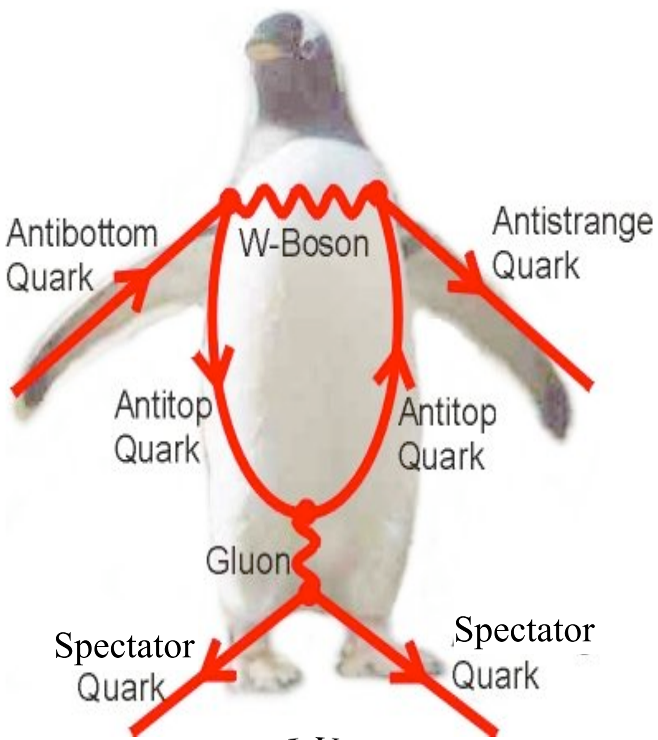
BABAR

TM and © Laurent de Brunhoff

...and the Search for New Physics



Or

"Finding Nils Olav"

Steve Playfer

THE UNIVERSITY OF EDINBURGH

B-factory Symposium, Stanford, October 27th 2008

Nils Olav is a non-Standard Model Penguin

- He has just been knighted (arise Sir Nils Olav)
- There is a statue of him
- He has a Wikipedia page

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The Free Encyclopedia

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Nils Olav

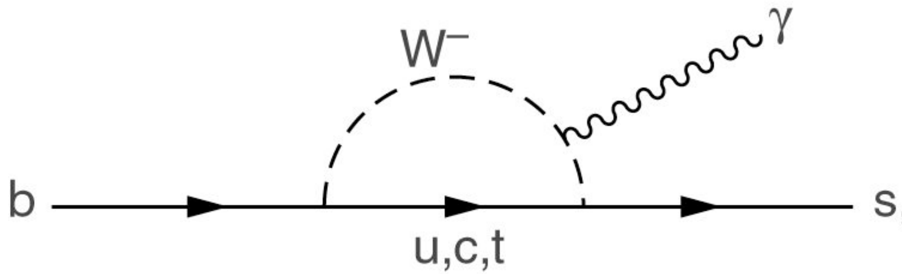
From Wikipedia, the free encyclopedia

Sir Nils Olav is a King Penguin living in Edinburgh Zoo, Scotland. He is the mascot and Colonel-in-Chief of the Norwegian King's Guard. Nils was visited by the Norwegian King's Guard on the 15 August 2008 and awarded a knighthood. The honour was approved by the king of Norway, King Harald V. During the ceremony a crowd of several hundred people joined the 130 guardsmen at the zoo to hear a citation from King Harald the Fifth of Norway read out, which described Nils as a penguin "in every way qualified to receive the honour and dignity of knighthood".[1]

Finding Nils Olav is ... difficult!

- You have to study a lot of penguins
  - Thanks to PEP-II we have 423/fb of Υ(4S) data
  - BaBar physics book was based on 30/fb (sometimes 300/fb)
- All (king) penguins look the same
  - The Standard Model explains everything
  - There is Minimal Flavour Violation
- What is the signature for Nils Olav?
  - A name tag? A radio collar?
  - Ask a zookeeper (theorist)

The first penguin $b \to s\gamma$ (b. 1993)



Branching Fraction

Before BaBar:

Experiment	$(3.15 \pm 0.54) \times 10^{-4}$
Theory	$(3.28 \pm 0.33) \times 10^{-4}$

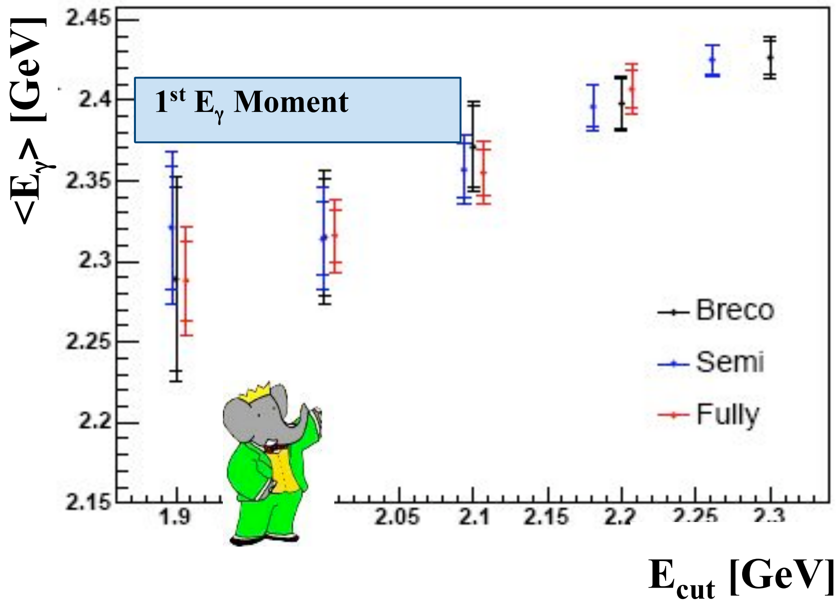
Now (82-210/fb):

Experiment	$(3.52 \pm 0.25) \times 10^{-4}$
Theory	$(3.15 \pm 0.23) \times 10^{-4}$

Final analysis (423/fb):

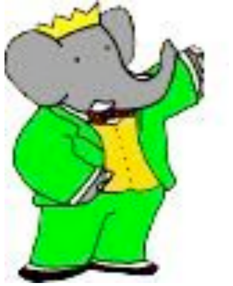
Experiment?	$(3.52 \pm 0.17) \times 10^{-4}$

Photon Energy Spectrum



$m_b^{\overline{MS}} = 4.243 \pm 0.042$ GeV (Gardi)

$m_b^{SF} = 4.631 \pm 0.038$ GeV (Neubert)

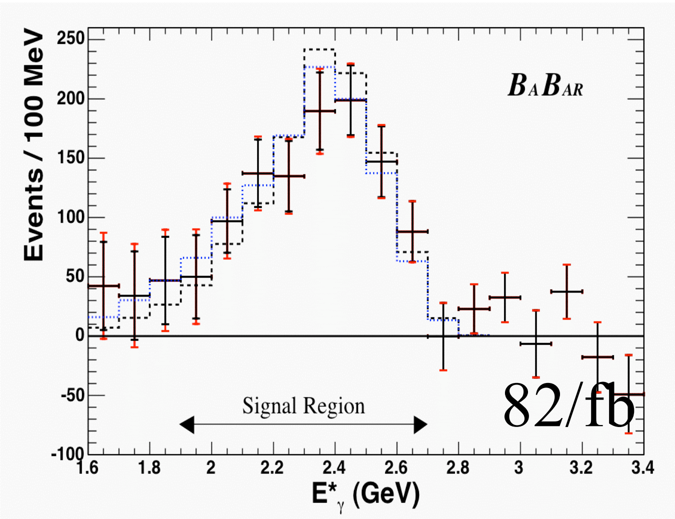


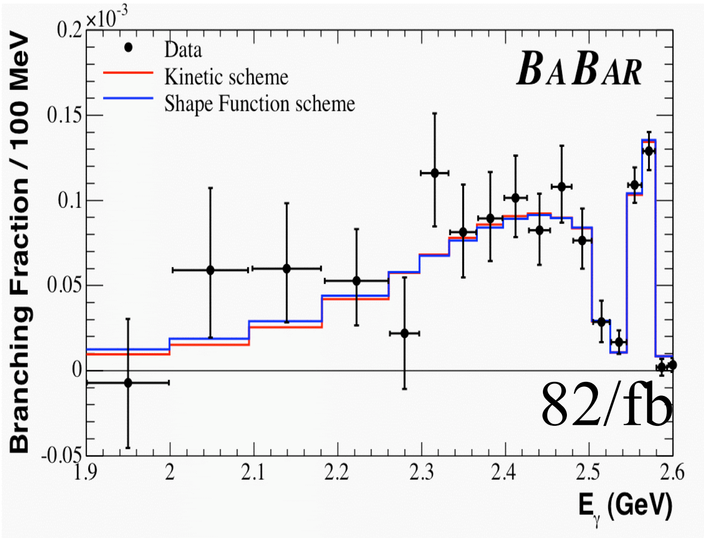
Three different $b \rightarrow s\gamma$ analyses

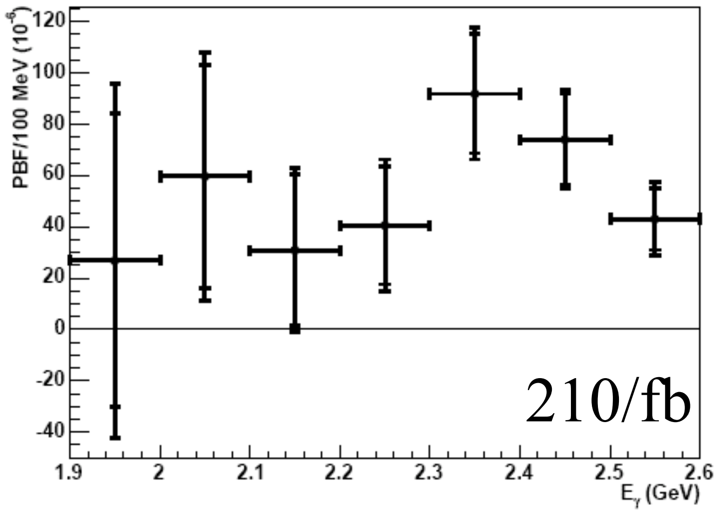
Fully Inclusive γ
(Lepton-tagged)

Semi Inclusive $B \rightarrow X_s\gamma$
(Sum of Exclusive modes)

Breco-tagged γ
(reconstruct other B)







High backgrounds
High efficiency

Good energy resolution
Missing final states?

Low backgrounds
Low efficiency

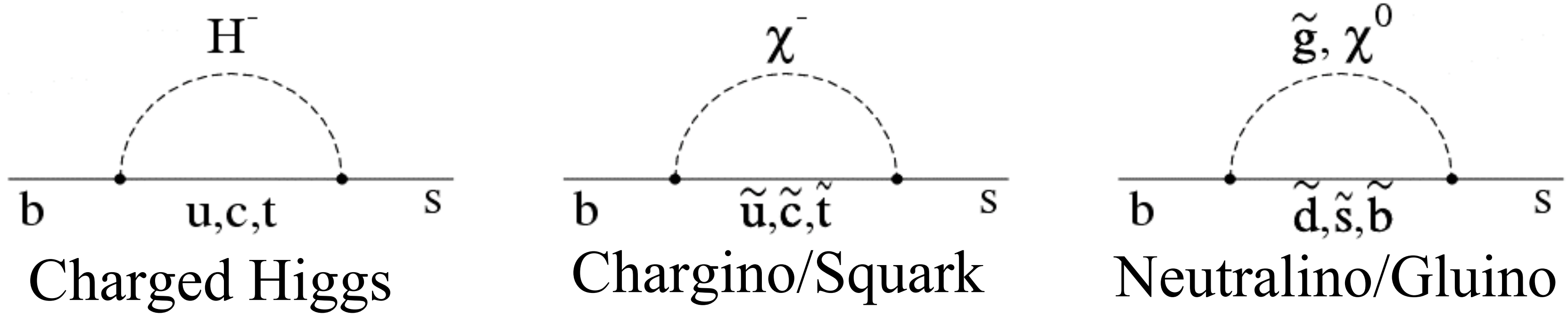
PRL 97, 171803 (2006)

PRD 72, 052004 (2005)

PRD-RC 77, 051103 (2008)

Constraints on New Physics from $b \to s\gamma$

- Two Higgs Doublet Model (2HDM)
  - Tan β is ratio of doublet vacuum expectation values
  - Charged Higgs boson $M_H > 300$GeV



- Supersymmetry (SUSY)
  - "Impossible to obtain model-independent bounds on SUSY"

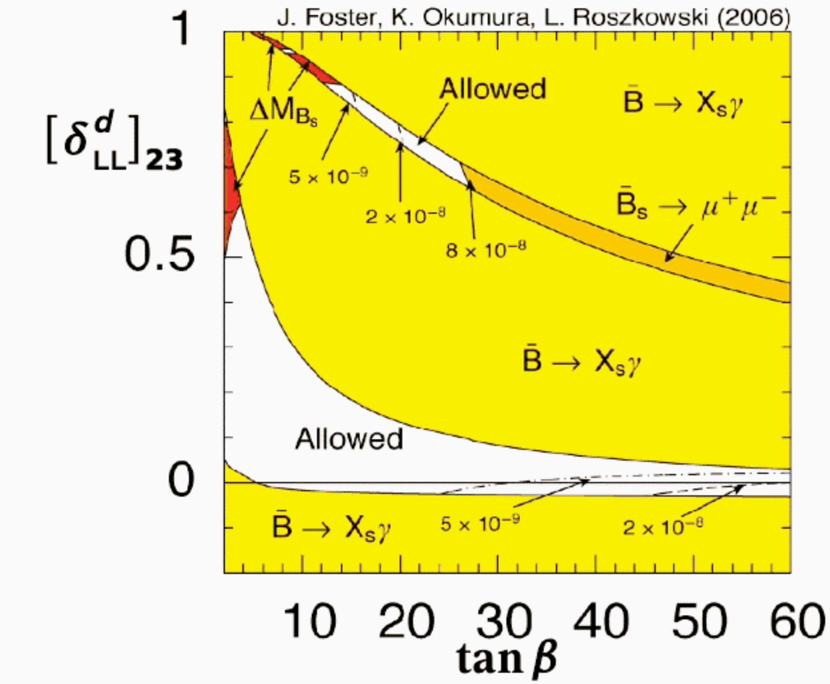
    (Wick & Altmannshofer 2008, arXiv: 0810.2874)
  - Competition between H⁻, chargino, gluino contributions
  - Non-Standard Model insertions δ_{LL}, δ_{LR}, δ_{RL}, δ_{RR} (next slide)

    (L = left-handed, R = right-handed, LR/RL change quark helicity)

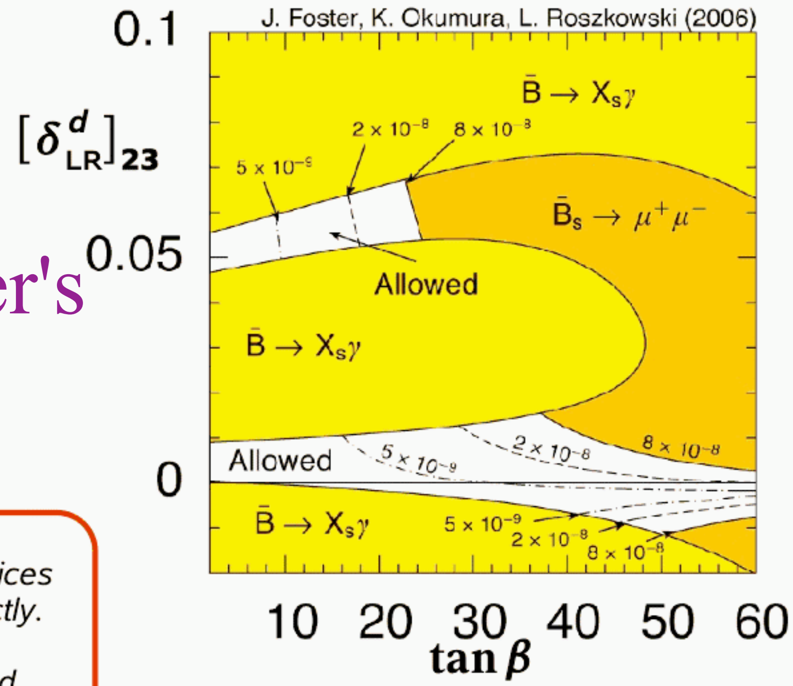
- Universal Extra Dimensions (UED)
  - Compactification radius $1/R > 300$ GeV (Agashe, Deshpande, Wu 2001)

General flavor mixing: $B \to X_s \gamma$ vs. other FCNCs

For previous, single-insertion analyses, see:
Gabbiani *et al.*, 96; Everett et al., 01; Ciuchini et al., 02

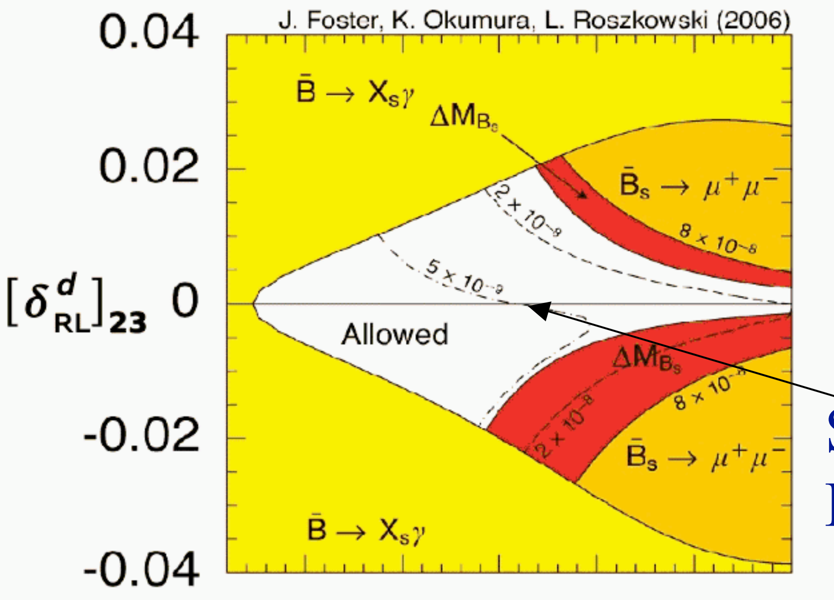


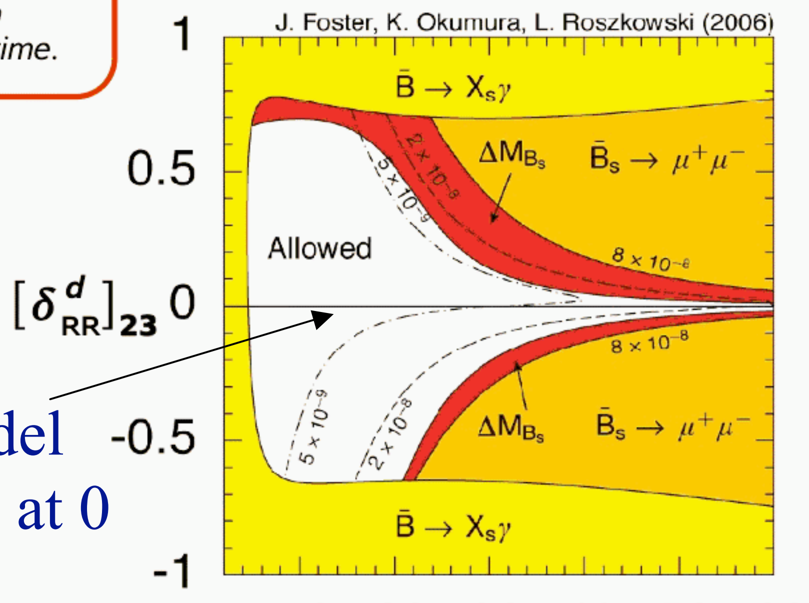
The Zookeeper's maps



Squark mass matrices diagonalized exactly.

Bounds obtained switching on only one δ at a time.

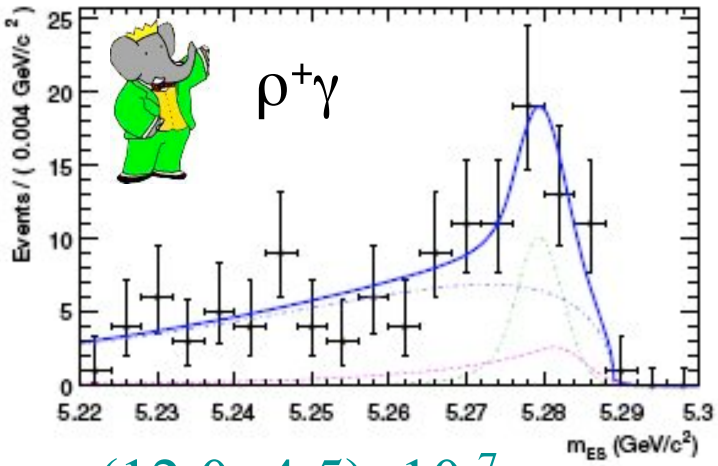




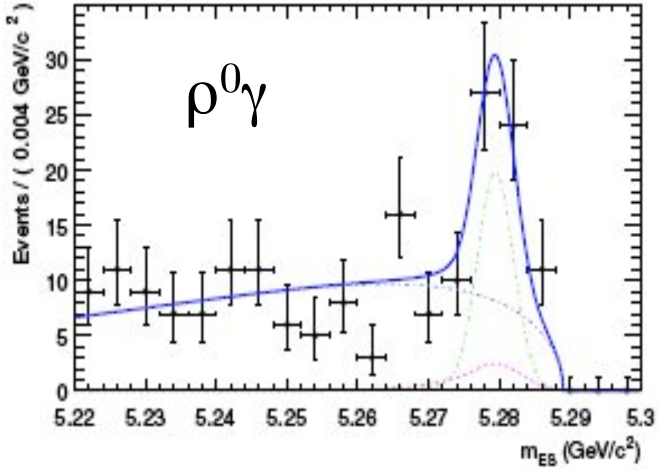
Standard Model Penguins live at 0

A rare penguin $b \to d\gamma$ (b. 2004)

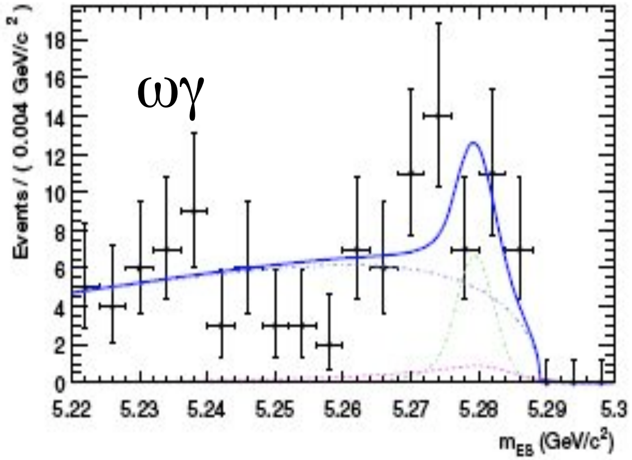
Exclusive decays with 423/fb



$(12.0\pm4.5)\times10^{-7}$



$(7.9\pm2.4)\times10^{-7}$



$(4.0\pm2.7)\times10^{-7}$

Assume isospin symmetry $\Gamma(B^+ \to \rho^+\gamma) = 2\Gamma(B^0 \to \rho^0\gamma) = 2\Gamma(B^0 \to \omega\gamma)$

Branching fraction $B \to (\rho/\omega)\gamma = (11.4\pm2.3)\times10^{-7}$

arXiv:0808.1379 [hep-ex]; submitted to PRD

PRELIMINARY

Inclusive rate from sum of exclusive modes

arXiv:0807.4975 [hep-ex]; submitted to PRL

$$\frac{\Gamma(b \to d\gamma)}{\Gamma(b \to s\gamma)} = 0.033 \pm 0.013 \pm 0.009$$

Constraint on $|V_{td}/V_{ts}|$ from $b\to d\gamma / b\to s\gamma$

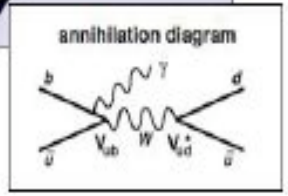
isopin factor: 1(.5) for $\rho^{\pm}(\rho^{0})$(and ω)

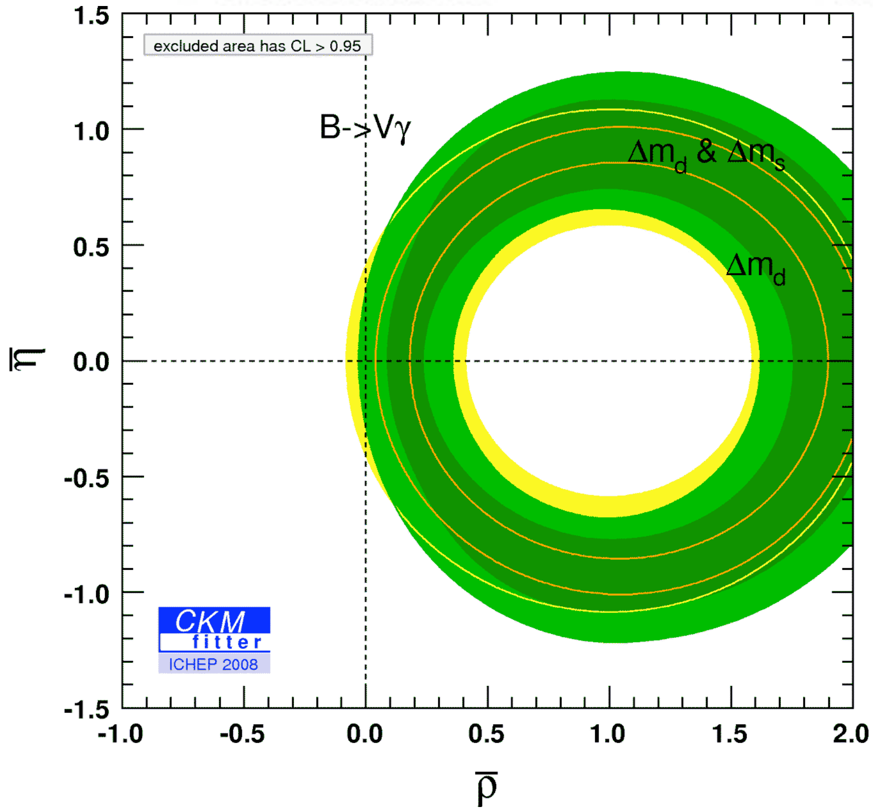
form factor ratio

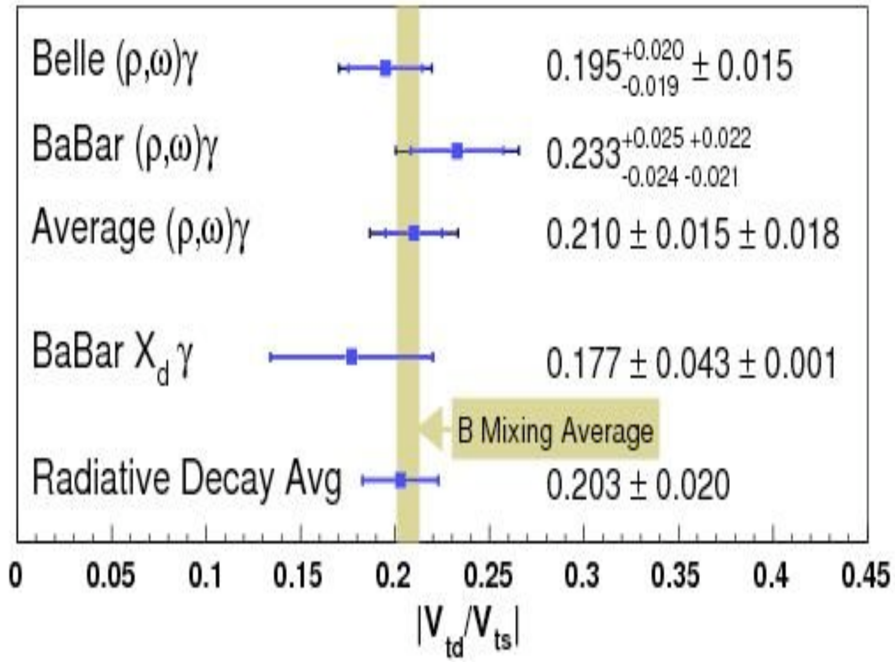
$$\frac{\mathcal{B}(B\to\rho\gamma)}{\mathcal{B}(B\to K^{*}\gamma)} = S_{\rho}\left|\frac{V_{td}}{V_{ts}}\right|^{2}\left(\frac{1-m_{\rho}^{2}/M_{B}^{2}}{1-m_{K^{*}}^{2}/M_{B}^{2})}\right)^{3}\zeta^{2}[1+\Delta R]$$

well measured

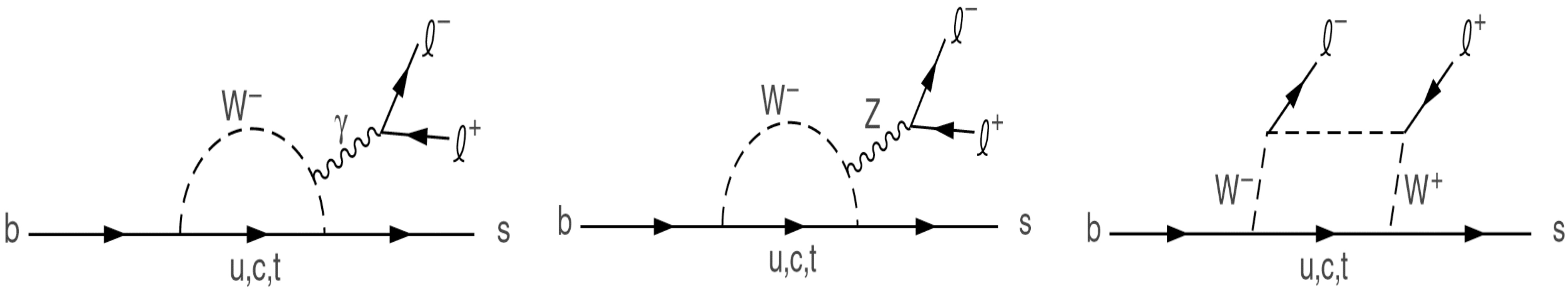
annihilation amplitude corrections



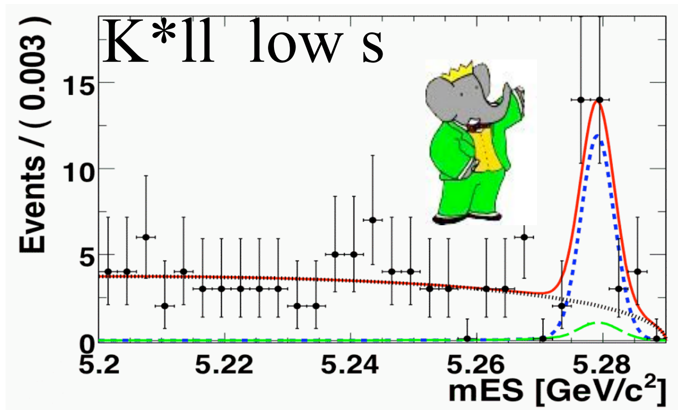


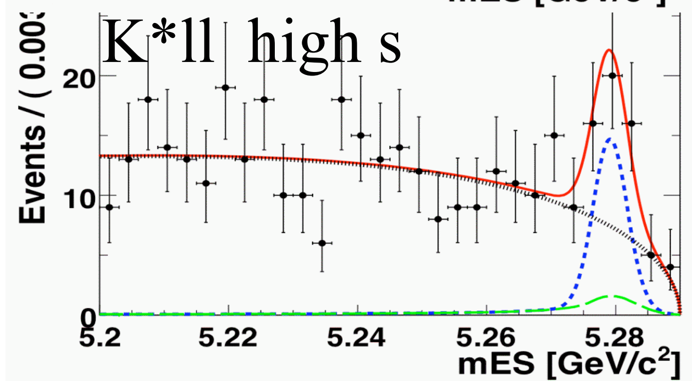


A very rare decay $b \to s l^+ l^-$ (b. 2003)



Radiative Penguins (C7) Electroweak Penguins V-A (C9-C10)

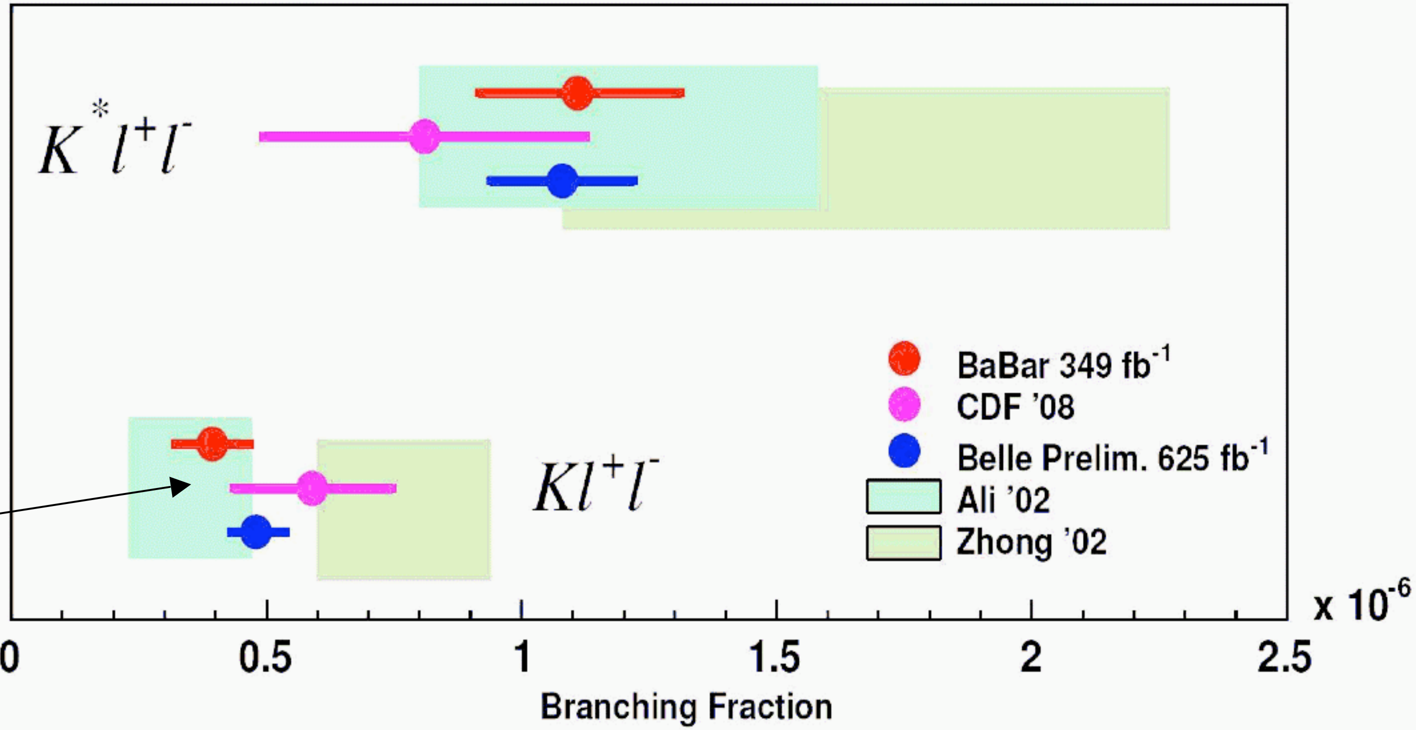




Measure interference between diagrams as a function of di-lepton mass squared (s)

- Branching fractions for Kll, K*ll and inclusive sll
- K* longitudinal polarization F_L
- Lepton forward-backward asymmetry A_{FB}
- Lepton universality: $K(^*)\mu\mu/K(^*)ee = 1$?
- Isospin asymmetry: $B^+/B^0 = 1$?

B→K(*)ll Branching Fractions



The rarest known B decay

BaBar preliminary – ICHEP '08 (349 fb^{-1})

$$\mathrm{B}(B \to K^*\ell^+\ell^-) = (11.1^{+1.9}_{-1.8} \pm 0.7) \times 10^{-7}$$

$$\mathrm{B}(B \to K\ell^+\ell^-) = (3.9 \pm 0.7 \pm 0.2) \times 10^{-7}$$

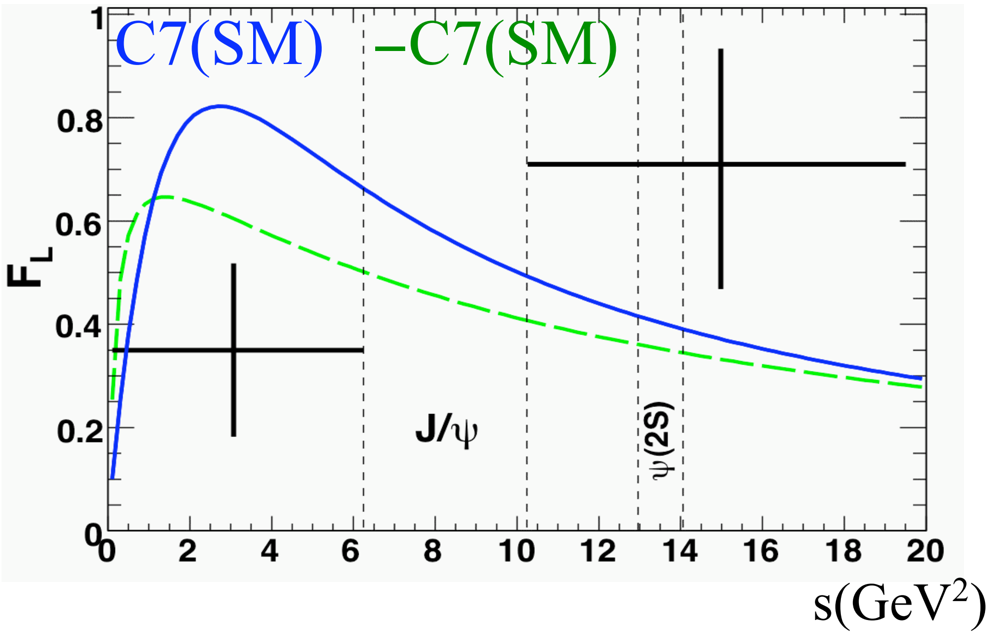
BELLE preliminary – ICHEP '08 (625 fb^{-1})

$$\mathcal{B}(B \to K^*\ell^+\ell^-) = (10.8^{+1.0}_{-1.0} \pm 0.9) \times 10^{-7}$$

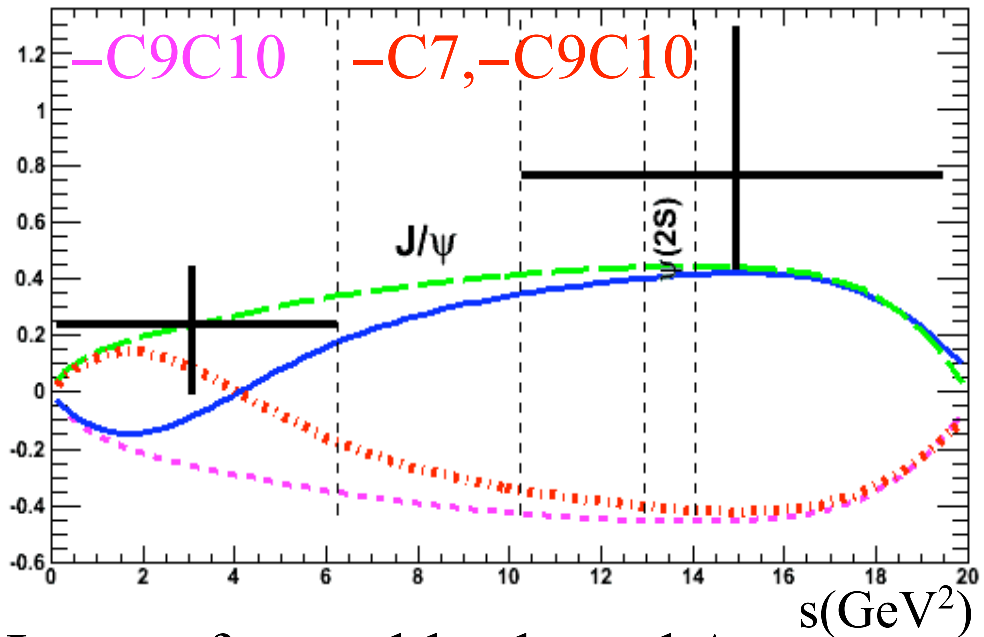
$$\mathcal{B}(B \to K\ell^+\ell^-) = (4.8^{+0.5}_{-0.4} \pm 0.3) \times 10^{-7}$$

Consistent with theory.
Next level of SM tests from rate asymmetries and angular information (as functions of $q^2 = s = m_{ll}^2$)

Angular and Rate Asymmetries in B→K(*)l^+l^-



K* Longitudinal Polarization



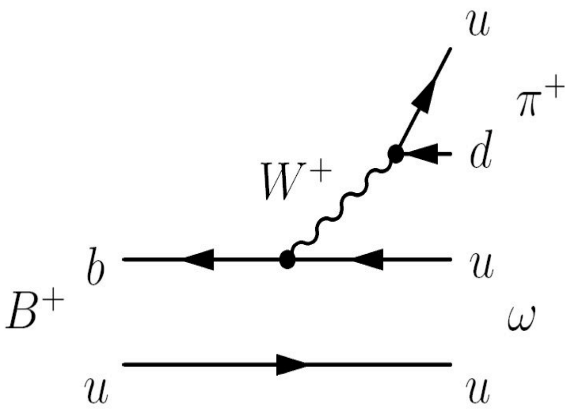
Lepton forward-backward Asymmetry

PRELIMINARY

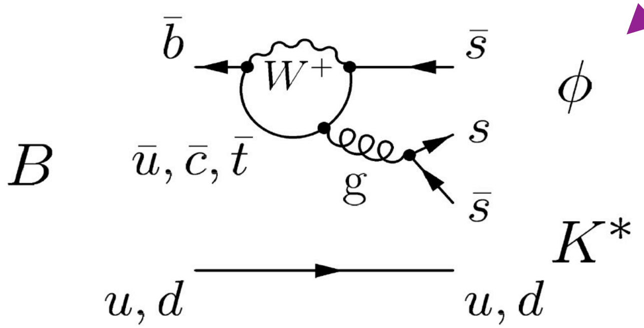
hep-ex: 0804.4412 & 0807.4119 (submitted to PRL)

	Direct CP	Isospin	μμ/ee
Kll (low s)	–0.18±0.18	$-1.43_{-0.85}^{+0.56}$	0.40±0.30
Kll (high s)	–0.09±0.39	0.28±0.27	1.06±0.66
K*ll (low s)	0.01±0.21	–0.56±0.17	1.01±0.51
K*ll (high s)	0.09±0.21	0.18±0.32	$2.15_{-0.78}^{+1.42}$

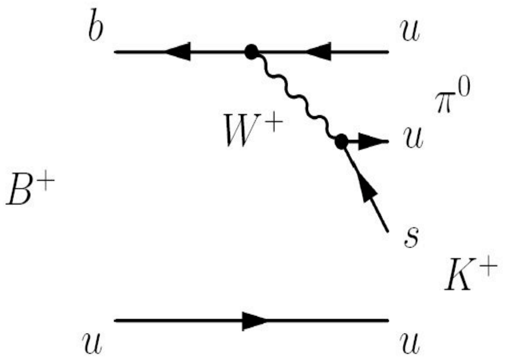
Charmless Hadronic B Decays



Tree,T



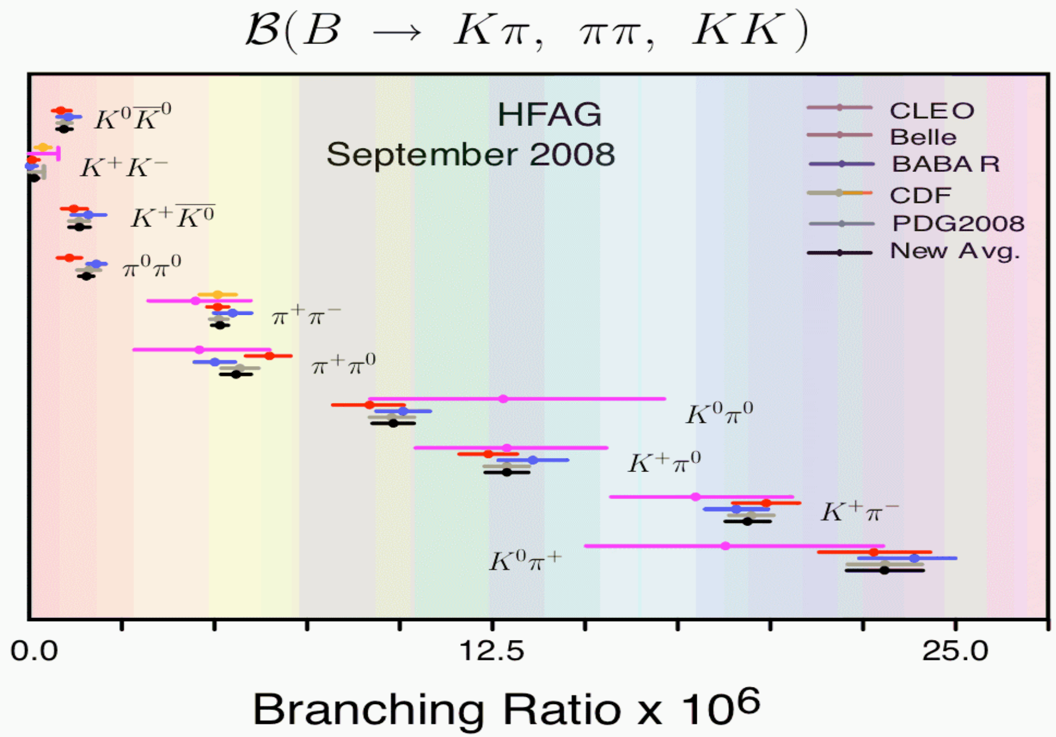
Gluonic penguin, P'



Color-suppressed tree, C'

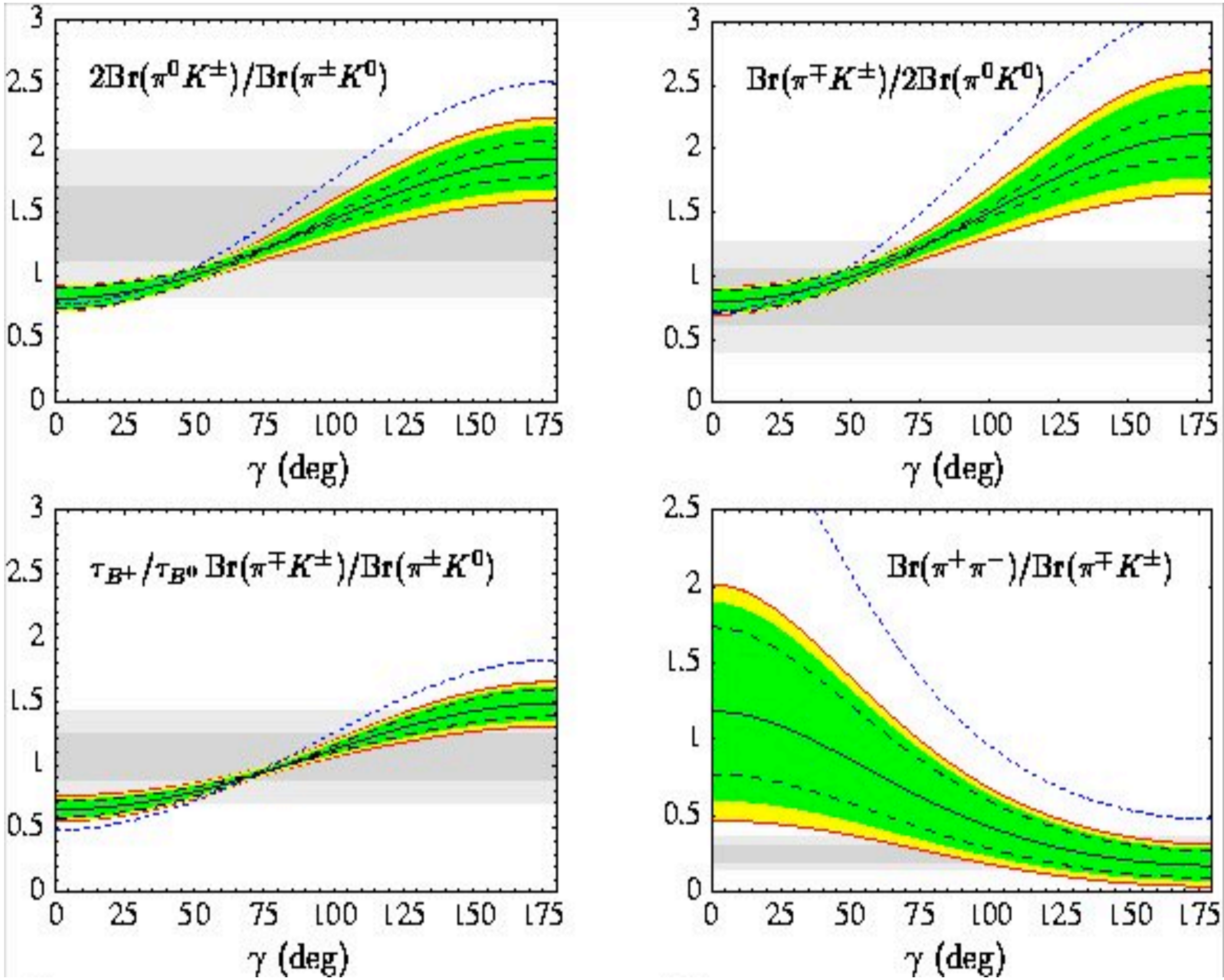
Many (~100) different decay modes!
Mostly described by sum of T,P,C diagrams

Focus on B→Kπ, Kϕ, Kη' which are mainly described by gluonic penguins (P)



Branching fractions B→Kπ are 1-2x10^{-5}

Predictions of QCD Factorization



Beneke et al (2001)

"The first Kπ Puzzle"

Possible inconsistency between $B(K^0\pi^0)$ and $B(\pi\pi)$ + other $B(K\pi)$?

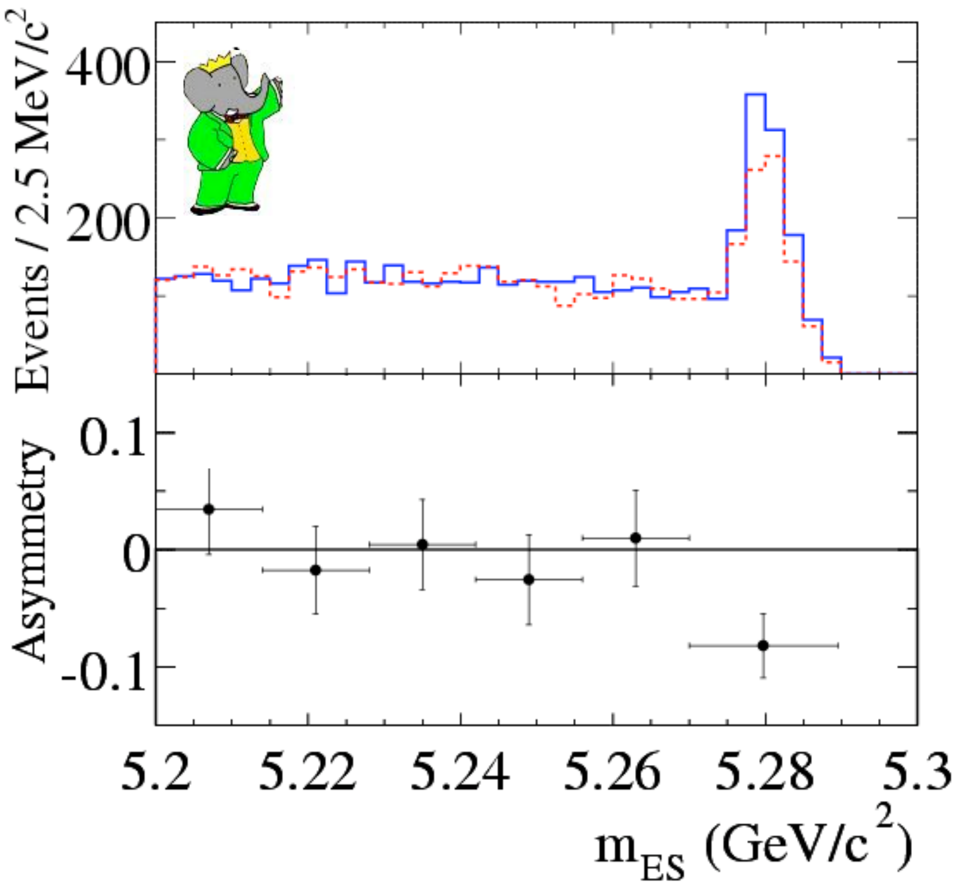
New physics from electroweak penguins? (Fleischer, Gronau)

$\gamma=(76\pm20)^o$ from $B\rightarrow DK$ (see talk by Yeche)

Direct CP Violation in B→Kπ

BaBar made the first observation of A_{CP} in B decays (2004)

$\bar{B}^0 \rightarrow K^- \pi^+$ $B^0 \rightarrow K^+ \pi^-$



"The second Kπ Puzzle"

$A_{CP}(K^0\pi^+)= 0.009\pm0.025$

$A_{CP}(K^+\pi^0)= 0.050\pm0.025$

Should be the same?

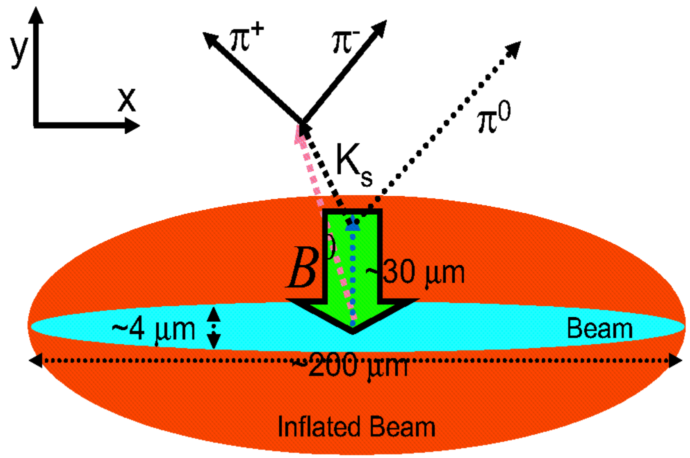
$A_{CP}(K^+\pi^-)= -0.097\pm0.012$

(HFAG 2008)

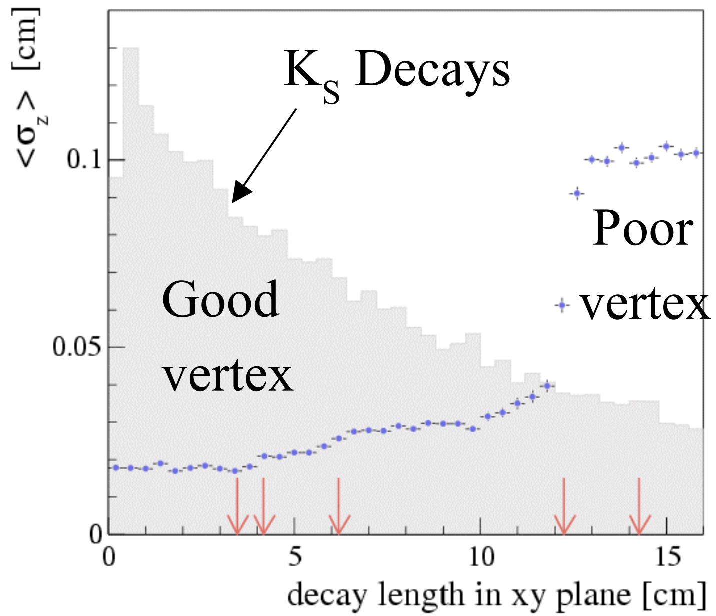
Belle finds a difference between direct CP violation in charged and neutral B meson decays (Nature, 2008)

で荷電Ｂ中間子と中性Ｂ中間子の崩壊で異なるCP対称性の破れを観測

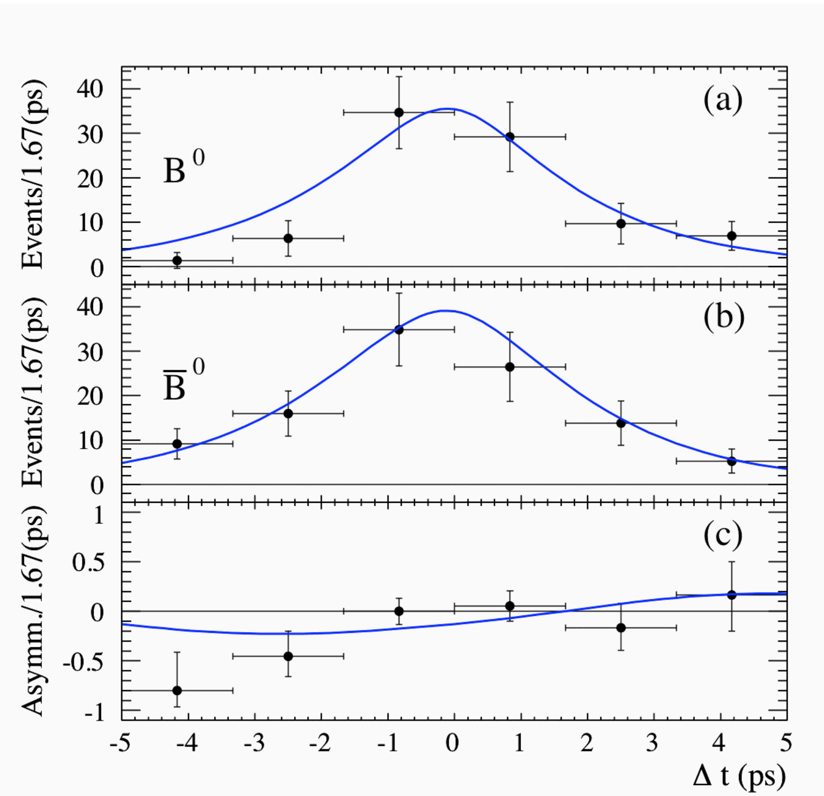
Time-dependent CP Violation in $B \to K_S \pi^0(\gamma)$



Determination of vertex of B decay from K_S extrapolation (BaBar 2003)



↓ Vertex Detector Layers



HFAG 2008

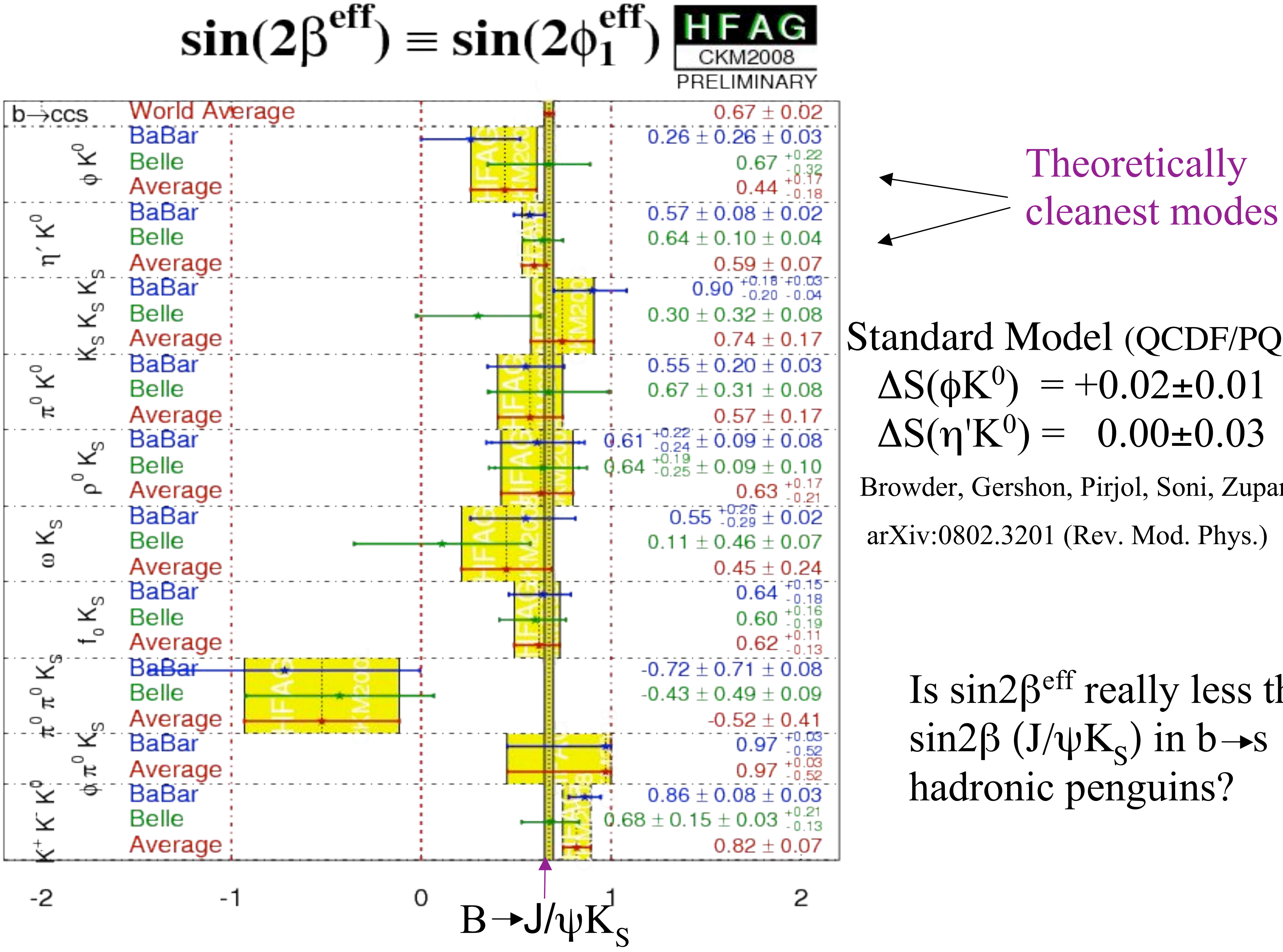
$S(K^0\pi^0)$	$C(K^0\pi^0)$
0.57±0.17	0.01±0.10

=sin 2β?

$S(K^0\pi^0\gamma)$	$C(K^0\pi^0\gamma)$
−0.15±0.20	-0.07±0.12

Helicity changes?

$\sin(2\beta^{eff}) \equiv \sin(2\phi_1^{eff})$



Standard Model (QCDF/PQCD)

$\Delta S(\phi K^0) = +0.02 \pm 0.01$

$\Delta S(\eta' K^0) = 0.00 \pm 0.03$

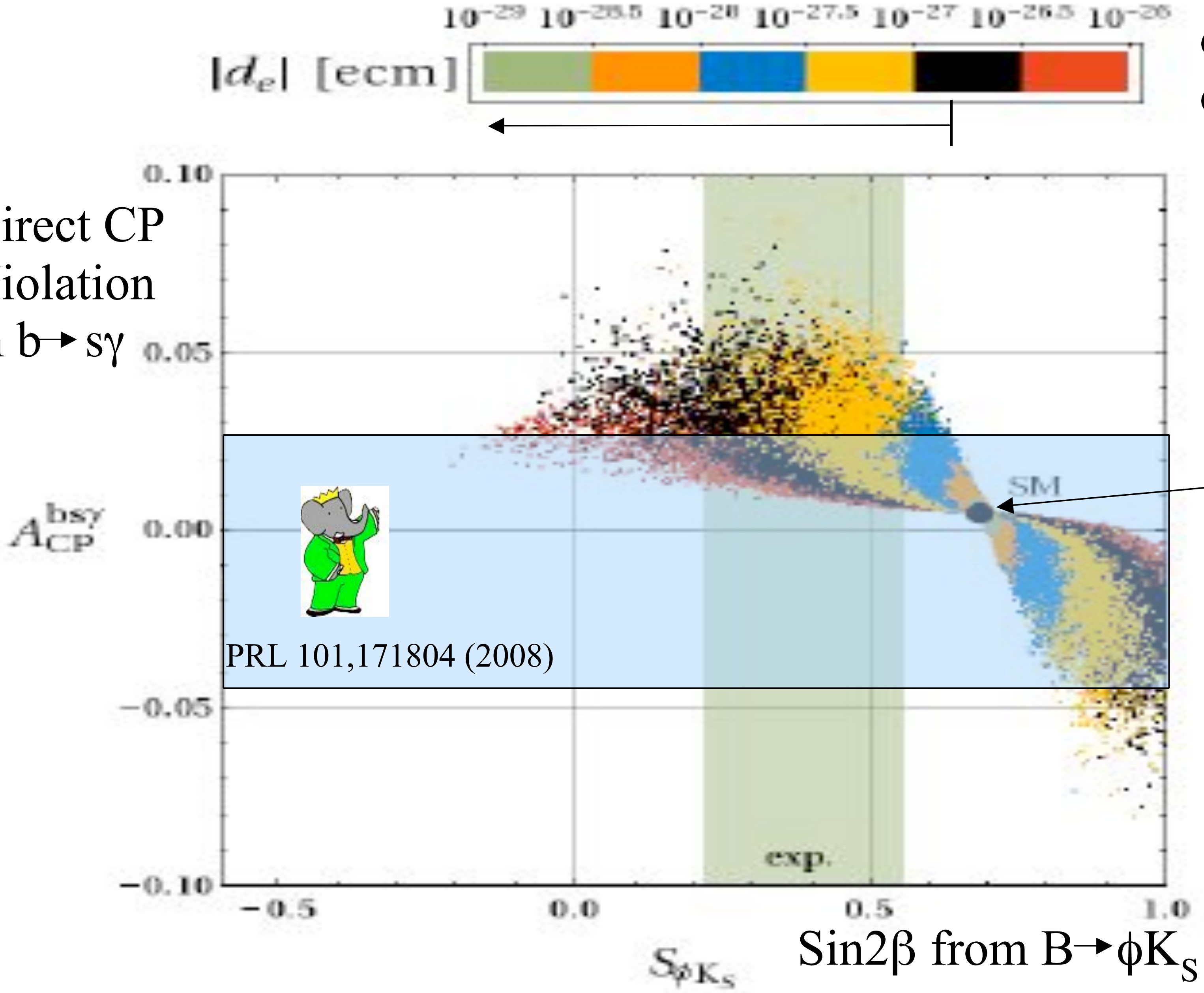
Browder, Gershon, Pirjol, Soni, Zupan

arXiv:0802.3201 (Rev. Mod. Phys.)

Is $\sin 2\beta^{eff}$ really less than $\sin 2\beta$ ($J/\psi K_S$) in $b \to s$ hadronic penguins?

electron electric dipole moment $d_e = (7\pm7)\times10^{-28}$ ecm

Direct CP Violation in $b\to s\gamma$



Standard Model

Sin2β from $B\to\phi K_S$

Masiero (CKM 2008) – Correlations between New Physics observables

Source of CP Violation for Baryon Asymmetry of the Universe

George W.S. Hou (侯維恕)
National Taiwan University

ICHEP 2008

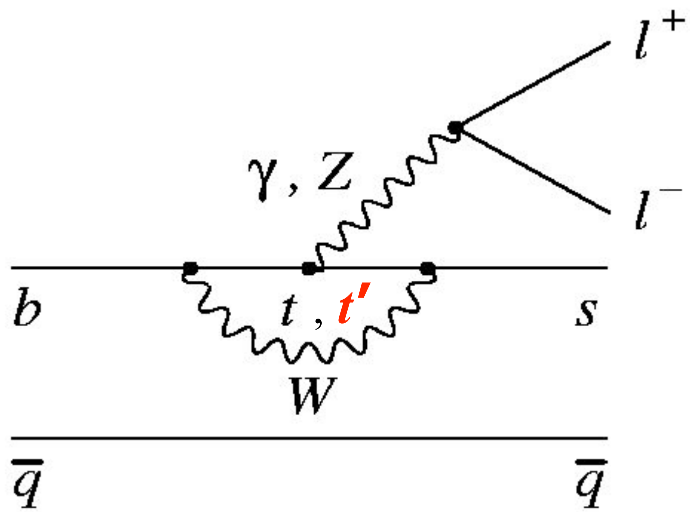
arXiv:0810.3396

In Public: the big question BaBar has been addressing

In Private: CP violation in B/K decays does not account for the baryon asymmetry of universe (by x10^{10})

…but it could if you add a ***t′*** quark (4th generation)

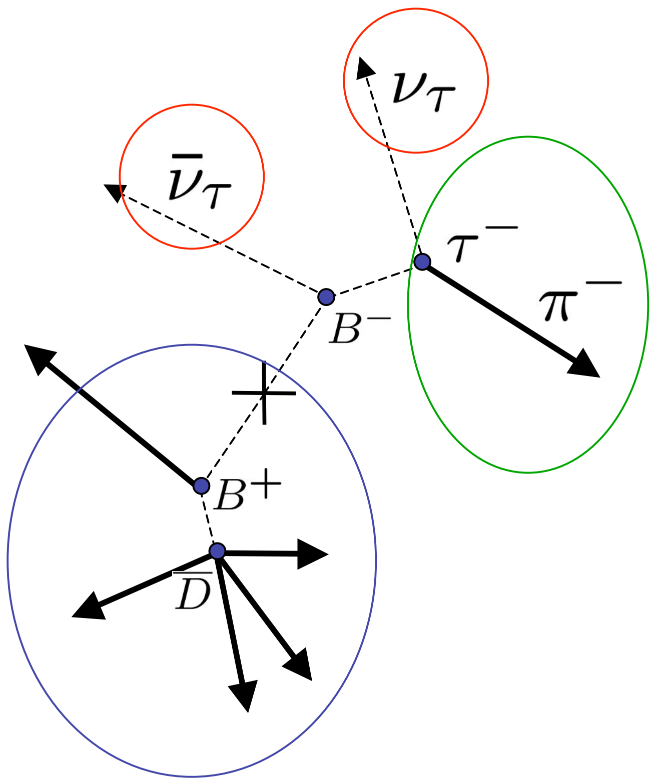
- New physics in electroweak penguins
  - Solves the two $K\pi$ puzzles
  - Different $\sin 2\beta$ in penguins
  - Should see effects in $b \to sll$



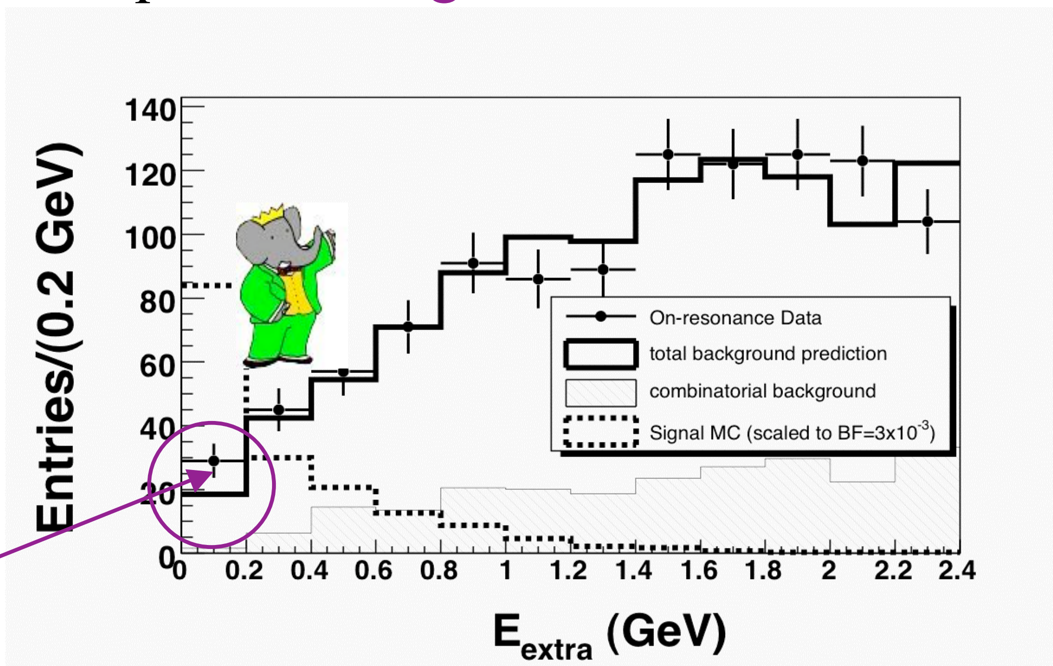
- New physics in mixing diagrams
  - Large phase ϕ_s in B_s mixing (Tevatron)
  - Different $\sin 2\beta$ in $J/\psi K_s$? (Soni, CKM 2008)
  - Effects in D mixing?

The leptonic decay B→τν (b. 2006)

- Very challenging due to the presence of at least two neutrinos
- Reconstruct the other B in the event (B→D*lν or hadronic decays)
- Reconstruct observable tau daughters in a few decay modes (e, μ, π...)
- Require nothing else in the event:

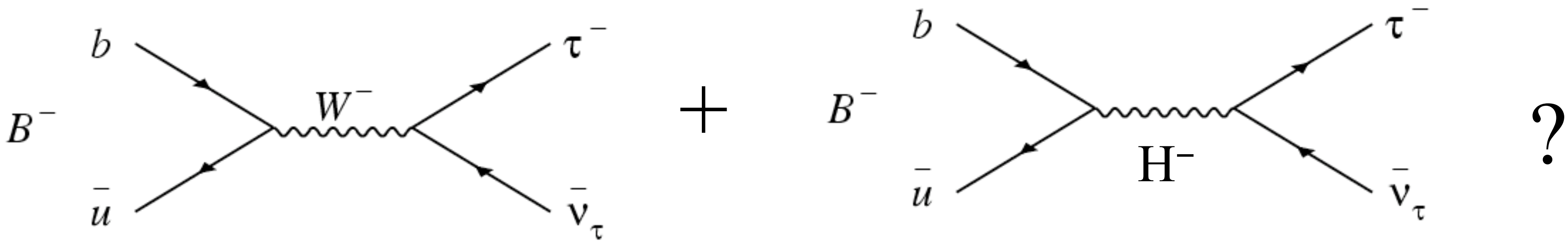


Tag B meson

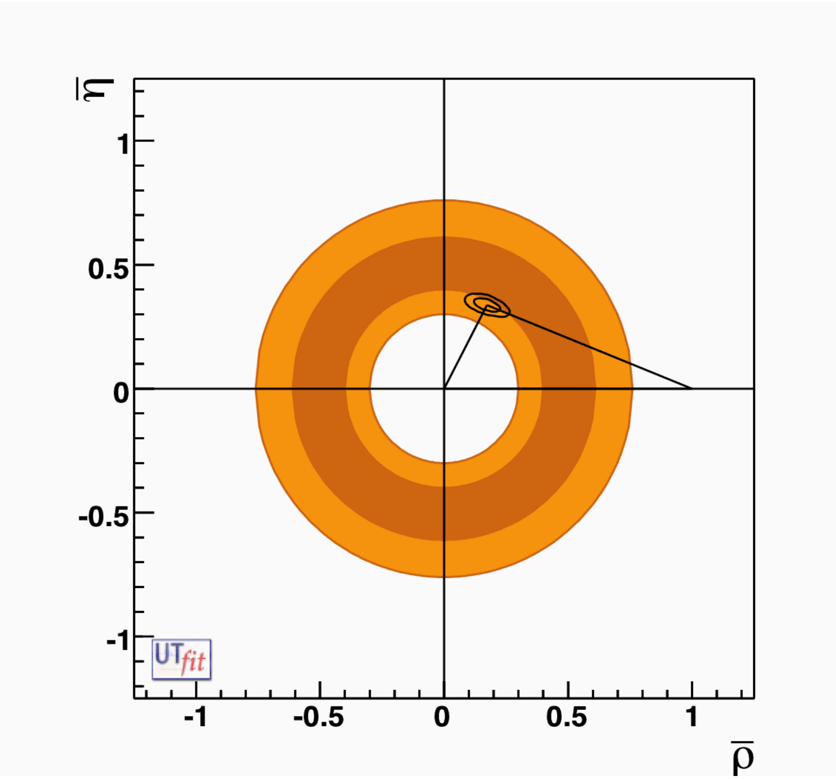


Evidence for signal

New Physics in B →τν



$$\mathcal{B}(B^- \to \tau^- \overline{\nu_\tau}) = \frac{G_F^2\, m_B\, m_\tau^2}{8\pi} \left(1 - \frac{m_\tau^2}{m_B^2}\right) f_B^2\, |V_{ub}|^2\, \tau_B$$



= $(1.51\pm0.33)\mathrm{x}10^{-4}$ Experiment (HFAG)

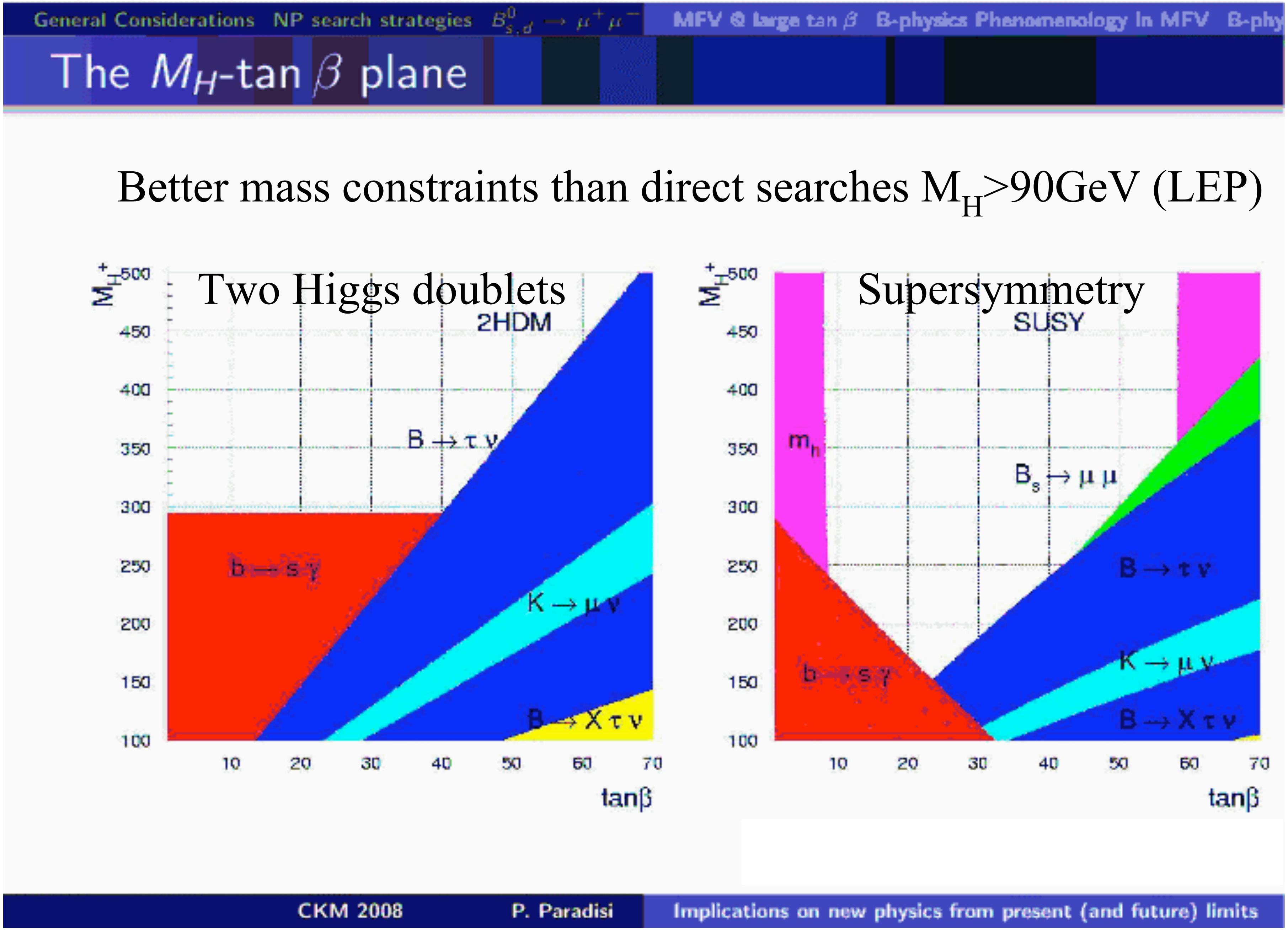
= $(1.39\pm0.44)\mathrm{x}10^{-4}$ (Standard Model)

- f_B= (189±27) GeV from lattice QCD
- $|V_{ub}|$ = $(44.9\pm3.3)\mathrm{x}10^{-4}$ inclusive b →ulν

= $(0.73\pm0.12)\mathrm{x}10^{-4}$ (UT_{fit})

- No lattice input
- All CKM constraints apart from V_{ub}

The Charged Higgs Map

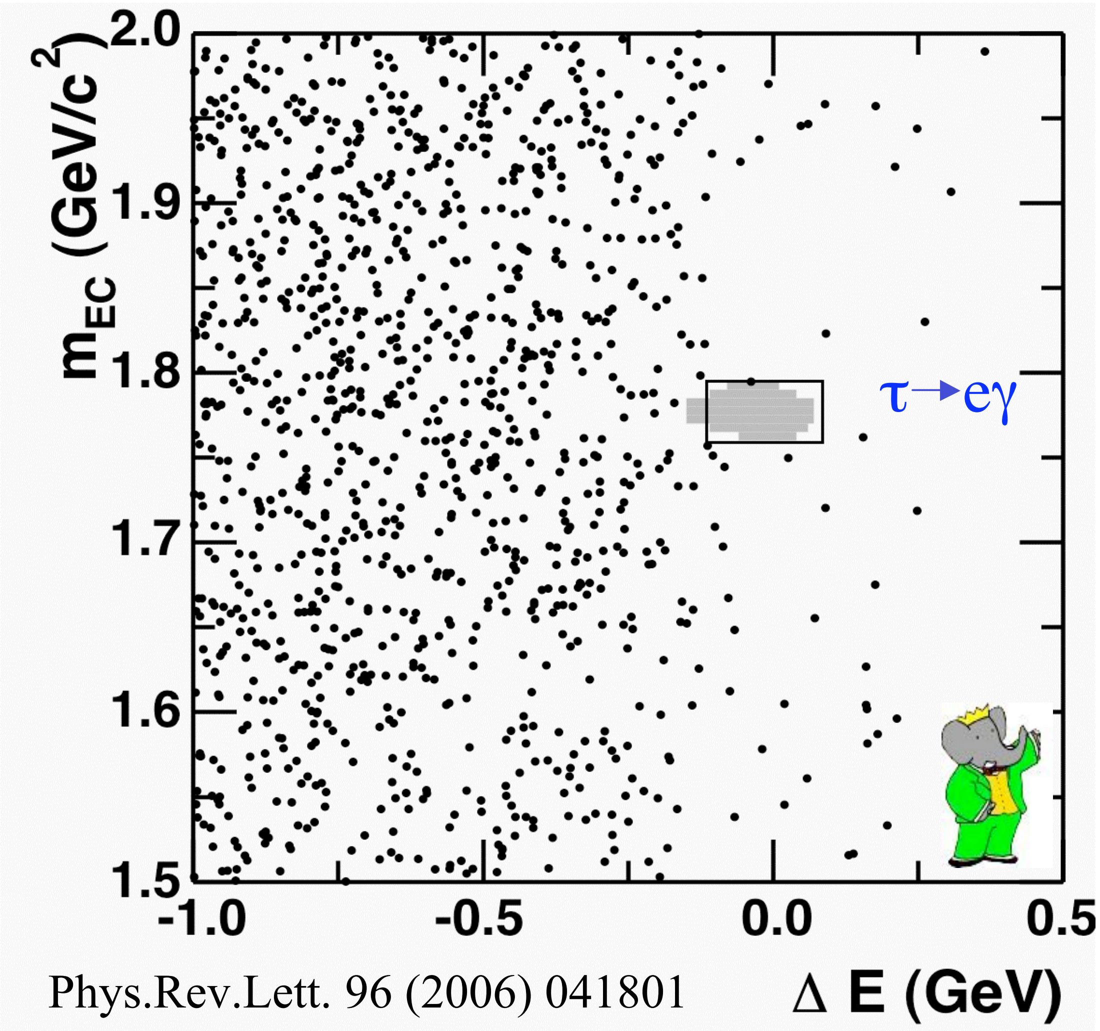


$b \to s\gamma$

$B \to \tau\nu$

Lepton Flavour Violation in Tau Decays

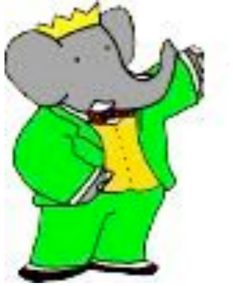
An example of a search:



Phys.Rev.Lett. 96 (2006) 041801

- Reconstruct the signal $\tau \to e\gamma$ decay and require the correct τ mass and energy
- In the rest of the event require the observable daughters of the other τ to be consistent with a known τ decay mode
- Account for backgrounds
  - $\tau \to e\nu\bar{\nu}$ decays
  - electromagnetic processes

$B(\tau \to e\gamma) < 1.1 \times 10^{-7}$



Some other things that we didn't find...

- The rare penguin decays $B \to K^{(*)}\nu\bar{\nu}$ $< 5\ (12)\ \mathrm{x}10^{-5}$
- The leptonic decays $B \to \mu\nu\ (e\nu)$ $< 1.3\ (5.2)\ \mathrm{x}10^{-6}$
- The leptonic decays $B \to \mu^+\mu^-\ (e^+e^-)$ $< 5.2\ (11.3)\ \mathrm{x}10^{-8}$
- The radiative decay $B \to \gamma\gamma$ $< 1.7\ \mathrm{x}10^{-6}$
- The lepton-flavour violating decays $\tau \to \mu\gamma\ (\mu\mu\mu)$ $< 6.8\ (5.3)\ \mathrm{x}10^{-8}$
- CP violation in D decays $\Delta Y < 1\%$

These upper limits are important for constraining new physics!

Summary & Conclusions

- No clear evidence for New Physics yet

- We found a lot of new penguins
  - they all fit the Standard Model
  - but there are a few puzzles
- We have pictures of Nils Olav
  - which give hints what to look for
- We have maps of where to look
  - given to us by the zookeepers

  → talk by Nir
- The search will continue

  → talk by Giorgi