxed{\Gamma(b \to u \ell \bar{\nu}) = \frac{G_F^2}{192\pi^2} |V_{ub}|^2 m_b^5}$$

- Sensitive to hadronic effects
  - Theory error not negligible
- Prob(b→c)/Prob(b→u)~50
  - V_{cb} precisely measured (±2%)
  - V_{ub} is the challenge

Two approaches to V_{ub}







Inclusive $B \to X_u l\nu$

- Hadronic final state is not specified
- b→c l ν background is suppressed using kinematical variables
- Partial rate is measured

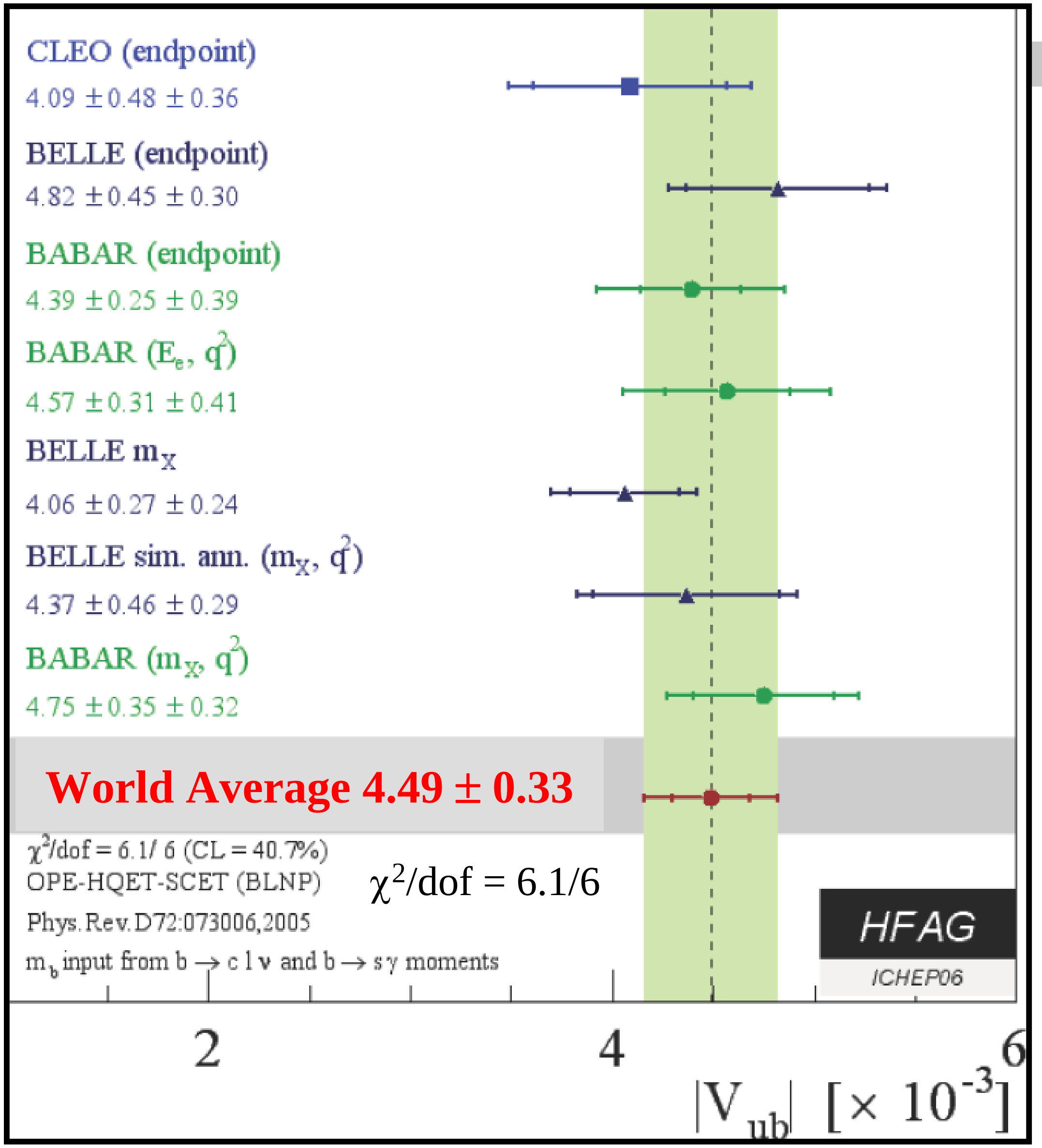
→ theoretical uncertainties ~5%

Exclusive $B \to \pi$ lν

- Better S/B but lower branching fraction (10^{-4})
- Needs form factor calculation from Lattice QCD

→ uncertainty of ~ 12%

$|V_{ub}|$ from Inclusive $B \rightarrow X_u l \nu$



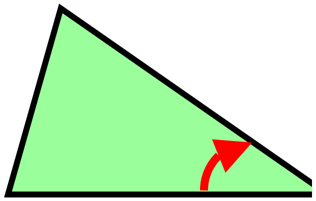
Close collaboration between theorists and experimentalists led to

Precision on V_{ub}: ±7.3%

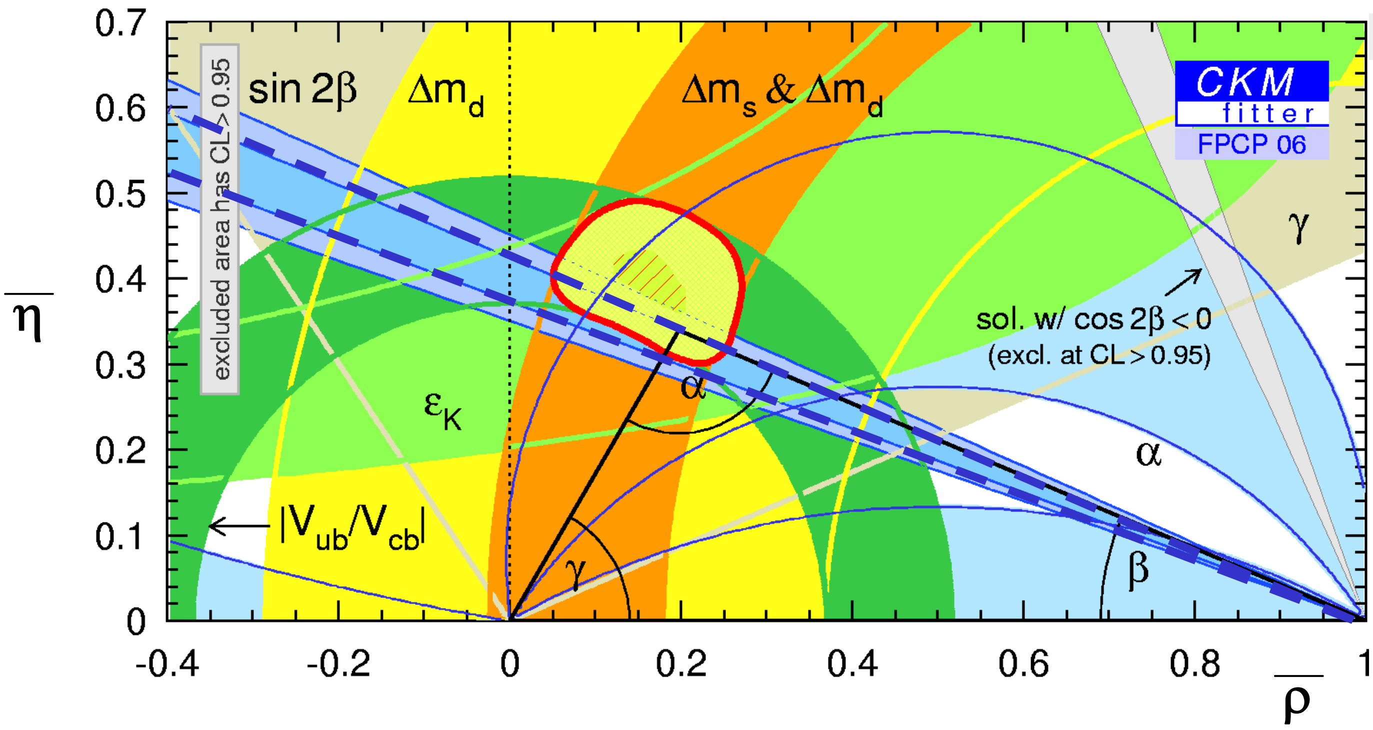
c.f.r.: precision on β: ±4.7%

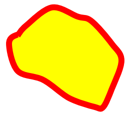
Goal in 2008: error on V_{ub}: ±5%

from CPV?



Unitarity Triangle constraints





95% CL
from sides

sin2β vs indirect UT constraints: very good agreement!

CKM mechanism is the dominant source of CPV at low energies

- New Physics does not show up in the golden mode →SM reference
    - Compare with sin2β in independent modes with different sensitivity to NP

How to look for New Physics (2)

- Beautiful measurement:
  - Error on sin2β is 0.026!
  - Error on β < 1 degree!

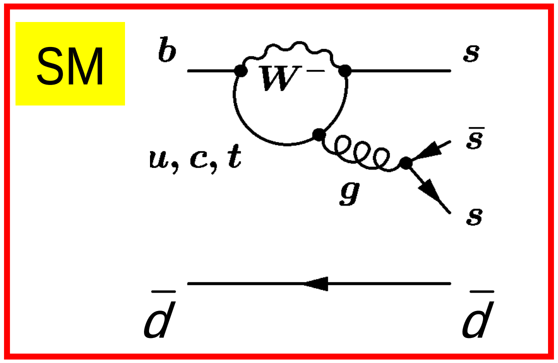
- But by itself is useless! To test the SM we need to compare it with other measurements:
  - Opposite side in the UT
  - Independent measurement of sin2β using channels mediated by other Feynman diagrams

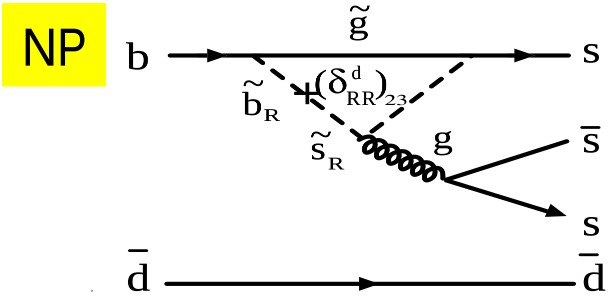
Another way to look for New Physics:

sin2β in Penguin Modes

Decays dominated by gluonic penguin diagrams

- The typical example: $B^0 \rightarrow \phi K_S$





  - No tree level contributions

- Impact of New Physics could be significant
  - New particles could participate in the loop → new CPV phases

- NP affects each channel differently; low branching fractions
  - Measure A_{CP} in as many $b \rightarrow s\bar{q}q$ penguins as possible!
    - $\boxed{\varphi K^0}$, $K^+ K^- K_S$, $\boxed{\eta' K_S}$, $K_S \pi^0$, $\boxed{K_S K_S K_S}$, ωK_S, $f_0(980)\, K_S$

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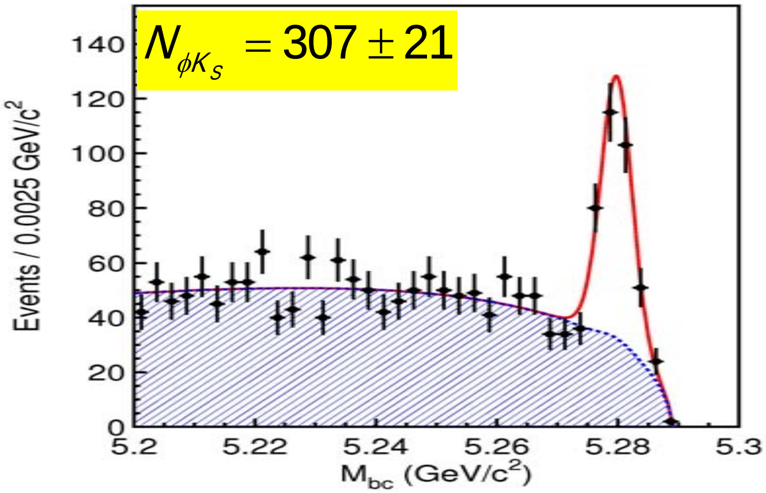
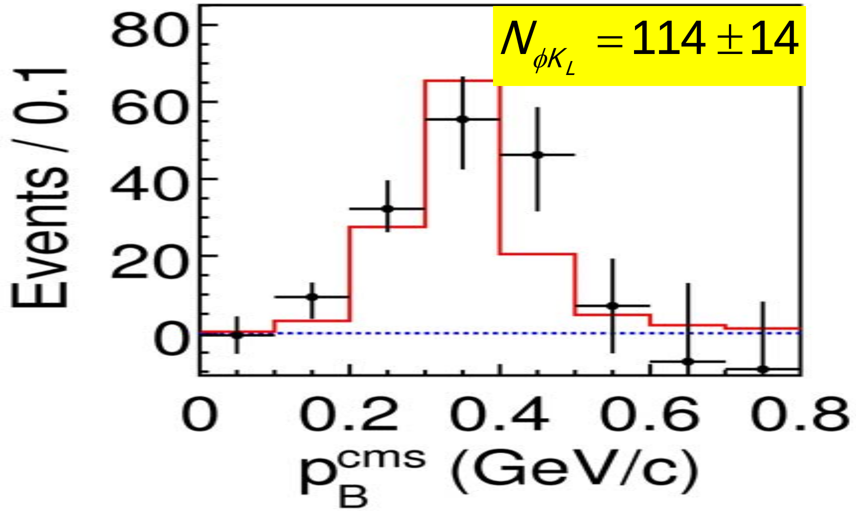
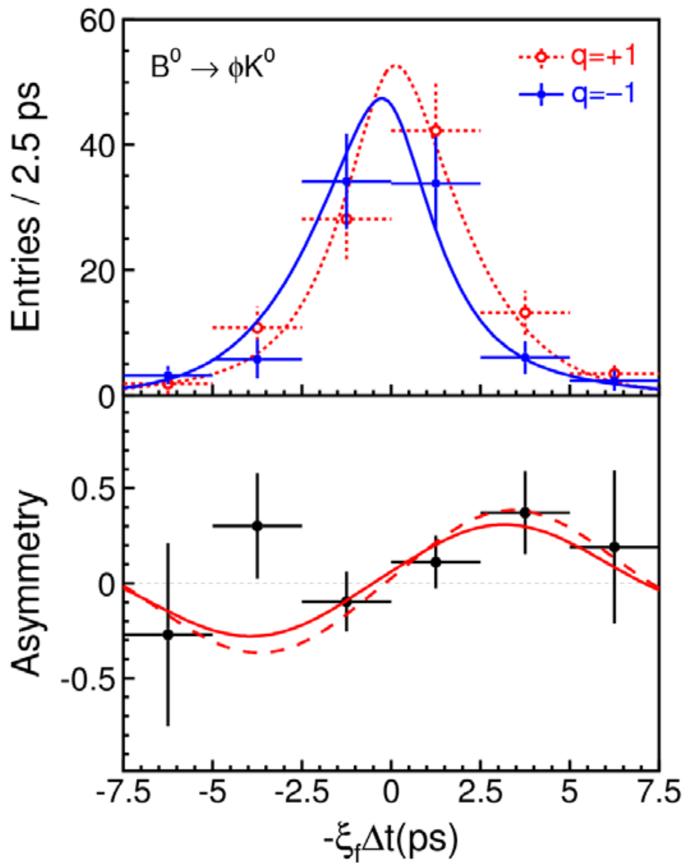
The golden penguin: $B^0 \rightarrow \phi K^0$



$N_{\phi K_S} = 307 \pm 21$



$N_{\phi K_L} = 114 \pm 14$



$$S_{\phi K^0} = +0.50 \pm 0.21 \pm 0.05$$

$$C_{\phi K^0} = -0.07 \pm 0.15 \pm 0.06$$

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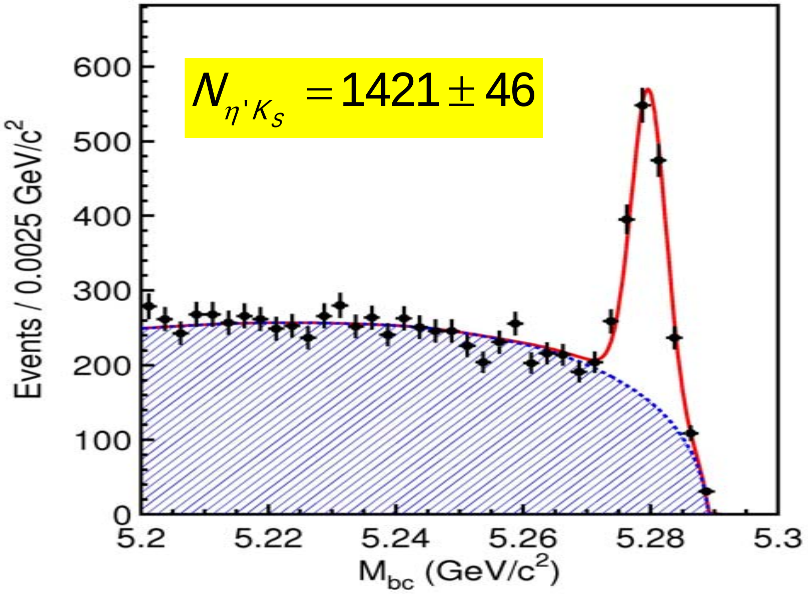
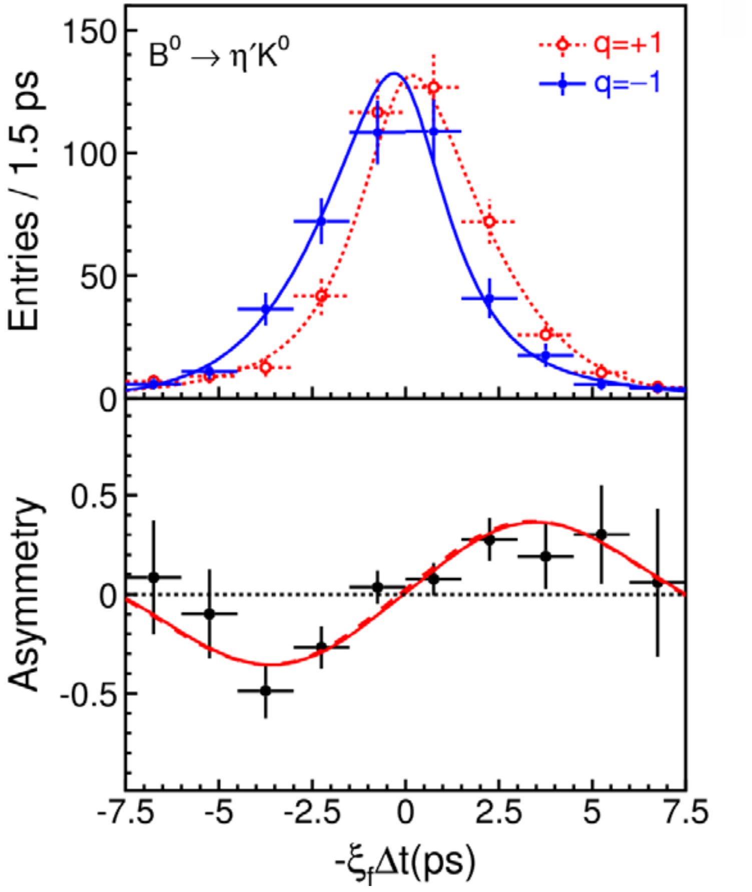
The silver penguin: $B^0 \rightarrow \eta' K_S$

- Relative large BF ~ 6 x 10^{-5}
- Theoretically less clean than ϕK_S
  - Tree diagram possible

    ... but Cabibbo and color suppressed...
  - $|\Delta S| = |S_{\Psi K} - S_{Penguin}| \sim 0.01_{QCDFact} \rightarrow 0.1_{SU(3)}$





$$S_{\eta' K_S} = 0.64 \pm 0.10 \pm 0.04$$
$$C_{\eta' K_S} = -0.01 \pm 0.07 \pm 0.05$$

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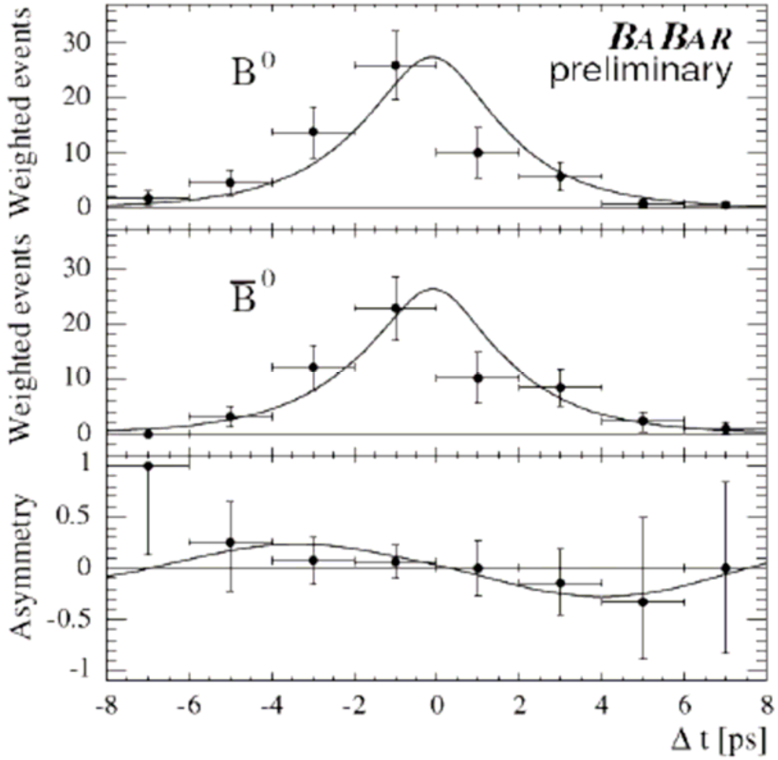
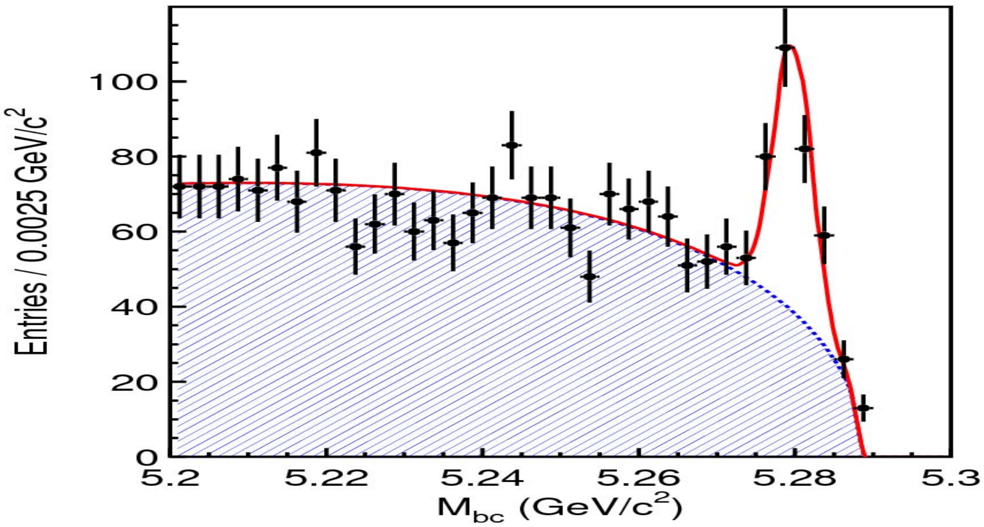
A new golden penguin: $B^0 \rightarrow K_S K_S K_S$

- Theoretically clean
  - Penguin dominated CP=+1 eigenstate
- Experimentally challenging
  - B decay vertex uses K_S pseudo-particles and beam spot constraint



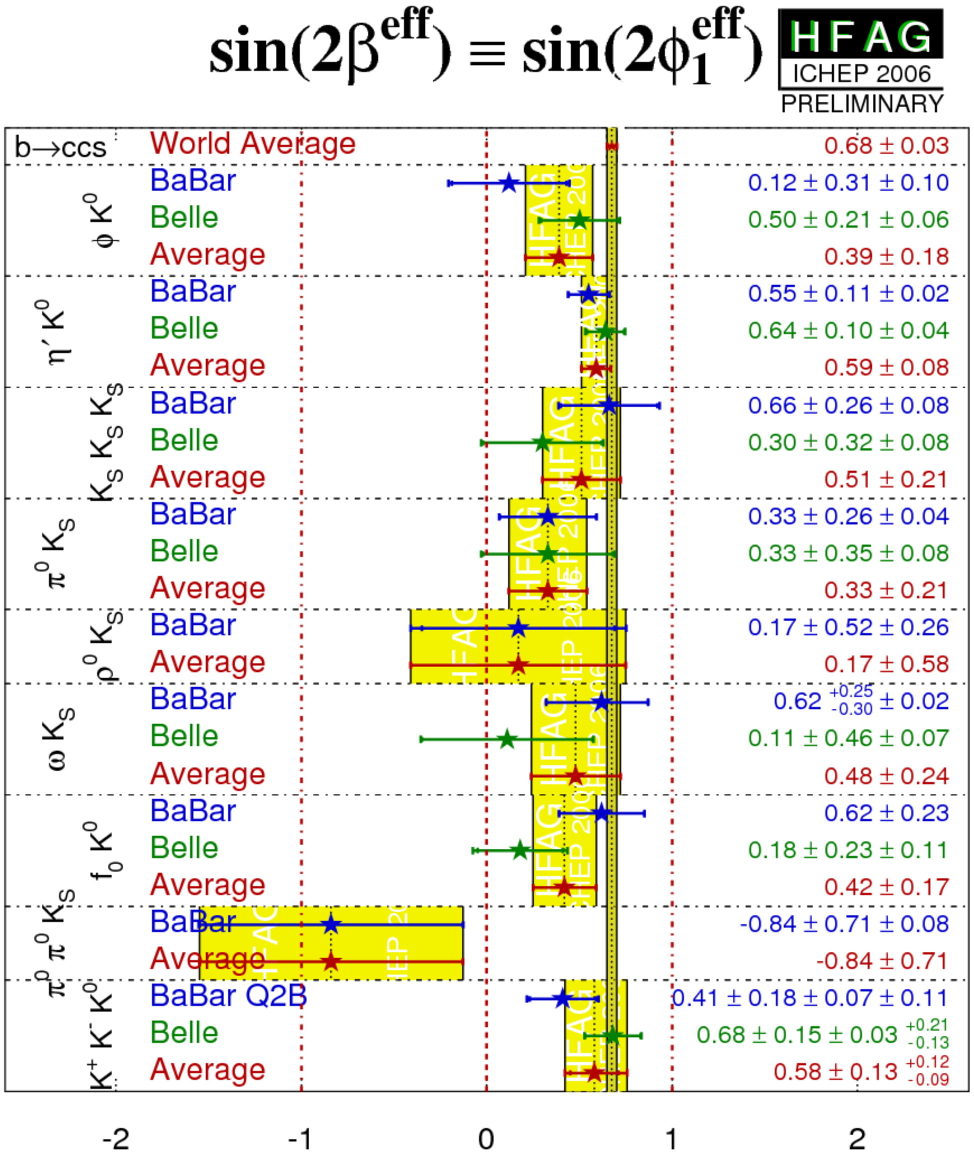


$$-S_{K_SK_SK_S} = +0.66 \pm 0.26 \pm 0.08$$

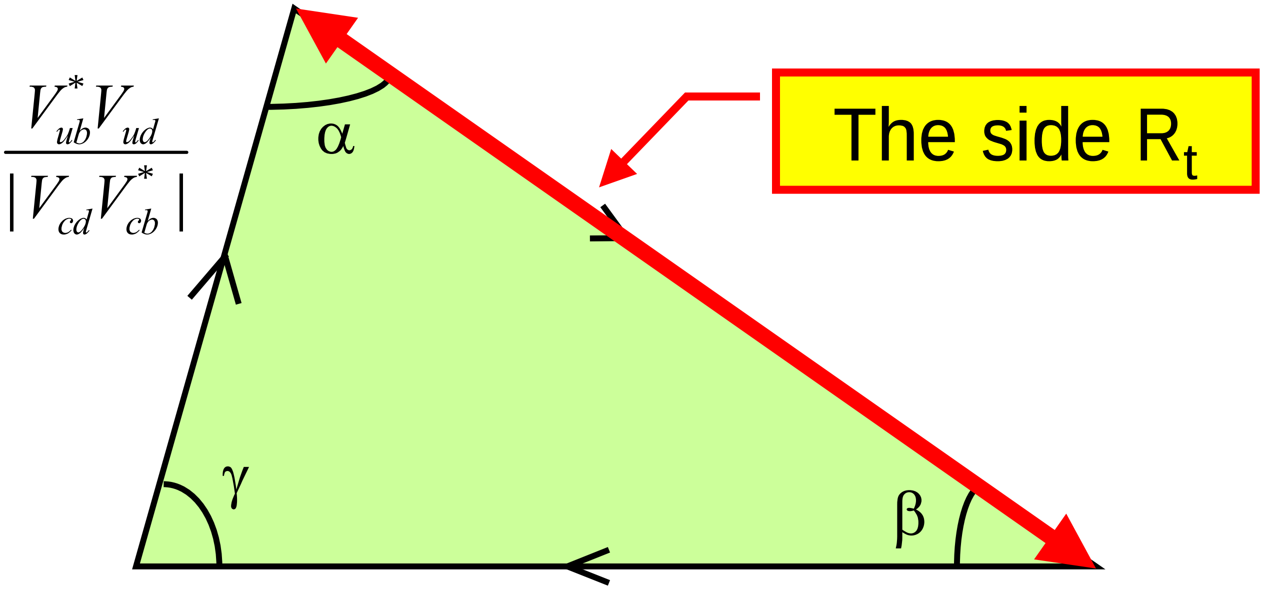
$$C_{K_SK_SK_S} = -0.14 \pm 0.22 \pm 0.05$$

“sin2β” in penguins

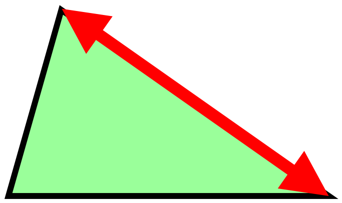
- No significant shift observed in each mode
  - although a trend is visible...
- Naïve average: 0.52±0.05
  - ~2.6σ from J/ΨK$_s$
- Statistical errors still large...

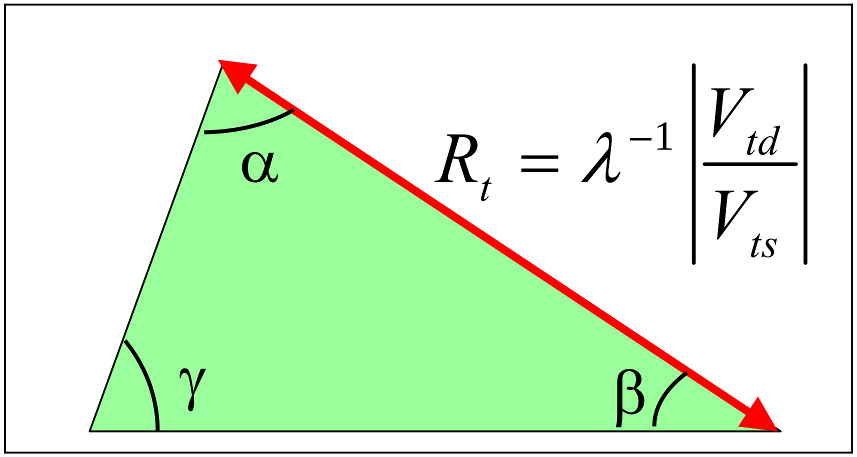


The measurements

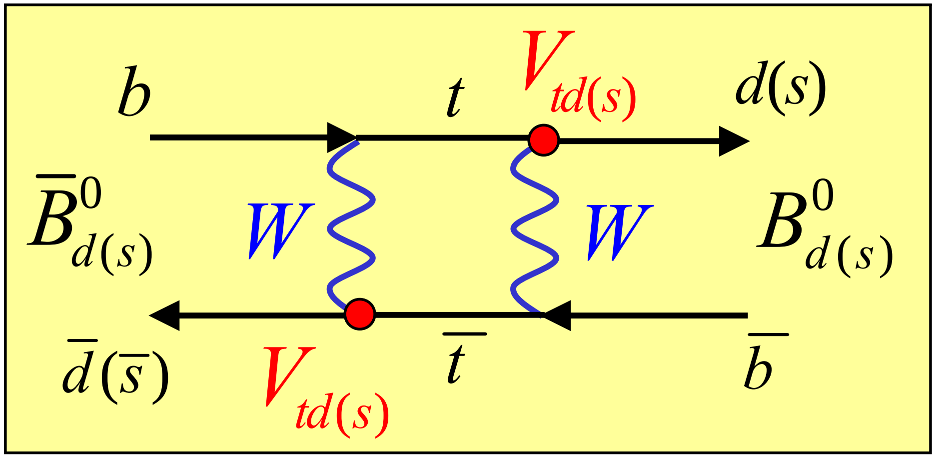


The measurement of R_t





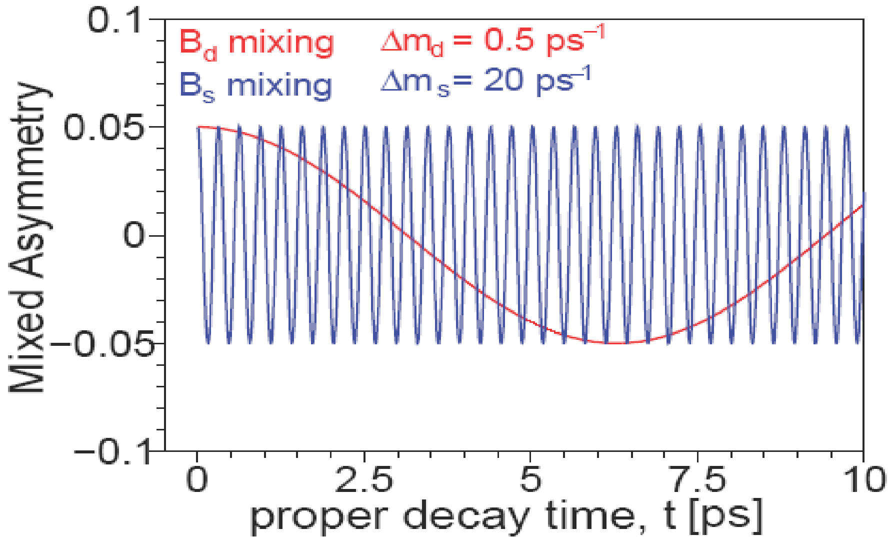
$$R_t = \lambda^{-1}\left|\frac{V_{td}}{V_{ts}}\right|$$



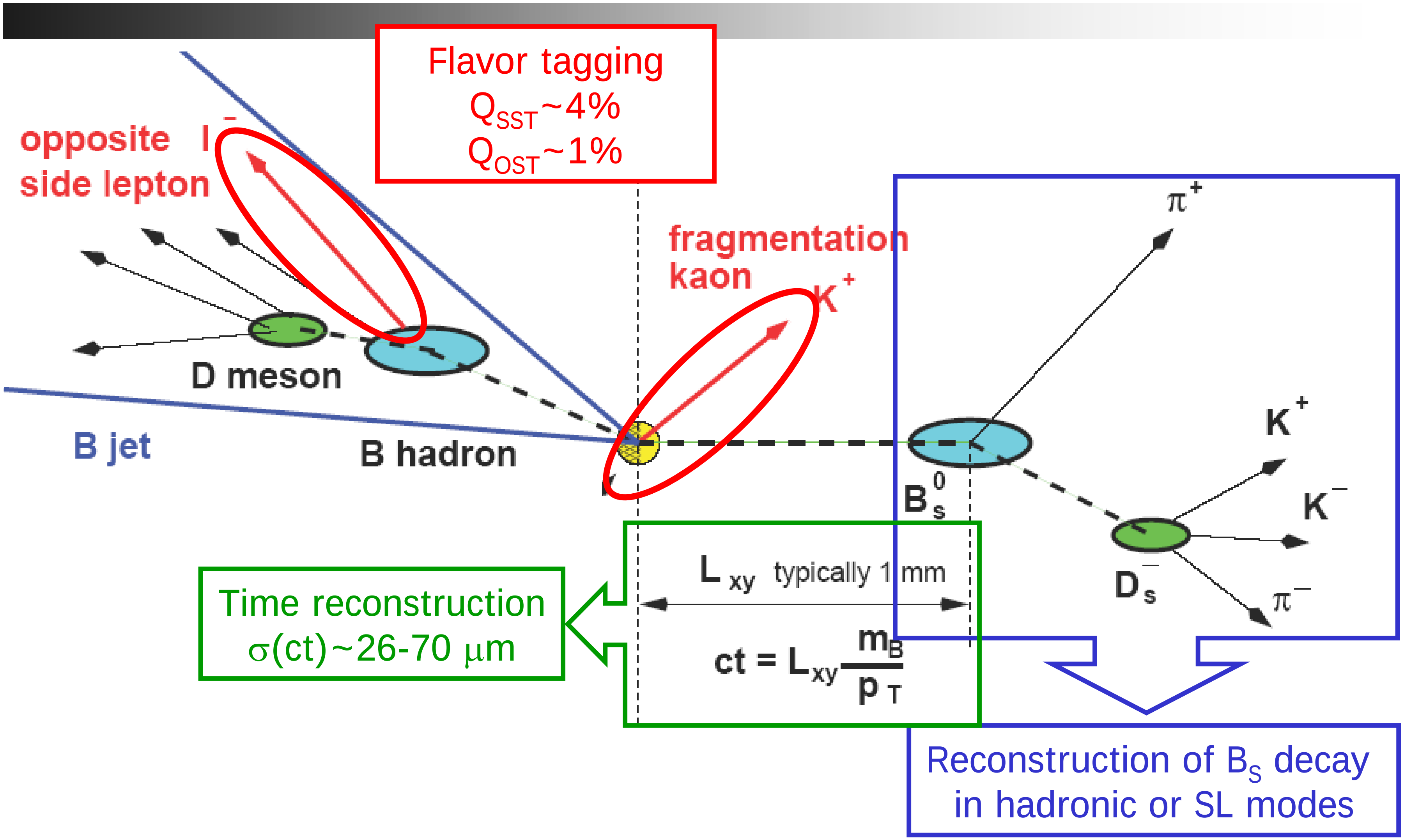
- B_s/B_d oscillations

$$\frac{\Delta m_d}{\Delta m_s} \propto \left|\frac{V_{td}}{V_{ts}}\right|^2$$

  - Theory error <5%
  - Δm_d is precisely measured
  - But B_s mixing is very hard…



B_S mixing at the Tevatron



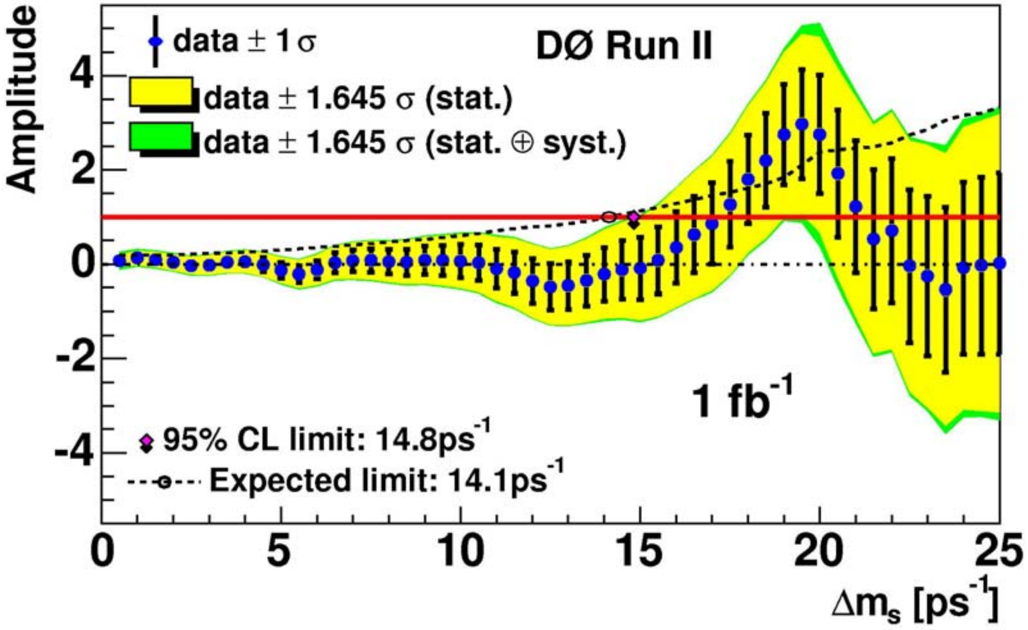
Flavor tagging
$Q_{SST}\sim4\%$
$Q_{OST}\sim1\%$

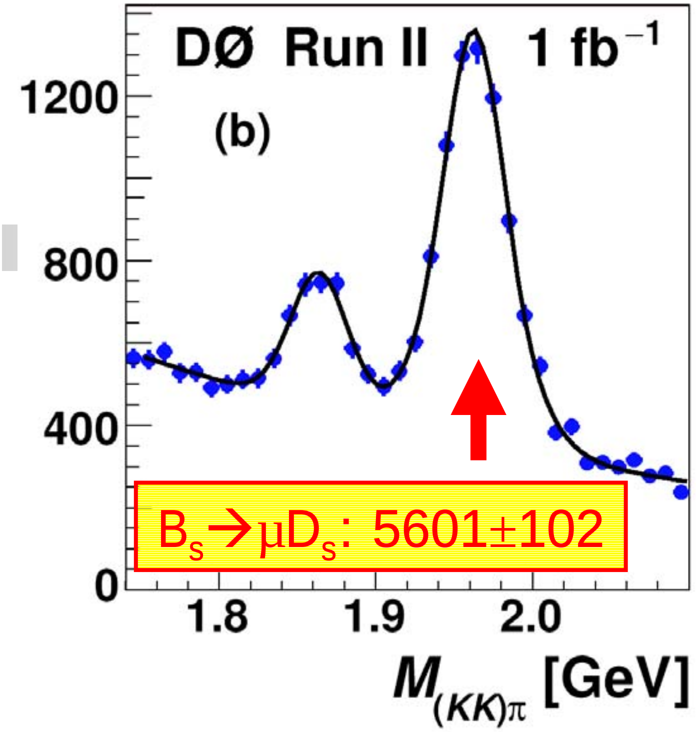
Time reconstruction
$\sigma(ct)\sim26\text{-}70\ \mu m$

$$ct = L_{xy}\frac{m_B}{p_T}$$

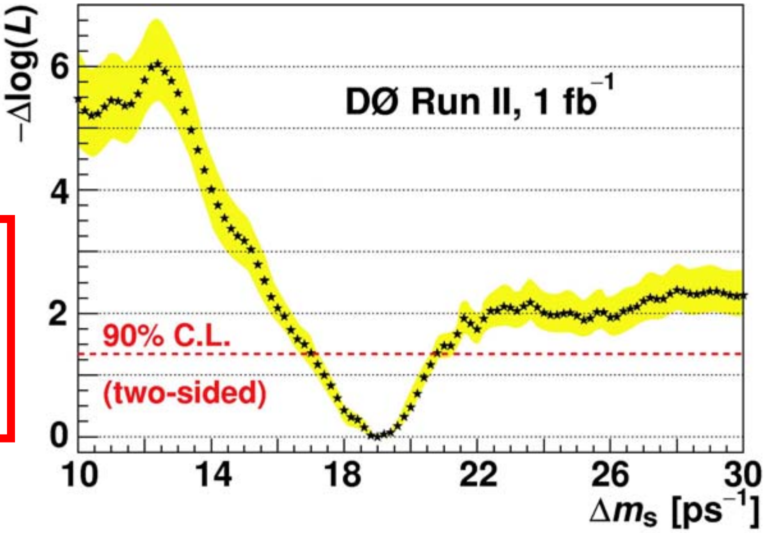
Reconstruction of B_S decay
in hadronic or SL modes

D0 result





$B_s \rightarrow \mu D_s$: 5601±102

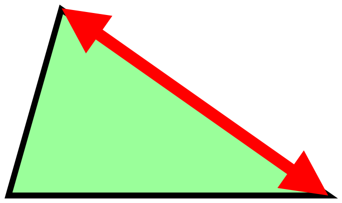


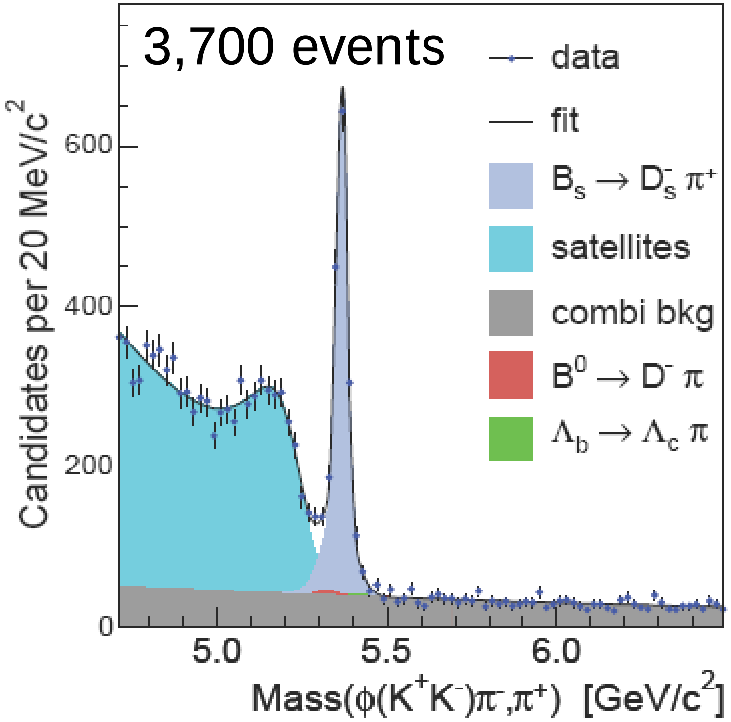
17 < Δm_s < **21 ps^{-1} @ 90% CL**

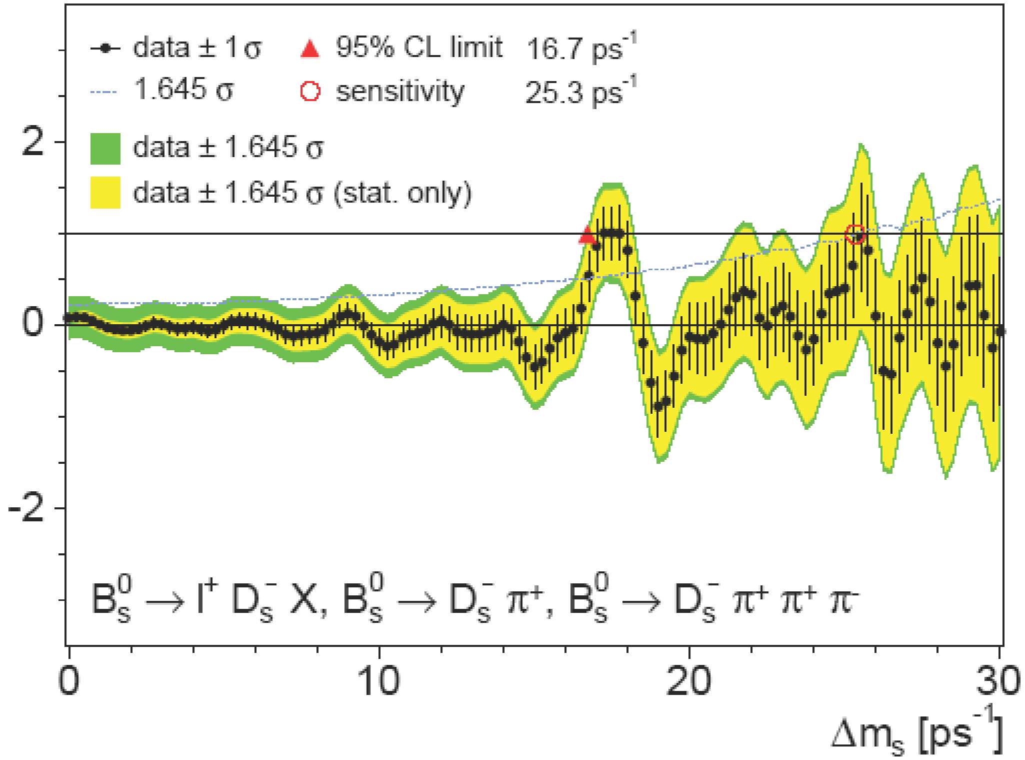
assuming Gaussian errors

Most probable value of Δm_s = 19 ps^{-1}

CDF result



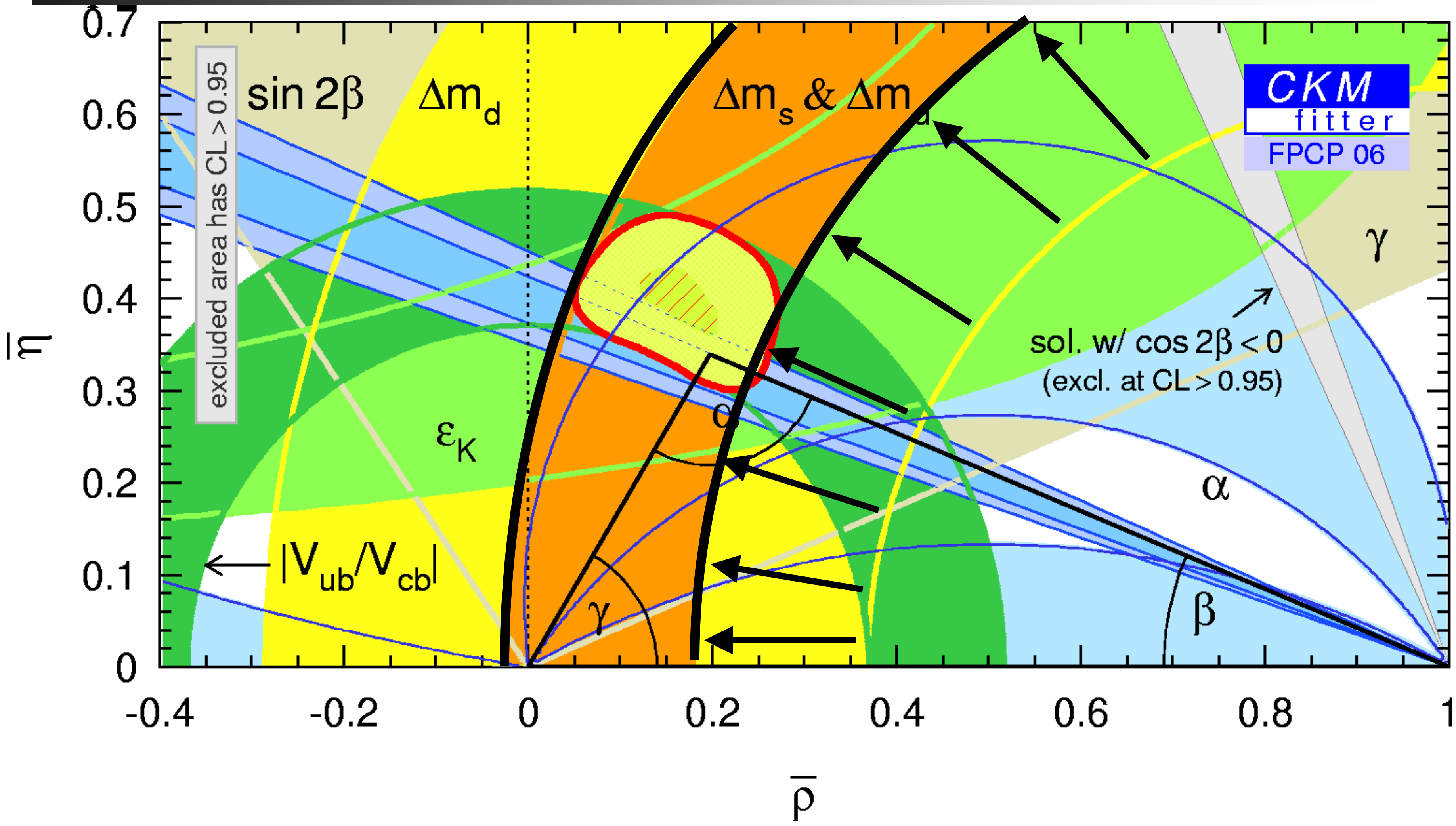




$$\boxed{\Delta m_s = 17.33^{+0.42}_{-0.21} \pm 0.07\ \text{ps}^{-1}} \Rightarrow \boxed{\left|\frac{V_{td}}{V_{ts}}\right| = 0.208^{+0.008}_{-0.007}}$$

- Probability of random fluctuation: ~0.5%

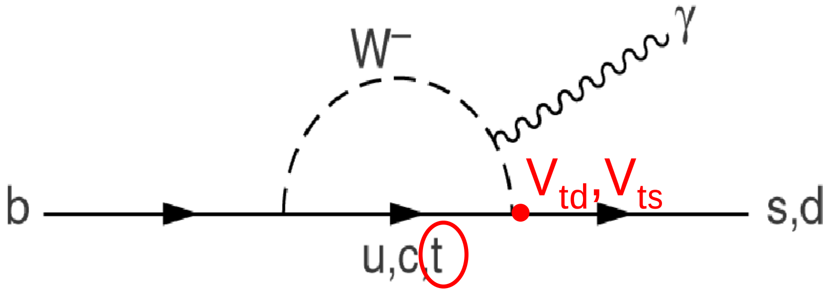
Impact of Δm_s on Unitarity Triangle



But to test the SB we need redundancy...

R_t from B→$\rho\gamma/\omega\gamma$ vs. B→$K^*\gamma$

- Radiative penguin decays with b→dγ and b→sγ



- Ratio of BF measures $|V_{td}/V_{ts}|$

Ali and Parkomenko

$$\frac{\mathcal{B}_{\rm th}(B \to \rho\gamma)}{\mathcal{B}_{\rm th}(B \to K^*\gamma)} = S_\rho \left|\frac{V_{td}}{V_{ts}}\right|^2 \frac{(1 - m_\rho^2/M^2)^3}{(1 - m_{K^*}^2/M^2)^3}\, \zeta^2 \,[1 + \Delta R(\rho/K^*)]$$

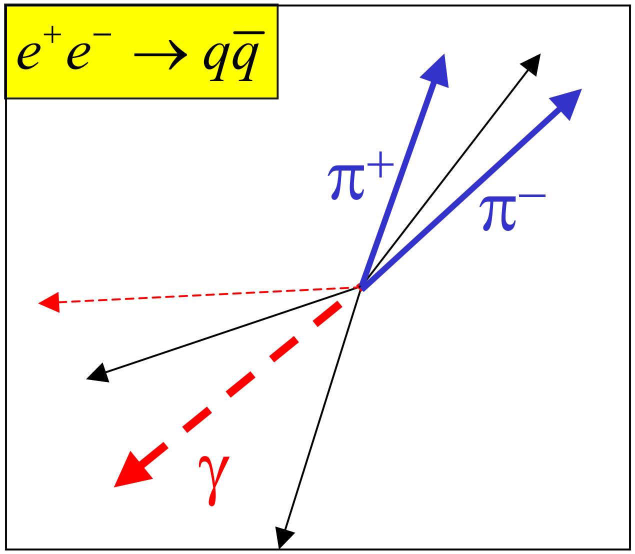
Theory error:
8% for $\rho^0\gamma$
15% for average

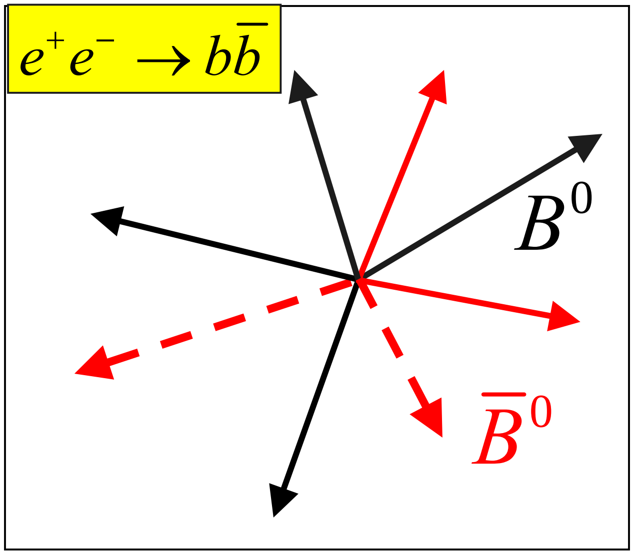
- B→$K^*\gamma$ well established; B→$\rho(\omega)\gamma$ is the challenge!
  - Standard Model expectation:
    - B→$\rho^0\gamma/\omega\gamma$: ~ 0.5 x 10^{-6}; B→$\rho^+\gamma$ ~ 1 x 10^{-6}

$B \rightarrow \rho\gamma/\omega\gamma$: analysis

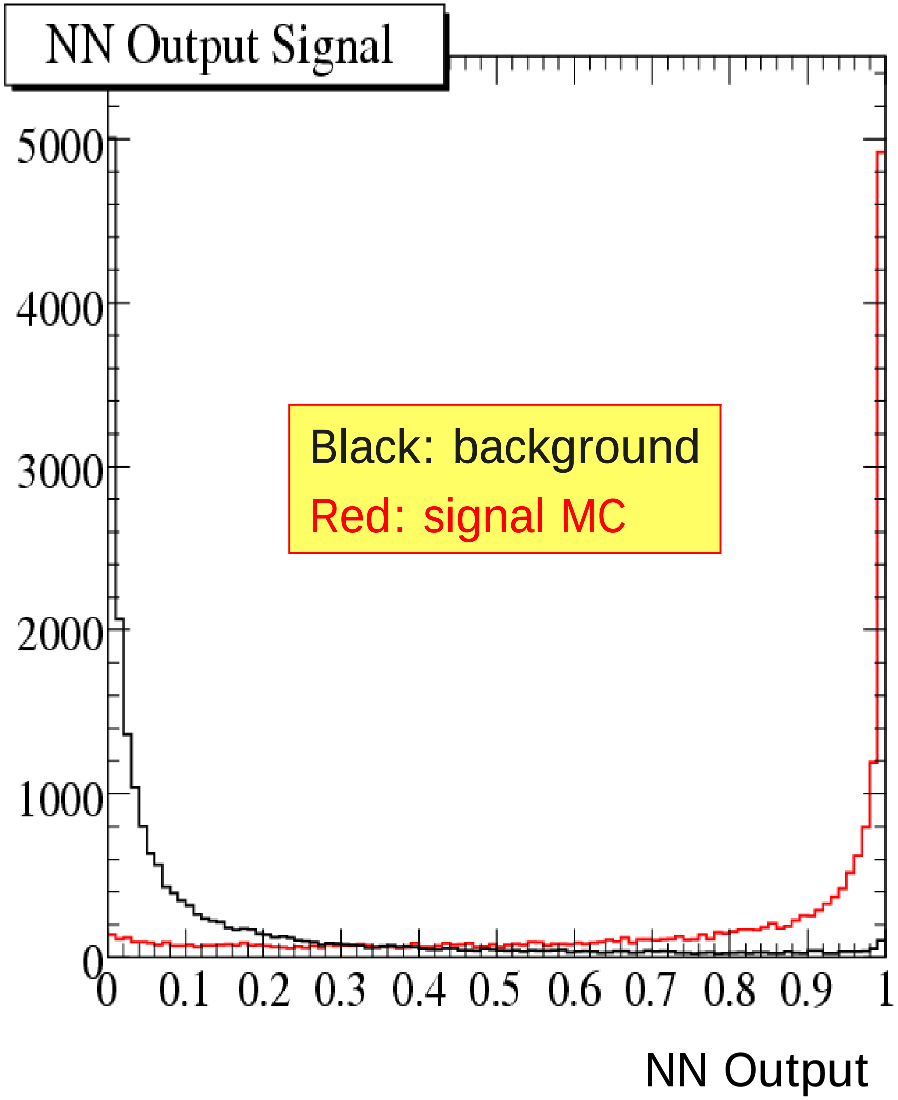
- In principle a simple analysis
  - Two body decay: $p_\gamma \sim m_B/2$
  - Exclusive meson reconstruction
    - $\rho^0 \rightarrow \pi^+\pi^-$
    - $\rho^+ \rightarrow \pi^+\pi^0$
    - $\omega \rightarrow \pi^+\pi^-\pi^0$
  - Exclusively reconstruct B meson
    - m_{ES} and ΔE
- But huge continuum background!
  - Eg: γ from π^0 vs pions in opposite jets
  - NN for continuum suppression is key
    - Shape variables (e.g.: R2)
    - Properties of B decay (e.g.: Δz)
    - "Tagging"-like variables (e.g.: p_{CMS} of leptons)

Pion identification is a must to reject $B \rightarrow K^*\gamma$ background



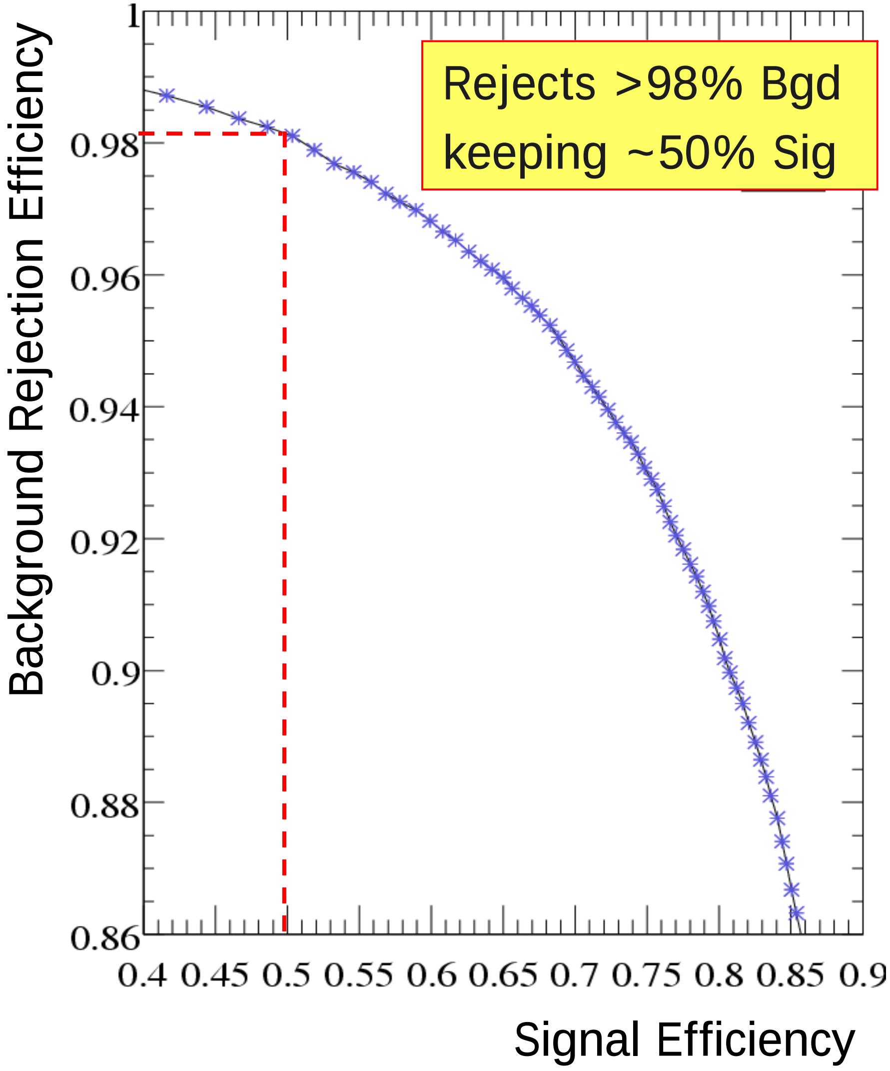


NN Output and performance



Black: background

Red: signal MC



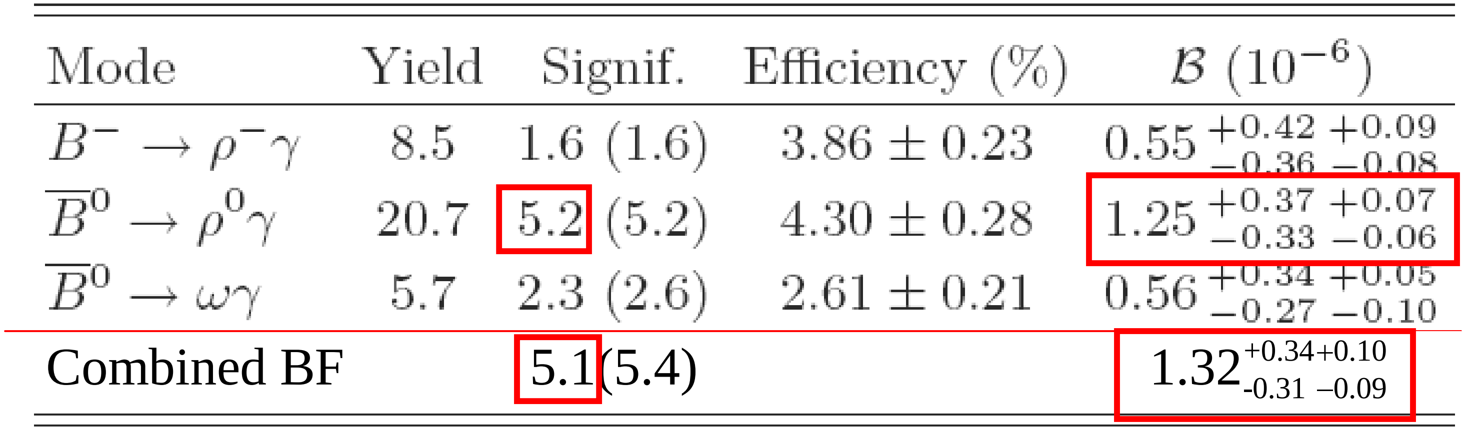
Rejects >98% Bgd
keeping ~50% Sig

Recent Results

SM expectation

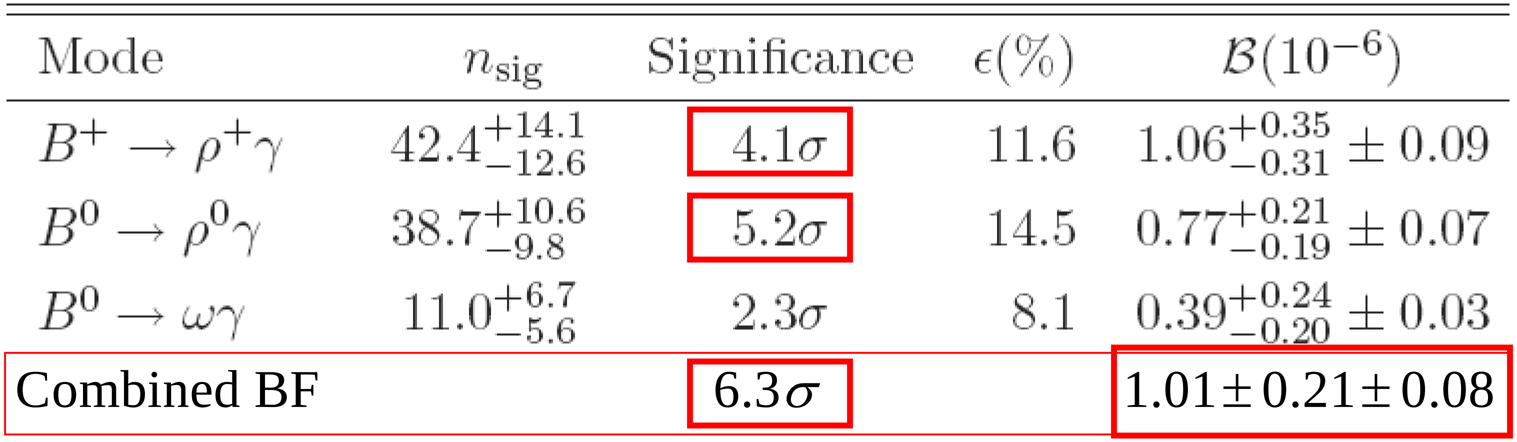
1.0×10^{-6}
0.5×10^{-6}
0.5×10^{-6}

- Belle - Summer 2005: 370 fb^{-1}



Mode	Yield	Signif.	Efficiency (%)	$\mathcal{B}$ (10^{-6})
$B^- \to \rho^-\gamma$	8.5	1.6 (1.6)	3.86 ± 0.23	$0.55\,^{+0.42}_{-0.36}\,^{+0.09}_{-0.08}$
$\overline{B}^0 \to \rho^0\gamma$	20.7	$\boxed{5.2}$ (5.2)	4.30 ± 0.28	$\boxed{1.25\,^{+0.37}_{-0.33}\,^{+0.07}_{-0.06}}$
$\overline{B}^0 \to \omega\gamma$	5.7	2.3 (2.6)	2.61 ± 0.21	$0.56\,^{+0.34}_{-0.27}\,^{+0.05}_{-0.10}$
Combined BF		$\boxed{5.1}$(5.4)		$\boxed{1.32\,^{+0.34+0.10}_{-0.31\,-0.09}}$

- BaBar - Summer 2006: 316 fb^{-1}

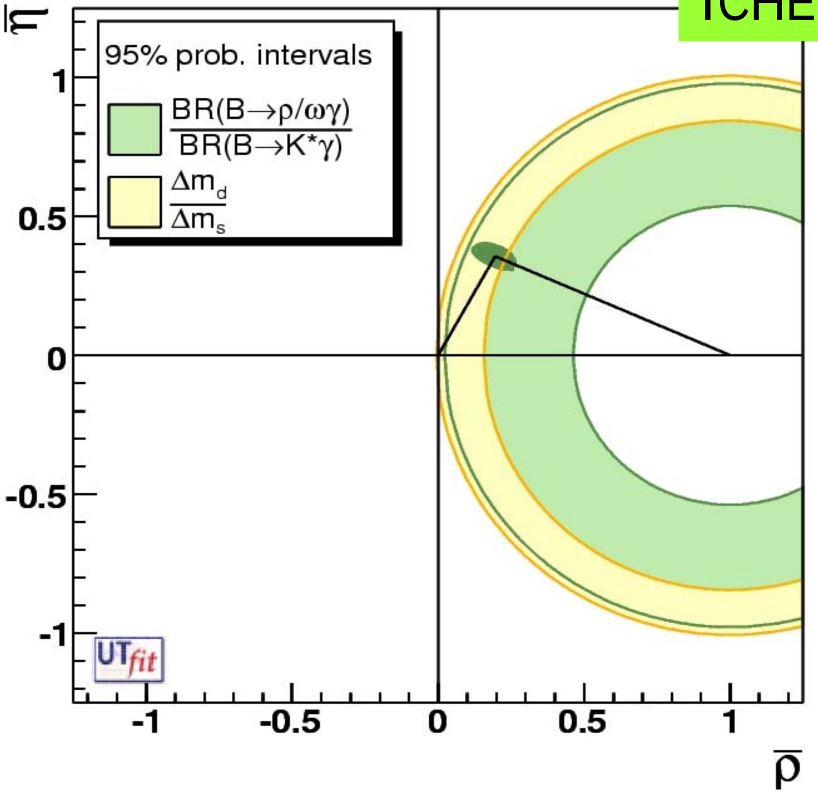


Mode	n_{sig}	Significance	$\epsilon(\%)$	$\mathcal{B}(10^{-6})$
$B^+ \to \rho^+\gamma$	$42.4^{+14.1}_{-12.6}$	$\boxed{4.1\sigma}$	11.6	$1.06^{+0.35}_{-0.31} \pm 0.09$
$B^0 \to \rho^0\gamma$	$38.7^{+10.6}_{-9.8}$	$\boxed{5.2\sigma}$	14.5	$0.77^{+0.21}_{-0.19} \pm 0.07$
$B^0 \to \omega\gamma$	$11.0^{+6.7}_{-5.6}$	2.3σ	8.1	$0.39^{+0.24}_{-0.20} \pm 0.03$
Combined BF		$\boxed{6.3\sigma}$		$\boxed{1.01 \pm 0.21 \pm 0.08}$

UT constraints

- From BF($\rho\gamma$)/BF($K^*\gamma$) one can extract V_{td}/V_{ts}:

ICHEP 2006 BaBar only



$$|V_{td}/V_{ts}| = 0.171^{+0.018}_{-0.021}(\mathrm{exp.})^{+0.017}_{-0.014}(\mathrm{theor.})$$

In agreement with B_S mixing results

Conclusion

- Precise and redundant measurements of sides and angles of UT allowed quantitative test of CKM mechanism
  - CKM works beautifully!

- No New Physics?
  - If Λ_{NP}~1 TeV → effects in CP ~ m_W / Λ_{NP} ~ 10%
    - Precision ~ 3% needed: more data coming…

- Not seeing New Physics does mean something
  - CPV is just part of the puzzle
    - Many other NP studies at B factories: $B \to \tau\nu$, $B \to s\gamma$, $B \to sll$…
  - Constraints on New Physics models coming from B physics will help interpret the discoveries at the LHC

What have we learned?