Heavy Flavor Physics Experiment

David Hitlin
DPF 2009
July 29, 2009

Heavy Flavor Physics – past, present, future

- Flavor physics provides the experimental foundation of much of the Standard Model
  - Heavy flavor physics plays an important role, in that it furnishes many parameters that can be
    - determined experimentally with precision
    - compared with reliable theoretical predictions
  - As such, heavy flavor physics has served to
    - establish the Standard Model:
      - the particle content
      - the weak couplings
      - the suppression of flavor-changing neutral currents, ……

      and
    - constrain what lies beyond the Standard Model
  - When new physics is found at the LHC
    - Flavor physics will provide unique information on the nature of the new physics
- This talk will highlight selected topics, emphasizing what we know and what we don't, and discuss what can be learned in the new generation of flavor physics experiments

Tests of the Standard Model Flavor Sector

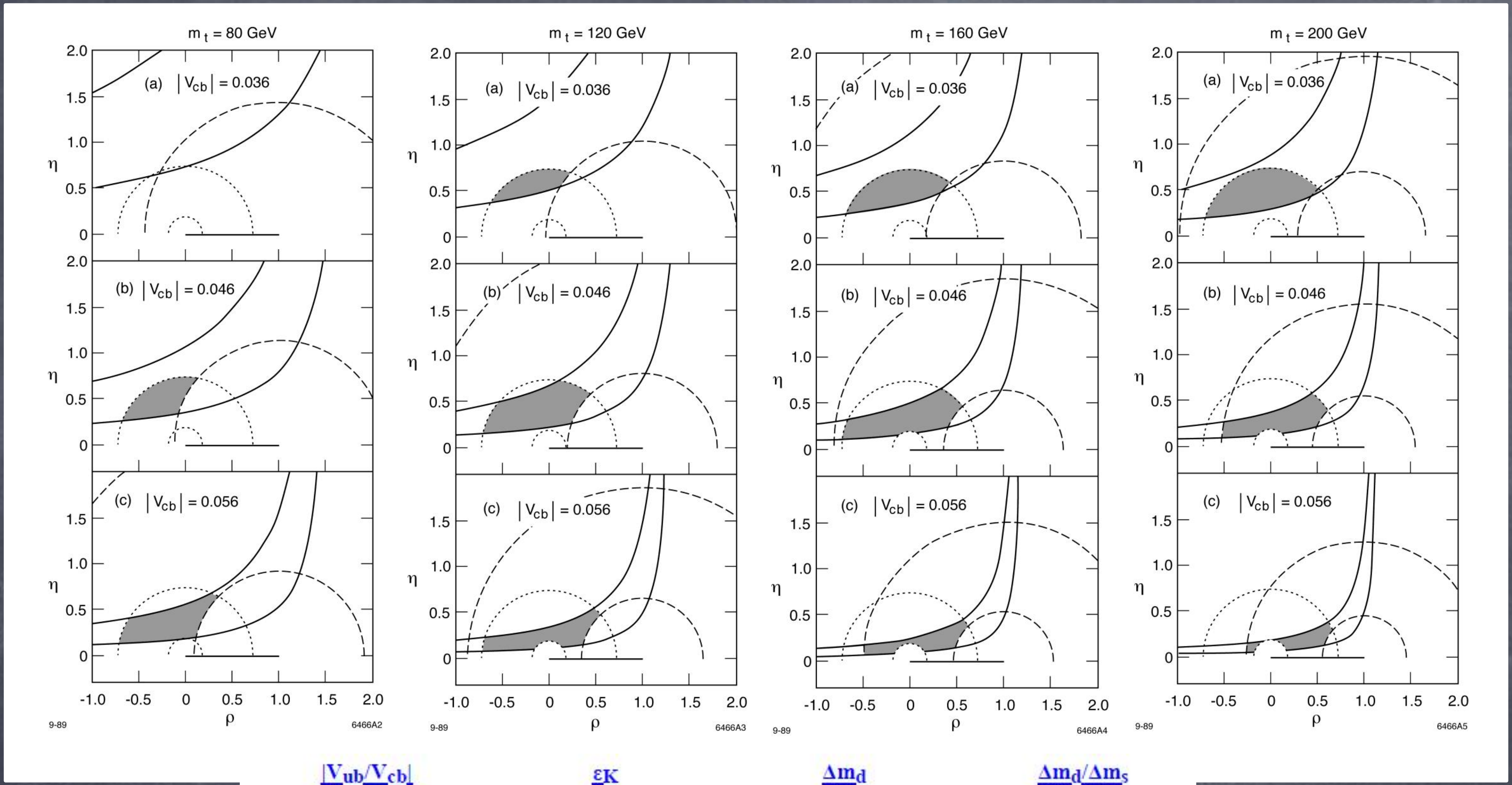
- Unitarity triangle tests
  - These primarily involve measurements in the B system, but require measurements of the m_t, Cabibbo angle, ε_K and theoretical inputs – CP-conserving and violating
  - A closer look reveals some issues and potential inconsistencies

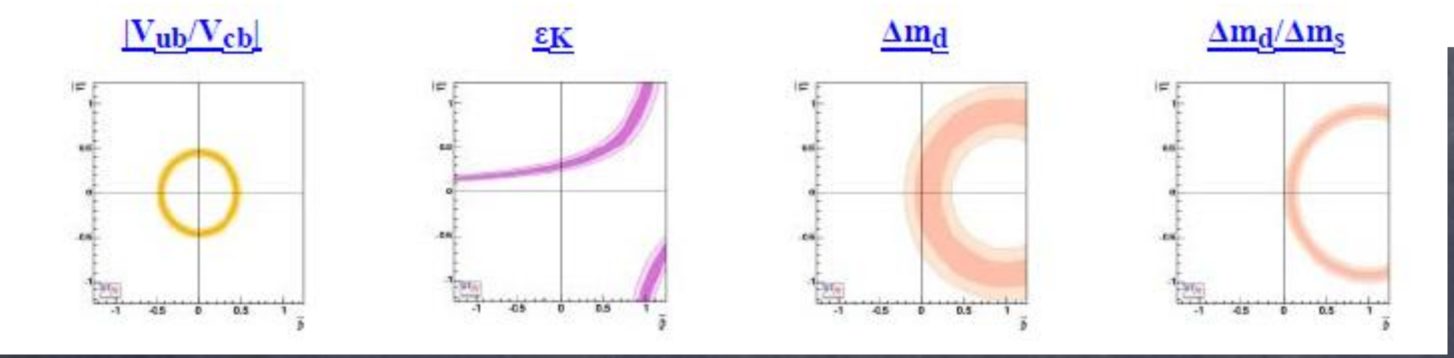
  - Fitted, *i.e.*, SM-predicted value of $\sin 2\beta$ vs directly measured value using tree decays and loop decays
  - Direct CP violation in $K^+\pi^-$ *vs* $K^+\pi^0$ decays
  - $\mathcal{B}(B\to\tau\nu)$ conflict
  - $B_s \to \psi\phi$ phase
  - Each of these is a ~2.5σ issue : ????

- There are also further tests and sensitive searches possible
  - Three generation unitarity
  - Does the unitarity triangle close ?
  - Are there extra mixing phases ?
  - Are there extra CP-violating phases ?

At the start of the "B Factory era"

Dib, Dunietz, Gilman and Nir - 1989

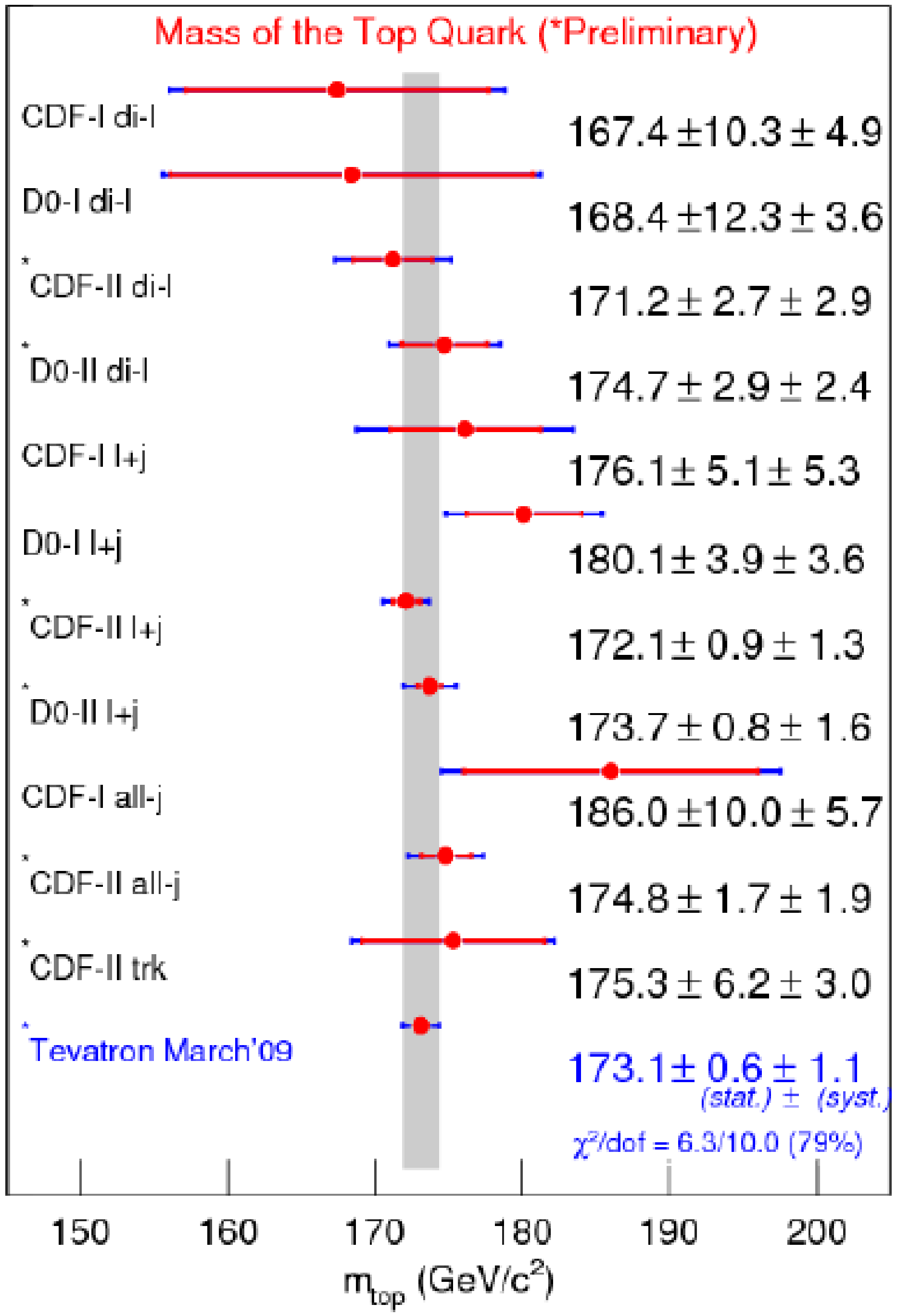




Mass of the top quark required to sharpen UT tests

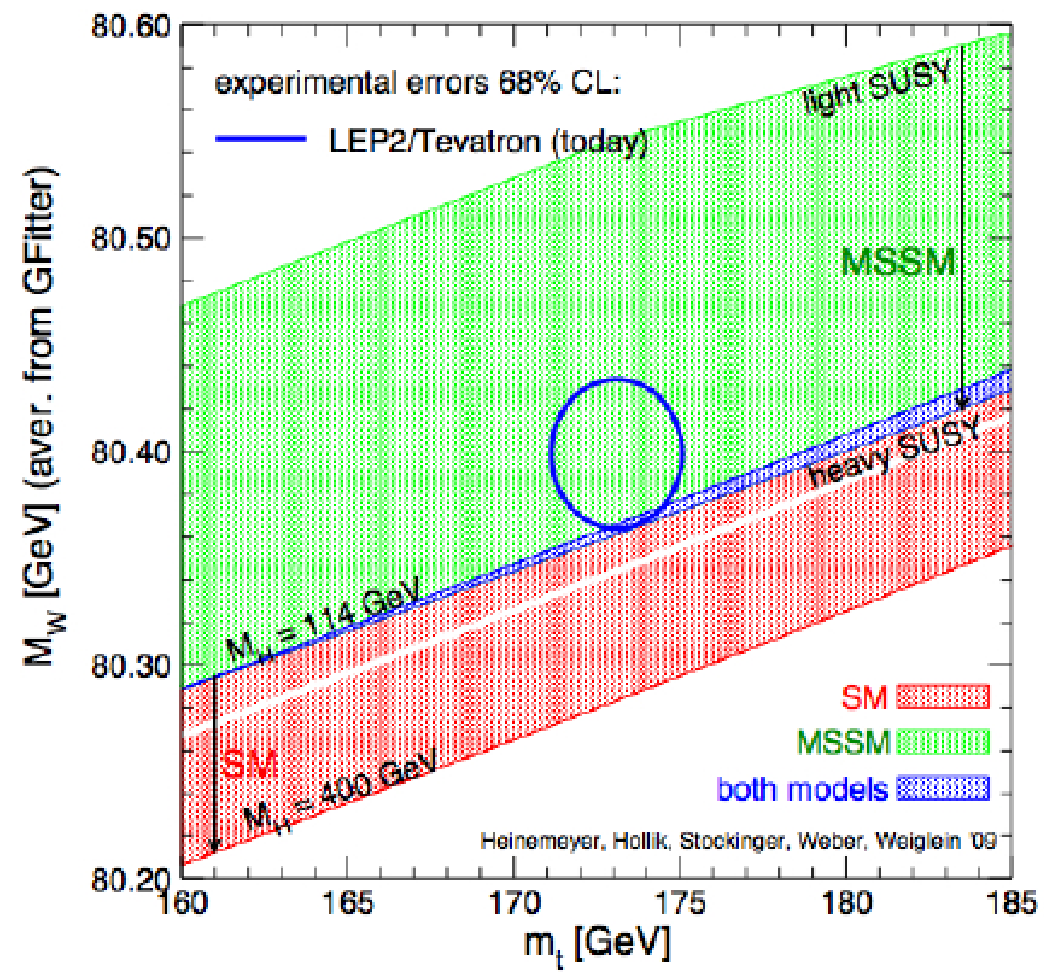
Tevatron Combination: March 2009

arXiv:0903.2503



m_{top} = 173.1 ± 1.3 GeV

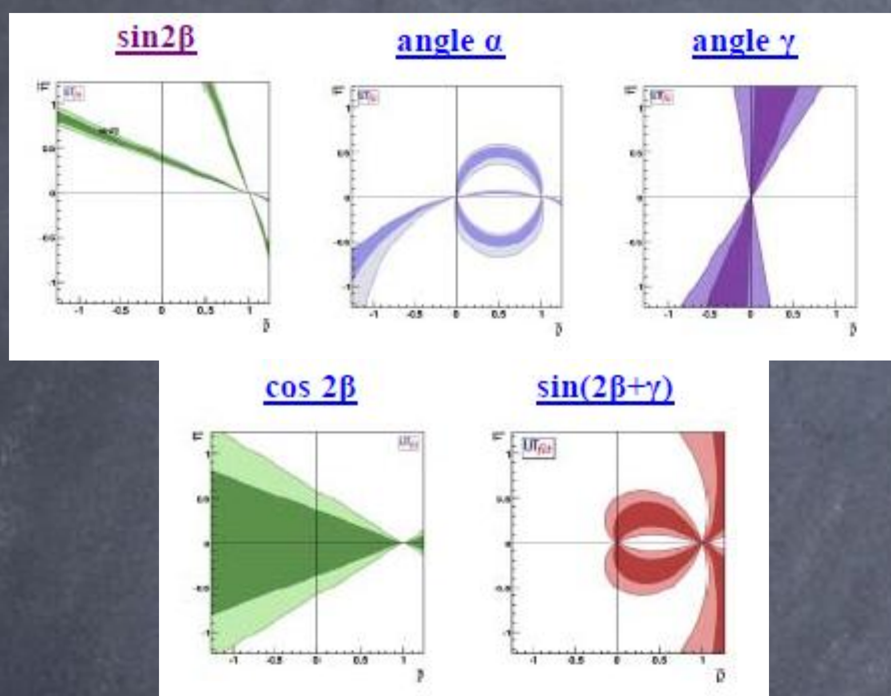
Heinemeyer et al. **±0.75%**



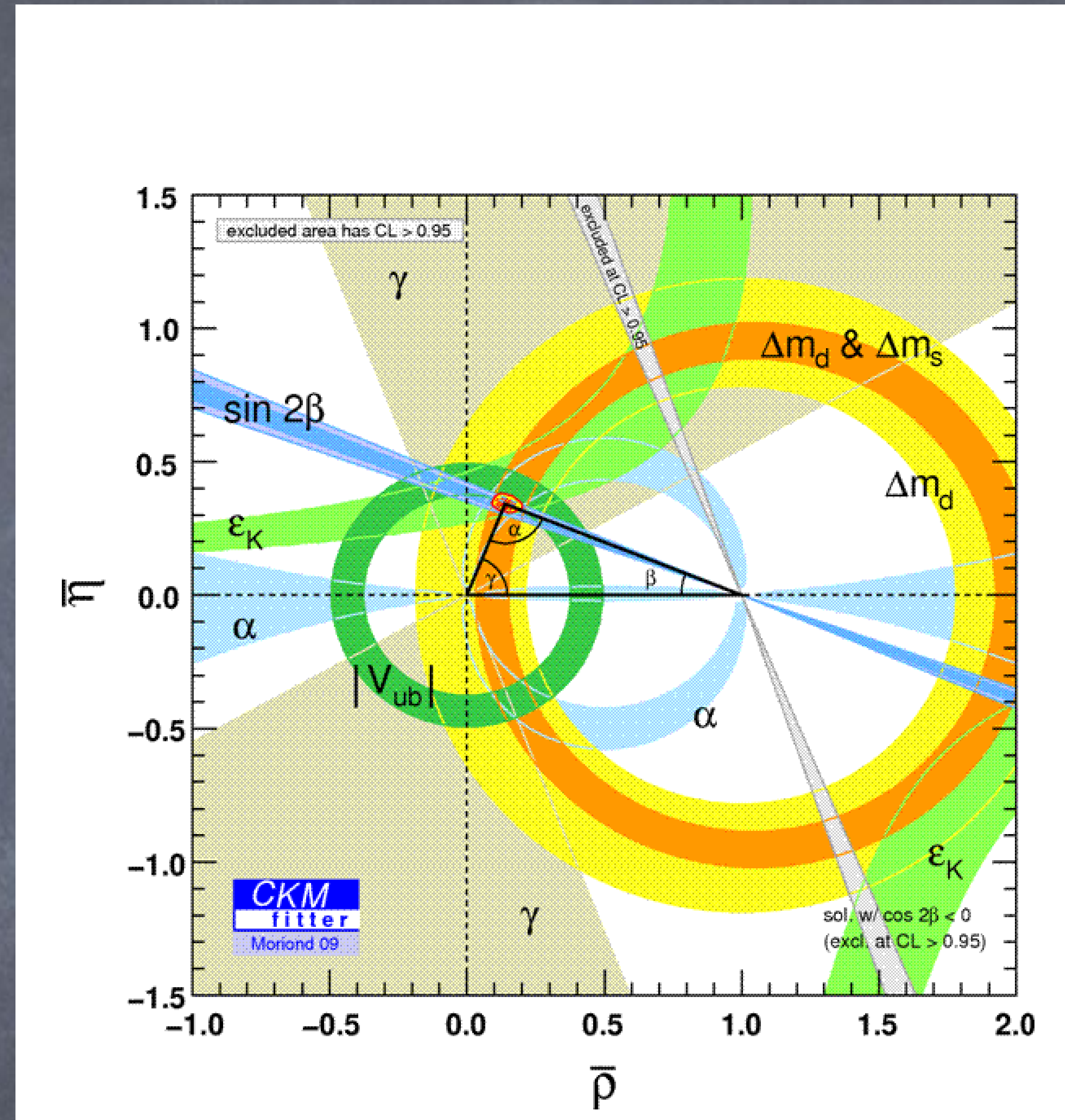
theory & experiment: uniform treatment of systematics

CKM Fitter results as of Moriond 2009

Adding in the *CP* asymmetry measurements from *BABAR* and Belle,

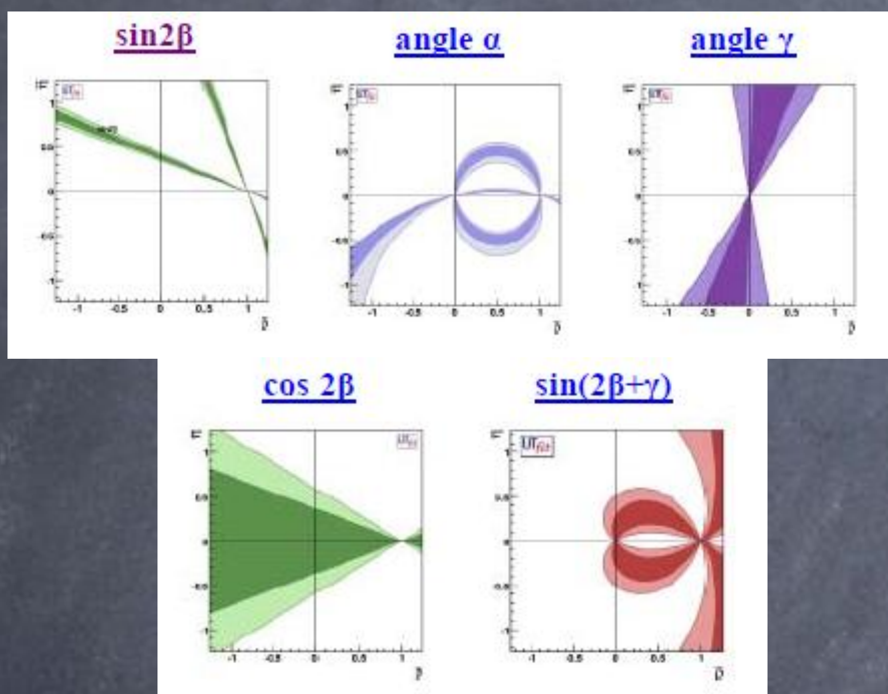


we now have a set of highly overconstrained tests, which *grosso modo*, are well-satisfied

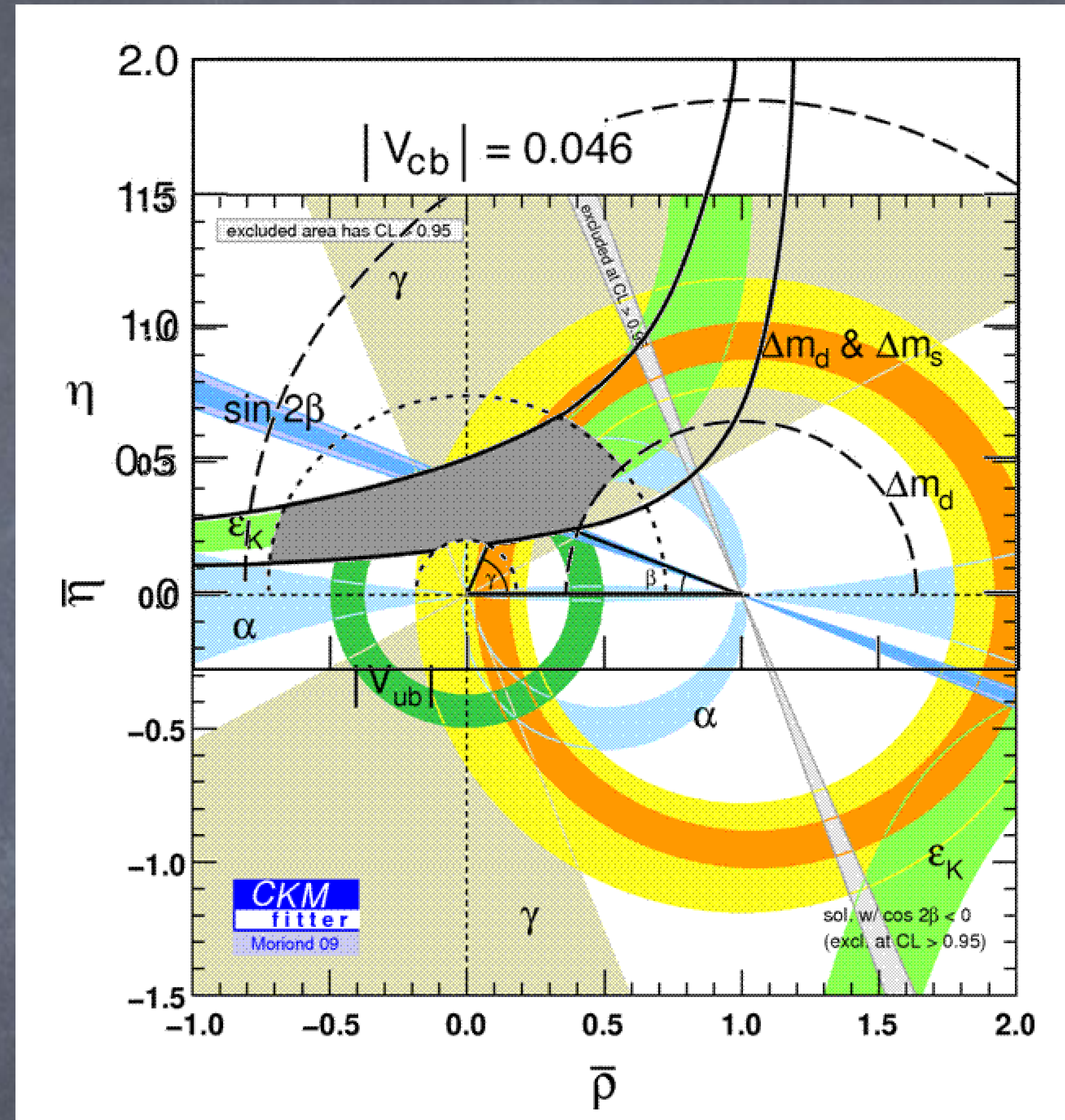


CKM Fitter results as of Moriond 2009

Adding in the *CP* asymmetry measurements from *BABAR* and Belle,

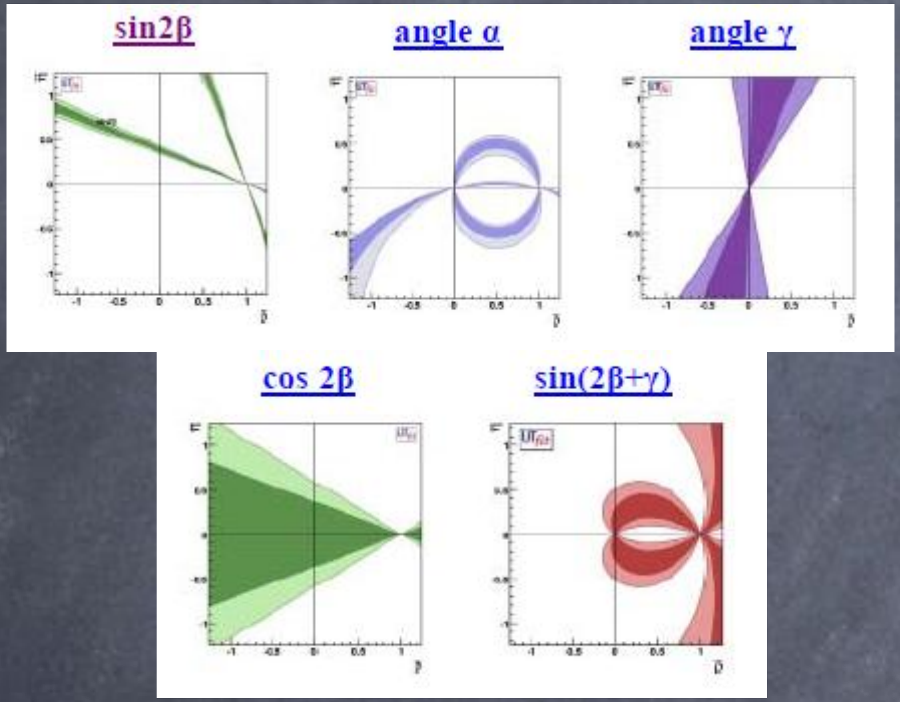


we now have a set of highly overconstrained tests, which *grosso modo*, are well-satisfied

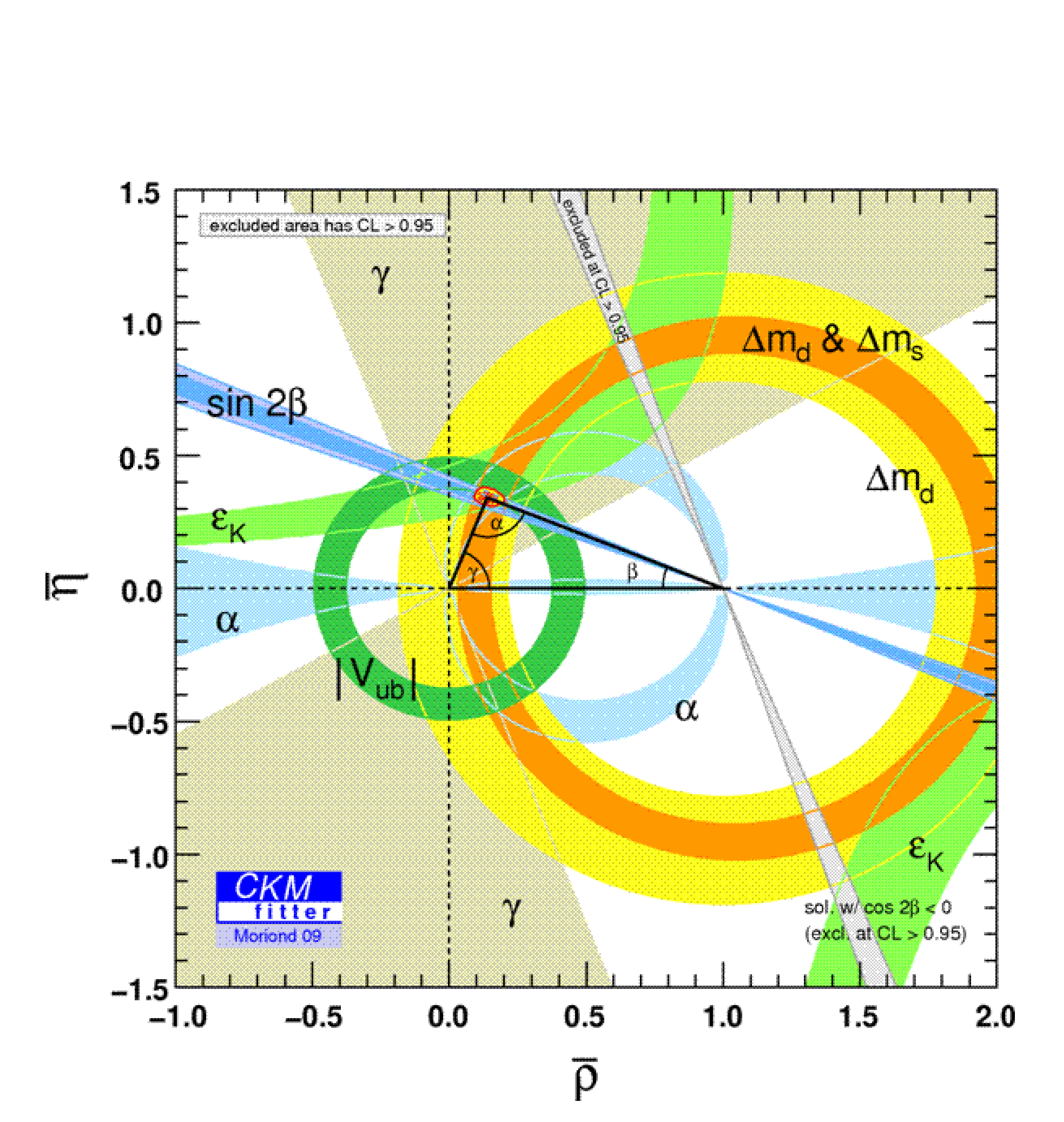


CKM Fitter results as of Moriond 2009

Adding in the *CP* asymmetry measurements from *BABAR* and Belle,



we now have a set of highly overconstrained tests, which *grosso modo*, are well-satisfied



Are we there yet?

Can we learn more ?

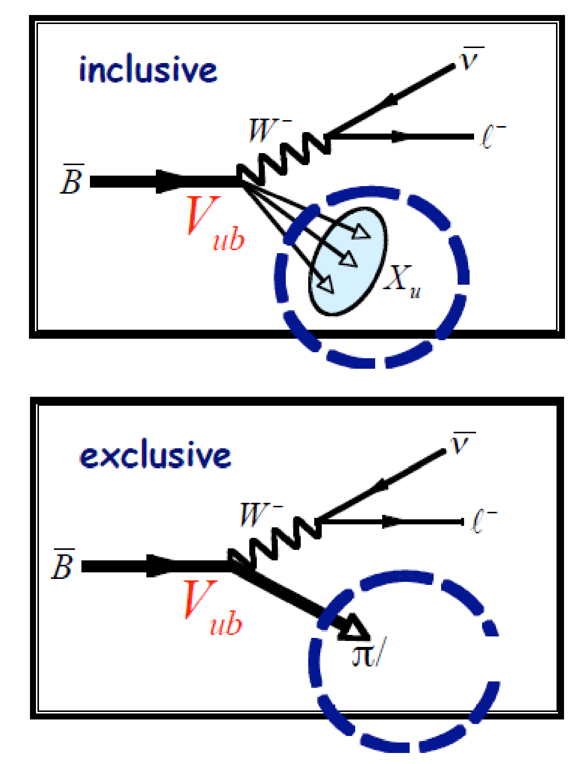
- Unitarity triangle tests
  - These primarily involve measurements in the B system (both CP-conserving and violating), but require measurements of the Cabibbo angle, ε_K and theoretical inputs
  1. Does the agreement of the overconstrained tests stand up to detailed scrutiny ?
  2. Can the UT tests be improved with better theoretical calculations and/or improved experiments ?
  3. Is there any room for new physics ?

  - There are a few issues
    - Overconstrained tests of three generation unitarity
    - Does the unitarity triangle close ?
    - Are there extra mixing phases ?
    - Are there extra CP-violating phases ?

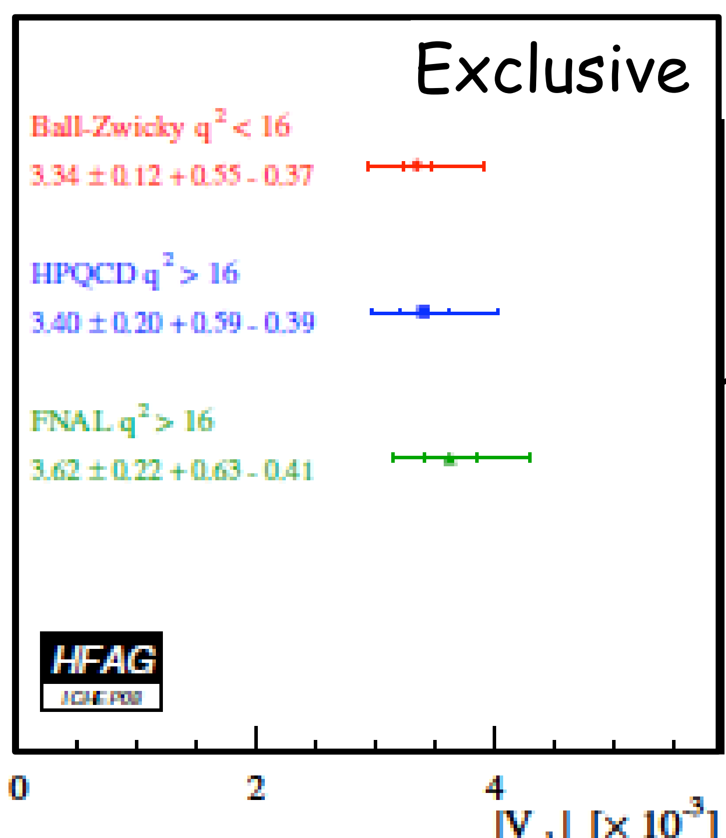
Does the agreement of the overconstrained tests stand up to detailed scrutiny ?

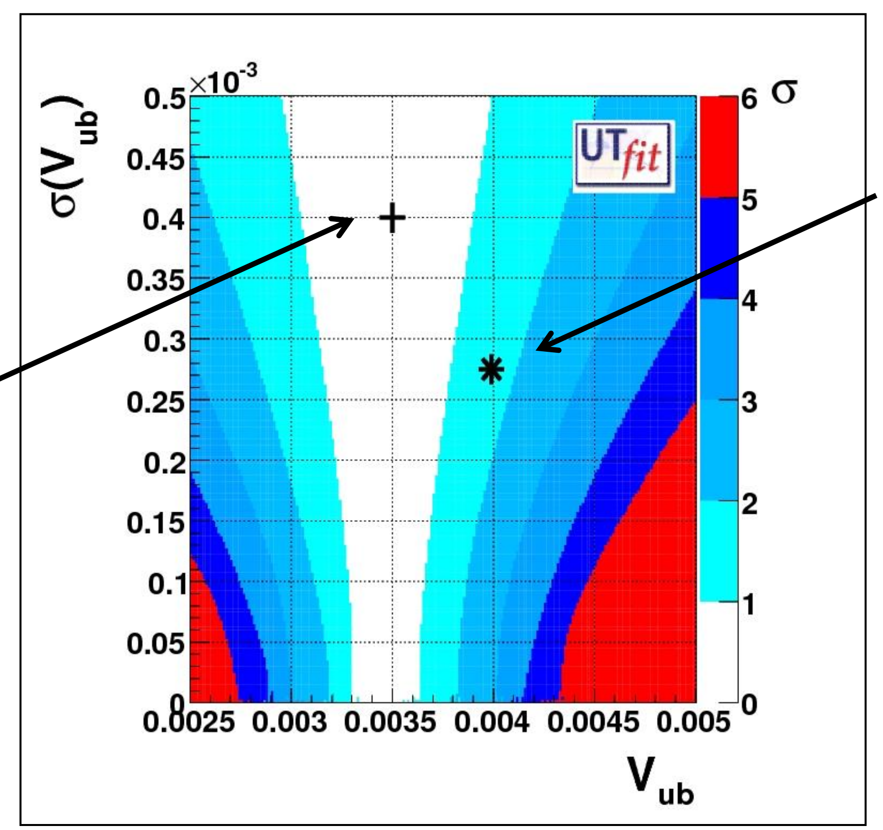
- There is actually some tension, and enough constraints to explore these issues
  - Inclusive and exclusive V_{ub} determinations are not in good agreement
    There are also issues with inclusive/exclusive V_{cb}
  - The $\mathcal{B}(B \to \tau\nu)$ conflict
  - The agreement of the fitted, *i.e.,* SM-predicted value of $\sin 2\beta$ vs the directly measured value using tree decays and loop decays is not perfect
  - The $B_s \to \psi\phi$ phase
  - The $K\pi$ problem

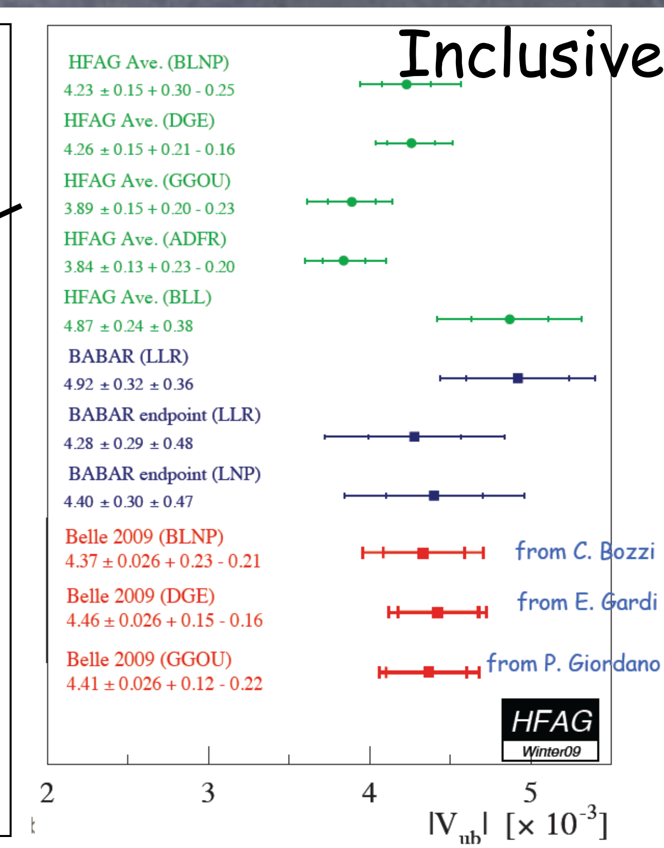
V_{ub} inclusive *vs* exclusive



- Inclusive $B \to X_u l \nu$
  - Separate $ul\nu$ from $cl\nu$ using detailed kinematics
  - Use theory to predict signal spectrum
- Exclusive, mainly $B \to \pi l \nu$
  - Signal/background improved
  - Use theory to predict form factor







V_{cb} inclusive *vs* exclusive

- There is also a 2.5s discrepancy between $|V_{cb}|$ inclusive and exclusive (D*ln) determinations

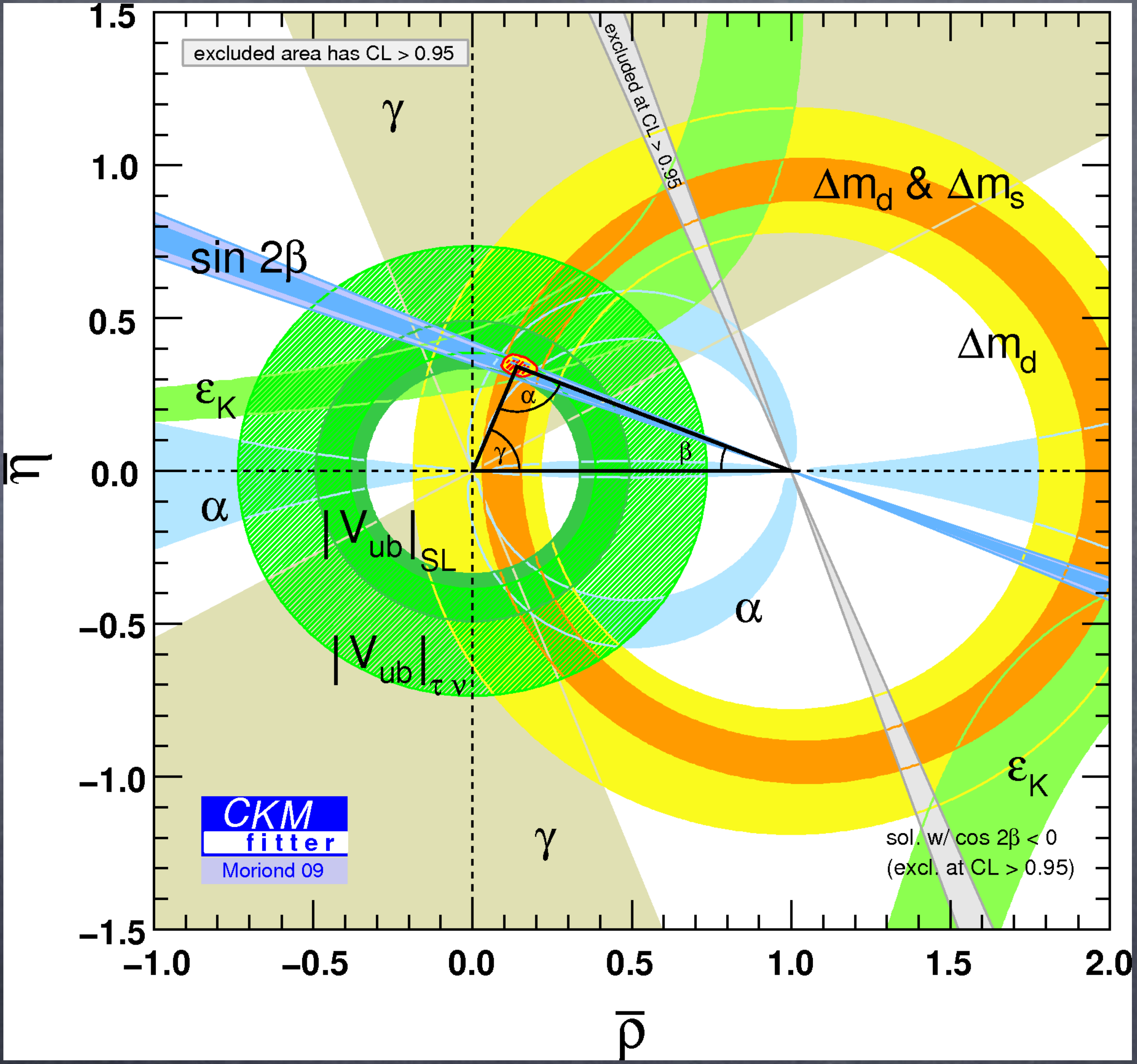
- $|V_{cb}|$ inclusive

	$\lvert V_{cb}\rvert$ (10^{-3})	m_b (GeV)
HFAG ICHEP08	$41.67 \pm 0.43_{fit} \pm 0.08_{\tau B} \pm 0.58_{th}$	4.601 ± 0.034

- $|V_{cb}|$ exclusive (HFAG winter 09)

	$\lvert V_{cb}\rvert$ (10^{-3})
HFAG D*lν / C. Bernard et al.	$38.3 \pm 0.5_{exp} \pm 1.0_{th}$
HFAG Dlν / M. Okamoto et al.	$39.1 \pm 1.4_{exp} \pm 0.9_{th}$

Which green annulus?

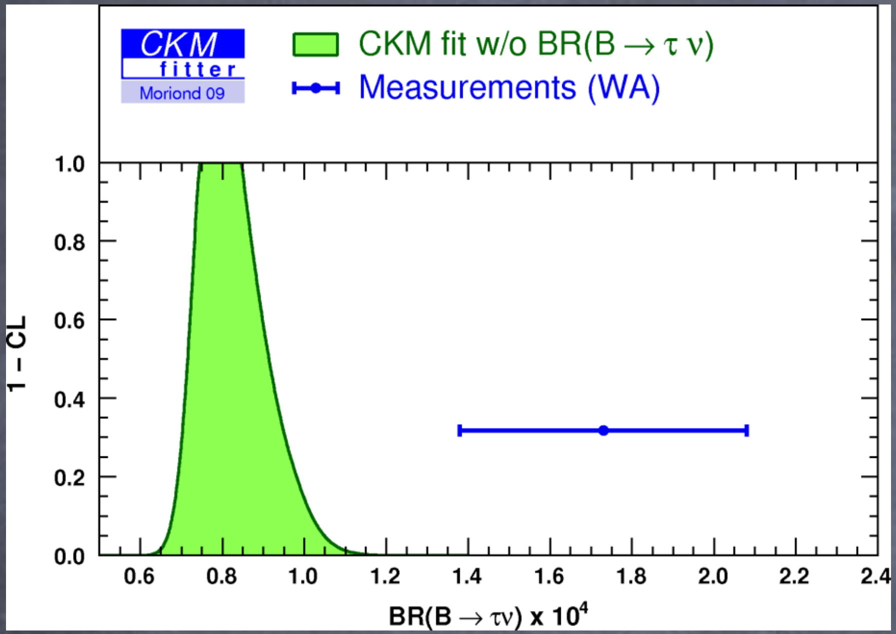


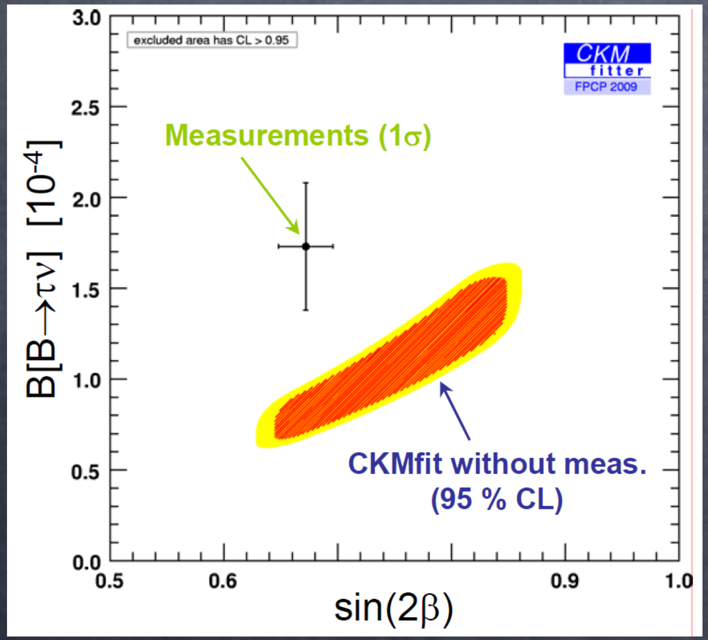
Does the agreement of the overconstrained tests stand up to detailed scrutiny ?

- There is actually some tension, and enough constraints to explore these issues
  - Inclusive and exclusive V_{ub} determinations are not in good agreement
    - There are also issues with inclusive/exclusive V_{cb}
  - The $\mathcal{B}(B\to\tau\nu)$ conflict
  - The agreement of the fitted, *i.e.,* SM-predicted value of $\sin 2\beta$ vs the directly measured value using tree decays and loop decays is not perfect
  - The $B_s \to \psi\phi$ phase
  - The $K\pi$ problem

The $\mathcal{B}(B\to\tau\nu)$ conflict

Effectively a measurement of f_B
Determines same constraint





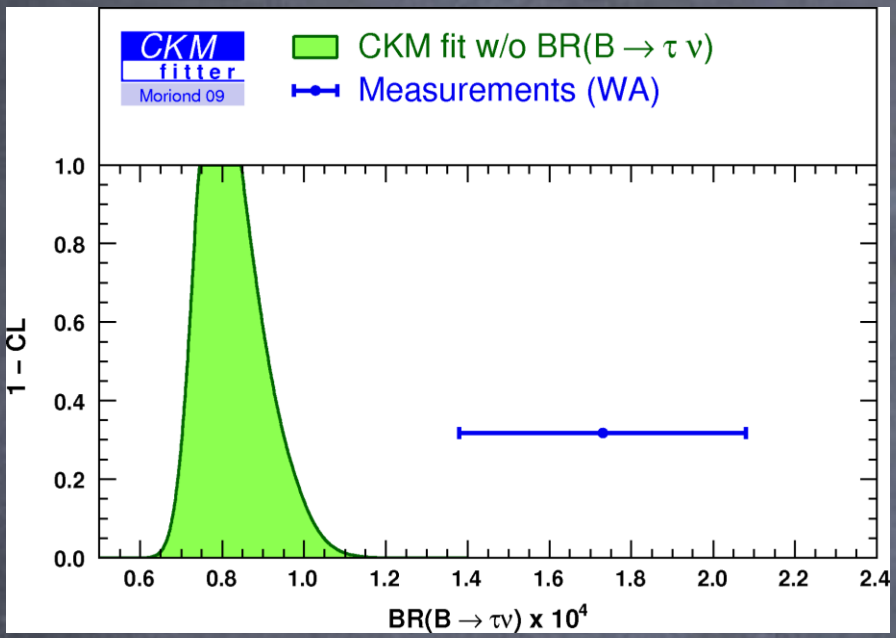
Experimental measurements

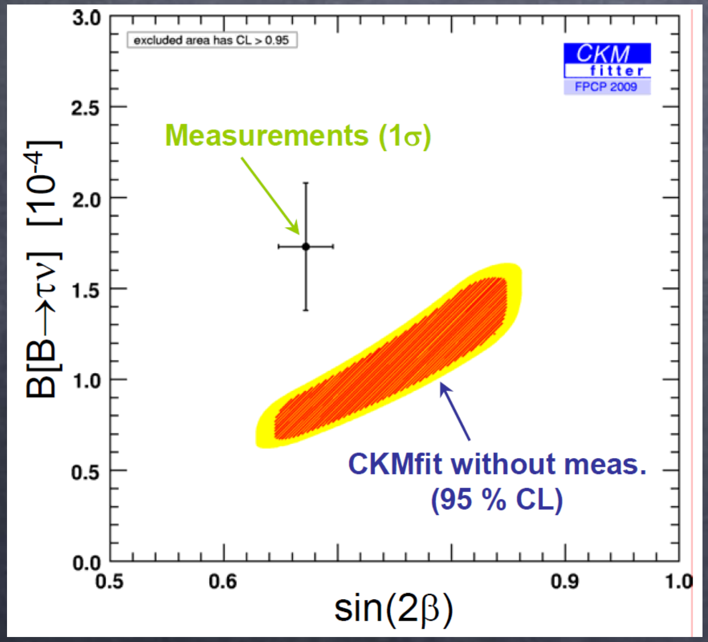
	$B[B\to\tau\nu]\times10^4$
Belle (hadronic)	1.79±0.71 [2006]
Belle (semi-leptonic)	1.65±0.52 [ICHEP08]
Belle	1.70±0.42
BABAR (hadronic)	1.80±1.00 [2007]
BABAR (semi-leptonic)	1.80±0.81 [CKM08]
BABAR	1.80±0.63
World Average	**1.73 ± 0.35**

CKMfit prediction: $(0.796^{+0.154}_{-0.093})\times10^{-4}$ (1σ, without meas.)

The $\mathcal{B}(B\rightarrow\tau\nu)$ conflict

Effectively a measurement of f_B
Determines same constraint



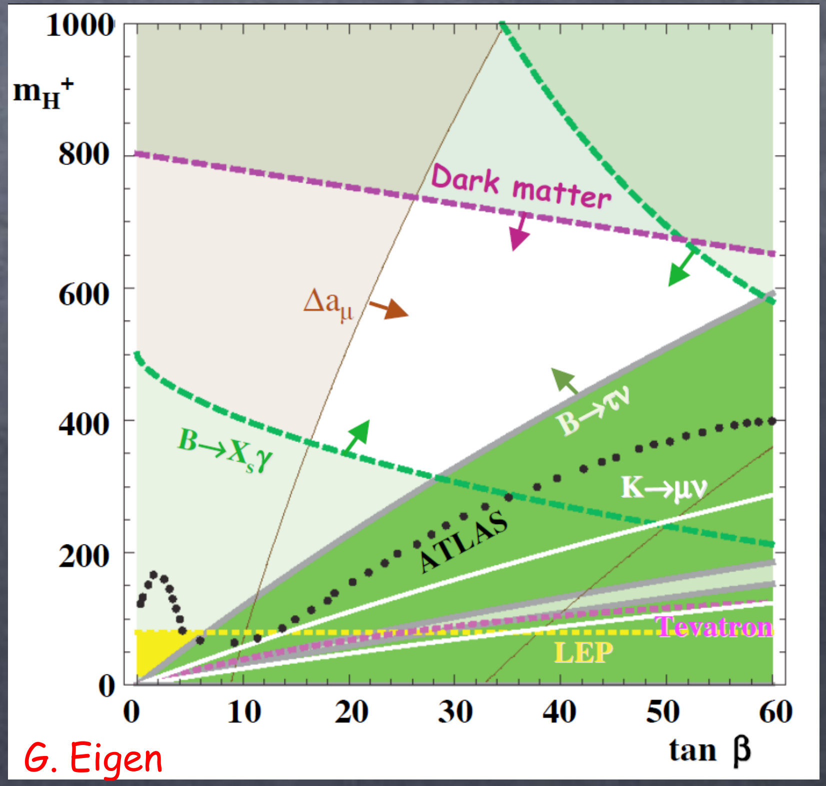


Experimental measurements

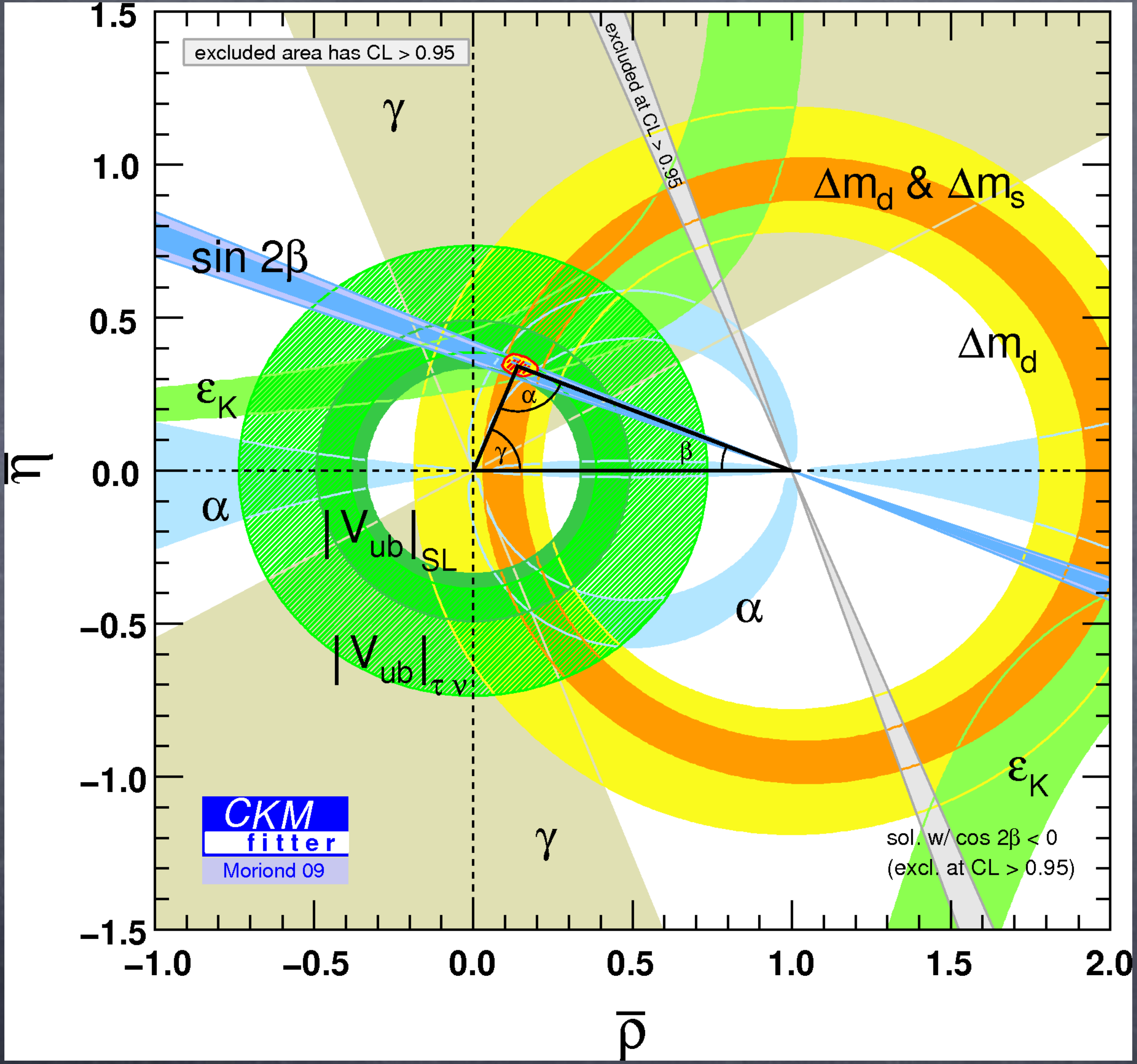
	$B[B\rightarrow\tau\nu]\times10^4$
Belle (hadronic)	1.79±0.71 [2006]
Belle (semi-leptonic)	1.65±0.52 [ICHEP08]
Belle	1.70±0.42
BABAR (hadronic)	1.80±1.00 [2007]
BABAR (semi-leptonic)	1.80±0.81 [CKM08]
BABAR	1.80±0.63
World Average	**1.73 ± 0.35**

CKMfit prediction: $(0.796^{+0.154}_{-0.093})\times10^{-4}$ (1σ, without meas.)

Also constrains Higgs doublet models



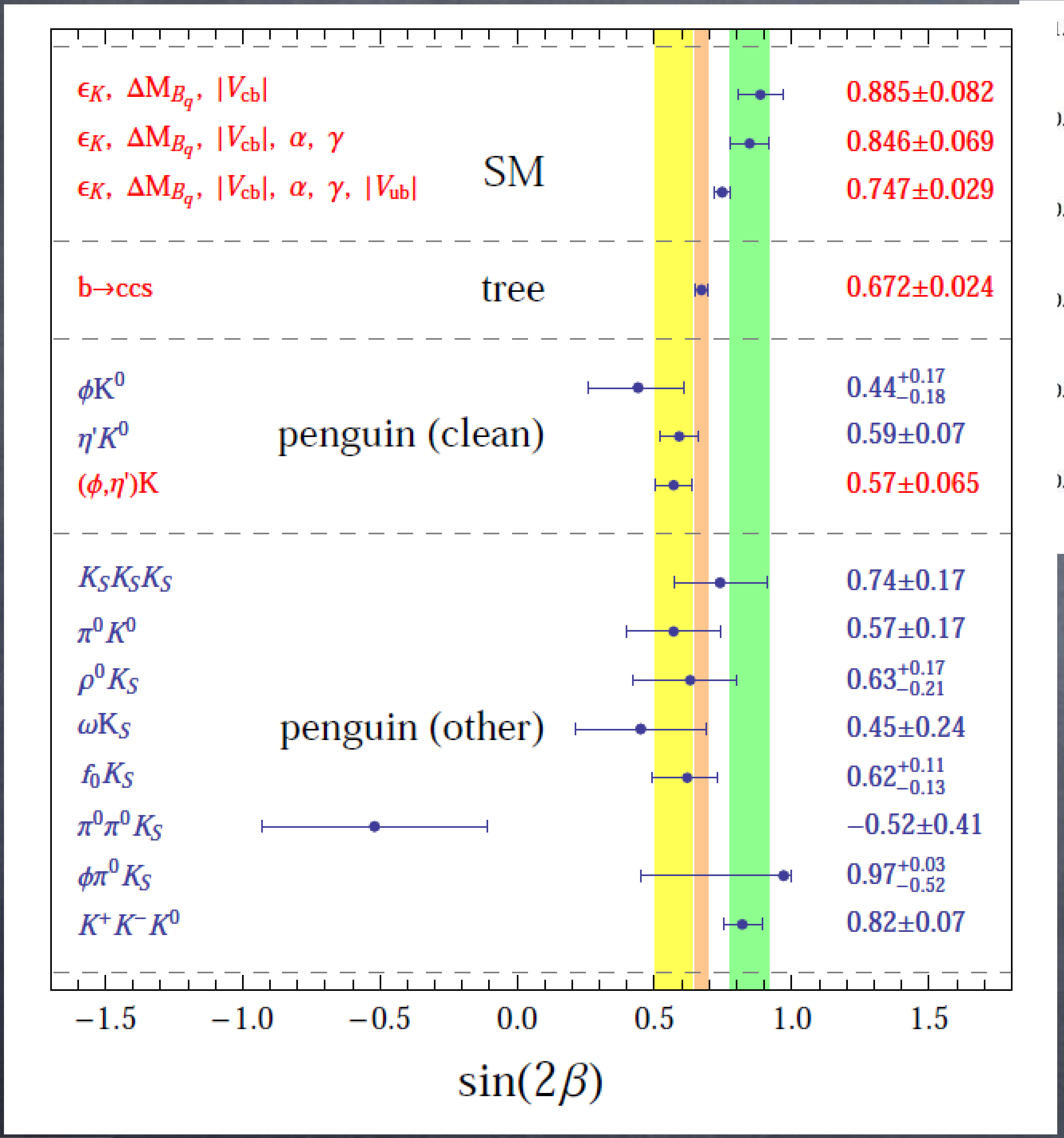
Which green annulus?

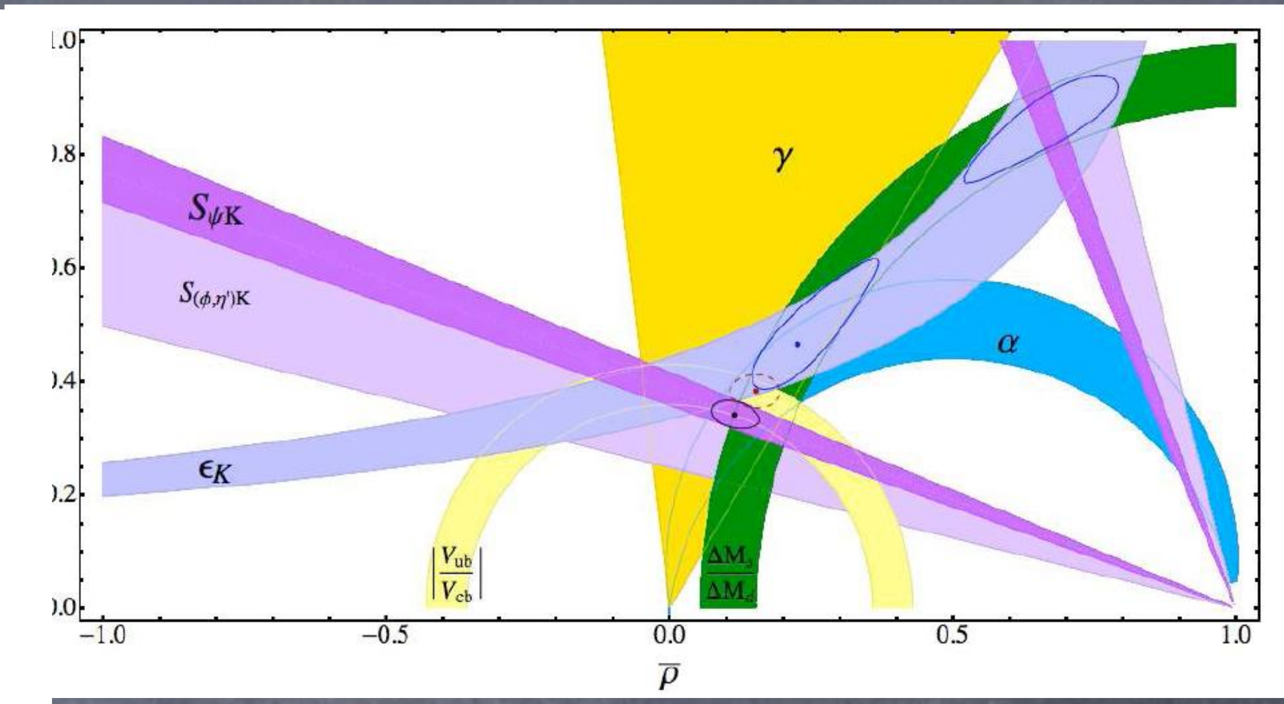


Does the agreement of the overconstrained tests stand up to detailed scrutiny ?

- There is actually some tension, and enough constraints to explore these issues
  - Inclusive and exclusive V_{ub} determinations are not in good agreement
    - There are also issues with inclusive/exclusive V_{cb}
  - The $\mathcal{B}(B \to \tau\nu)$ conflict
  - The agreement of the fitted, *i.e.,* SM-predicted value of $\sin 2\beta$ vs the directly measured value using tree decays and loop decays is not perfect
  - The $B_s \to \psi\phi$ phase
  - The $K\pi$ problem

Lunghi and Soni analysis



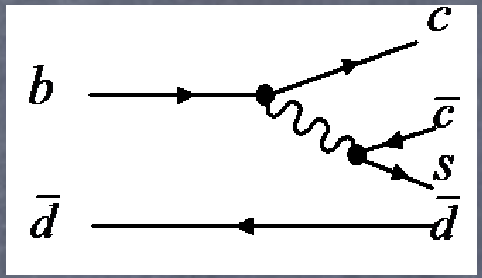


mode	w/out V_{ub}	with V_{ub}
$S_{\psi K_S}$	2.4 σ	2.0 σ
$S_{\phi K_S}$	2.2 σ	1.8 σ
$S_{\eta' K_S}$	2.6 σ	2.1 σ
$S_{(\phi+\eta')K_S}$	2.9 σ	2.5 σ

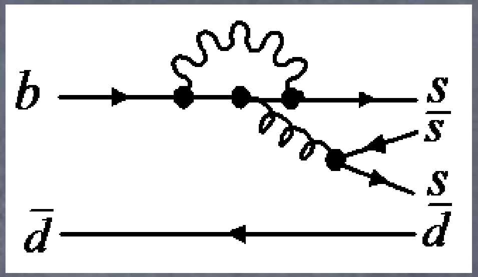
CPV Probes of New Physics

- In the Standard Model we expect the same value for "sin2β" in $b \to c\bar{c}s,\ b \to c\bar{c}d,\ b \to s\bar{s}s,\ b \to d\bar{d}s$ modes, but different SUSY models can produce different asymmetries
- Since the penguin modes have branching fractions one or two orders of magnitude less than tree modes, a great deal of luminosity is required to make these measurements to meaningful precision

$B^0 \to J/\psi K^0_S$

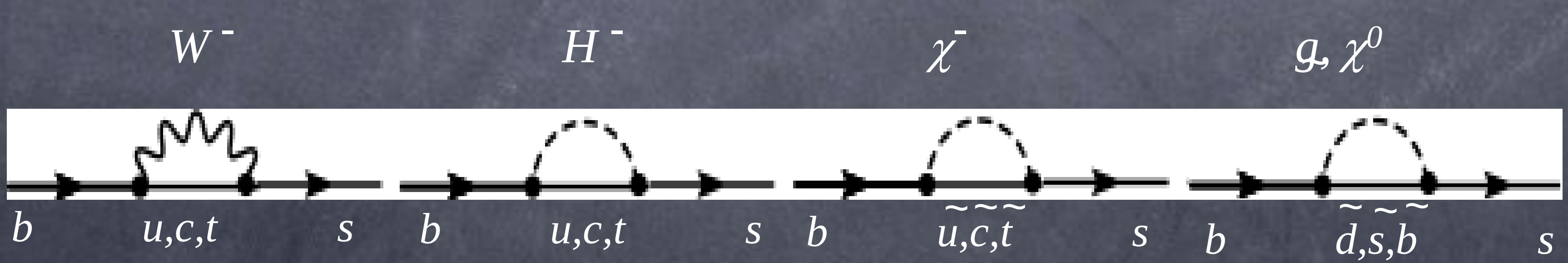


$B^0 \to \phi K^0_S$



$$\lambda_{tree} = \frac{q}{p}\frac{\bar{A}}{A} = \eta \frac{V^*_{tb}V_{td}}{V_{tb}V^*_{td}}\frac{V_{cb}V^*_{cs}}{V^*_{cb}V_{cs}} = (-1)e^{-2i\beta}$$

$$\lambda_{penguin} = \frac{q}{p}\frac{\bar{A}}{A} = \eta \frac{V^*_{tb}V_{td}}{V_{tb}V^*_{td}}\frac{V_{tb}V^*_{ts}}{V^*_{tb}V_{ts}} = (-1)e^{-2i\beta}$$



$$\lambda = e^{i(2\beta+\phi^{\mathrm{SUSY}})}\left|\frac{\bar{A}}{A}\right| \Rightarrow S_{\phi K} = \sin(2\beta + \phi^{\mathrm{SUSY}})$$

Does the agreement of the overconstrained tests stand up to detailed scrutiny ?

- There is actually some tension, and enough constraints to explore these issues
  - Inclusive and exclusive V_{ub} determinations are not in good agreement
    - There are also issues with inclusive/exclusive V_{cb}
  - The $\mathcal{B}(B\to\tau\nu)$ conflict
  - The agreement of the fitted, *i.e.,* SM-predicted value of $\sin 2\beta$ vs the directly measured value using tree decays and loop decays is not perfect
  - The $B_s \to \psi\phi$ phase
  - The $K\pi$ problem

New physics in B_d, B_s mixing ??

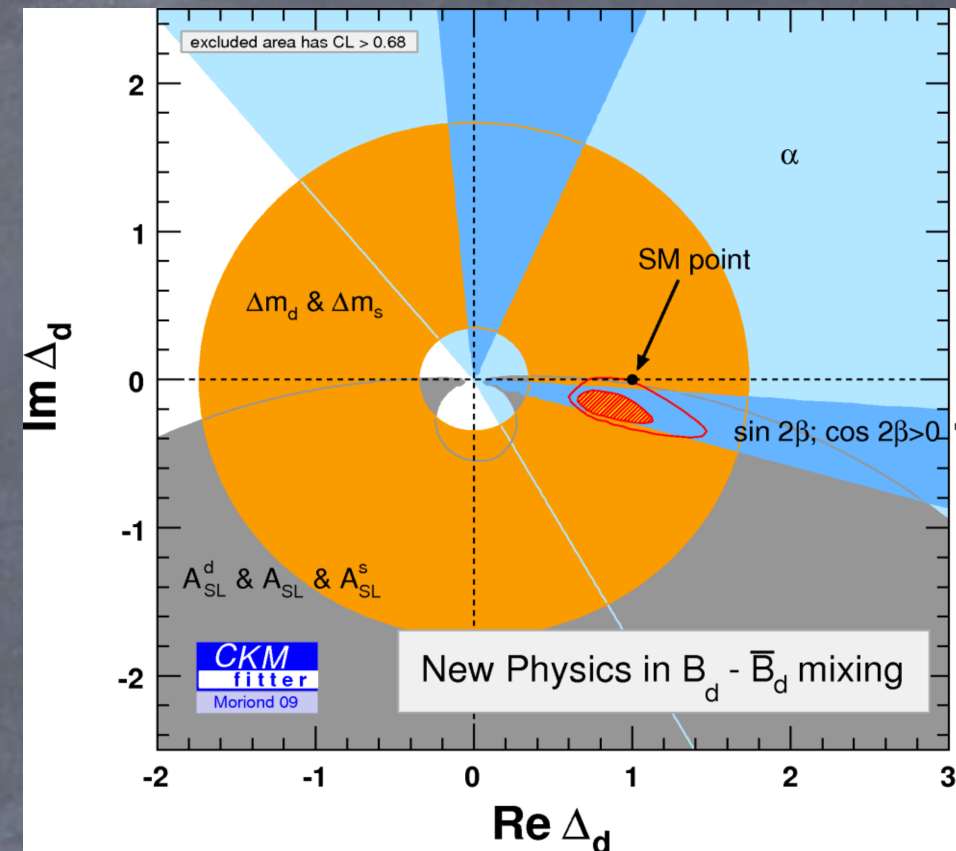
There is still room for sizeable contributions from New Physics

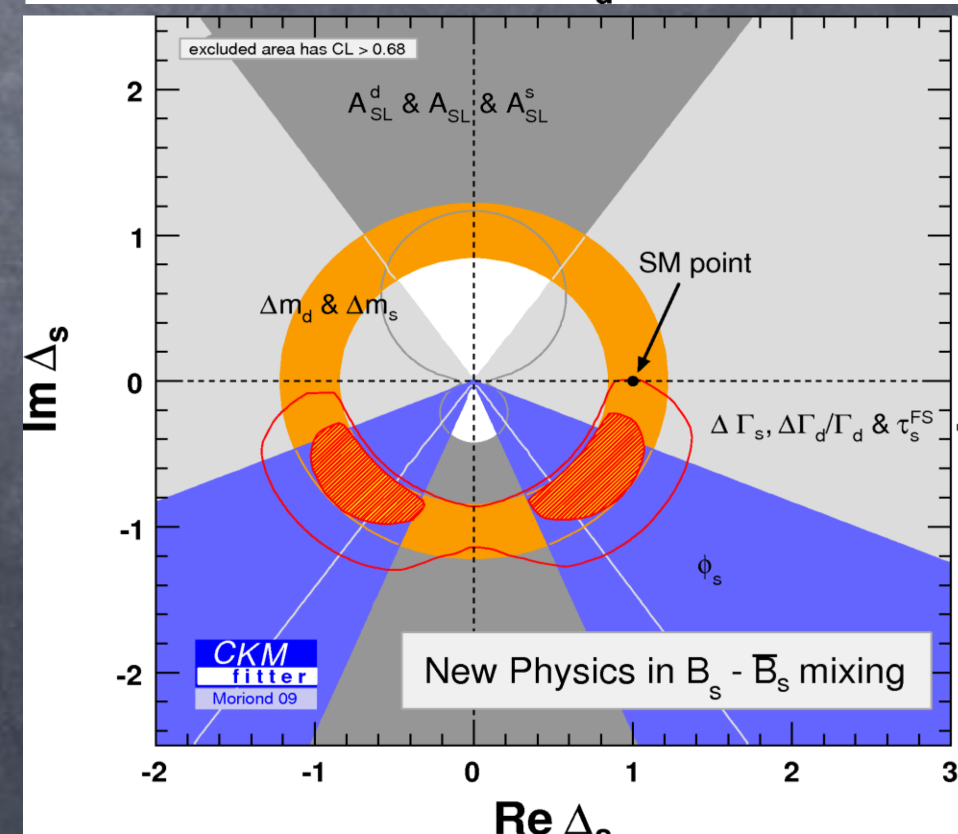
Model-independent parametrization for New Physics in ΔF=2 transitions

$$\langle B_q^0 | M_{12}^{SM+NP} | \bar{B}_q^0 \rangle \equiv \Delta_q^{NP} \cdot \langle B_q^0 | M_{12}^{SM} | \bar{B}_q^0 \rangle$$

$$\Delta_q^{NP} = \mathrm{Re}(\Delta_q) + i\ \mathrm{Im}(\Delta_q) = |\Delta_q| e^{i\varphi^{\Delta_q}} = r_q^2 e^{2i\theta_q} = 1 + h_q e^{2i\sigma_q}$$

The preferred (SM+NP) Δ^{NP} value is currently ~ 2σ from SM for both B_d and B_s systems





To clarify:

1. Tevatron update
2. LHCb $\sin 2\beta_s$ measurement

■ **Dominant constraints** from Tevatron direct measurement of ($\phi_s = -2\beta_s$, $\Delta\Gamma_s$) in $B_s \to J/\psi\ \phi$ and from Δm_s.

ϕ_s D0/CDF (HFAG 08 update, CDF 1.35 fb^{-1} only) is **2.2 σ away from SM** prediction.

Δm_s agrees with SM which constraints $|\Delta_s|$ to ~1.

Does the agreement of the overconstrained tests stand up to detailed scrutiny ?

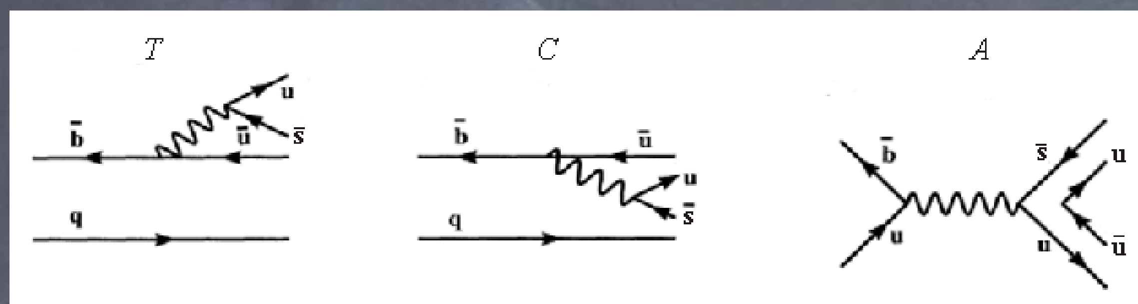
- There is actually some tension, and enough constraints to explore these issues
  - Inclusive and exclusive V_{ub} determinations are not in good agreement
    - There are also issues with inclusive/exclusive V_{cb}
  - The $\mathcal{B}(B\to\tau\nu)$ conflict
  - The agreement of the fitted, *i.e.,* SM-predicted value of $\sin 2\beta$ vs the directly measured value using tree decays and loop decays is not perfect
  - The $B_s \to \psi\phi$ phase
  - The $K\pi$ problem

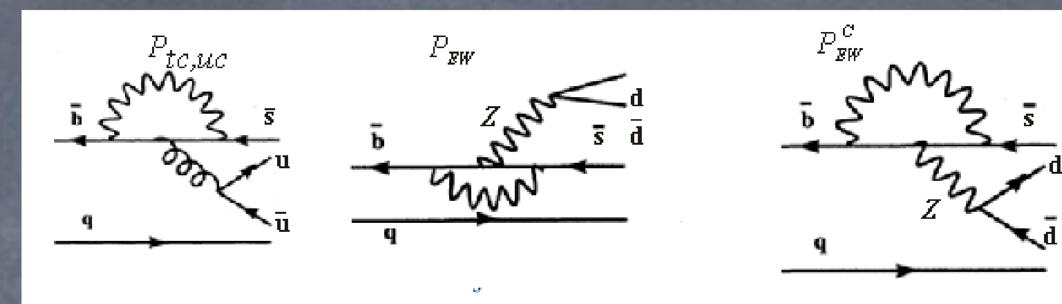
The $K\pi$ problem

- The four $B \to K\pi$ decays provide four branching fraction measurements, four direct CP asymmetries and one mixing-induced CP asymmetry ($B^0 \to K^0\pi^0$)
  - The decay amplitudes are related by isospin

$$A(B^0 \to K^+\pi^-) - \sqrt{2}A(B^+ \to K^+\pi^0) + \sqrt{2}A(B^0 \to K^0\pi^0) - A(B \to K^0\pi^+) = 0$$

  - The amplitudes can be written in terms of tree and penguin Standard Model amplitudes





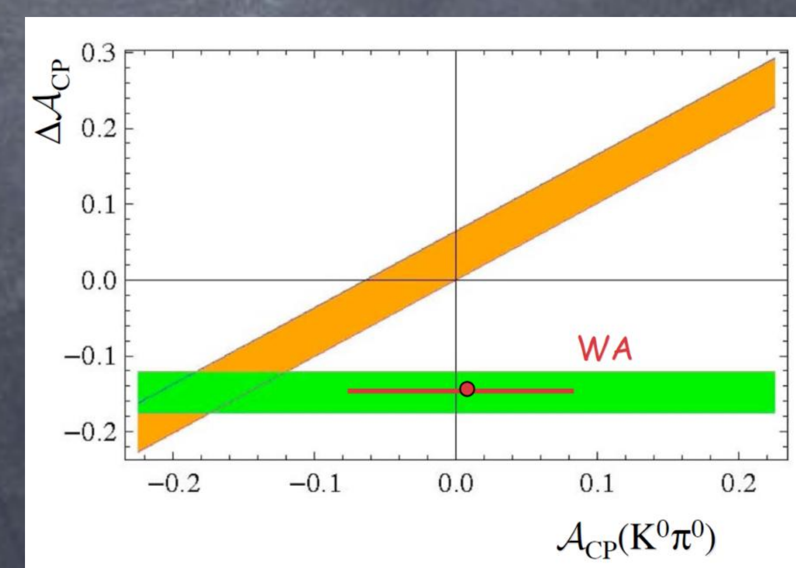
  - A SM sum rule (Gronau-Rosner) relates the asymmetries

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

  - Consistent with the SM at the 20% level
  - New Physics:

$$P_{NP}e^{i\phi_P} \equiv \frac{1}{3}A^{C,u}e^{i\phi_u^C} + \frac{2}{3}A^{C,d}e^{i\phi_d^C}$$

$$P_{EW,NP}^{C}e^{i\phi_{EW}^C} \equiv A^{C,u}e^{i\phi_u^C} - A^{C,d}e^{i\phi C_d^C}$$



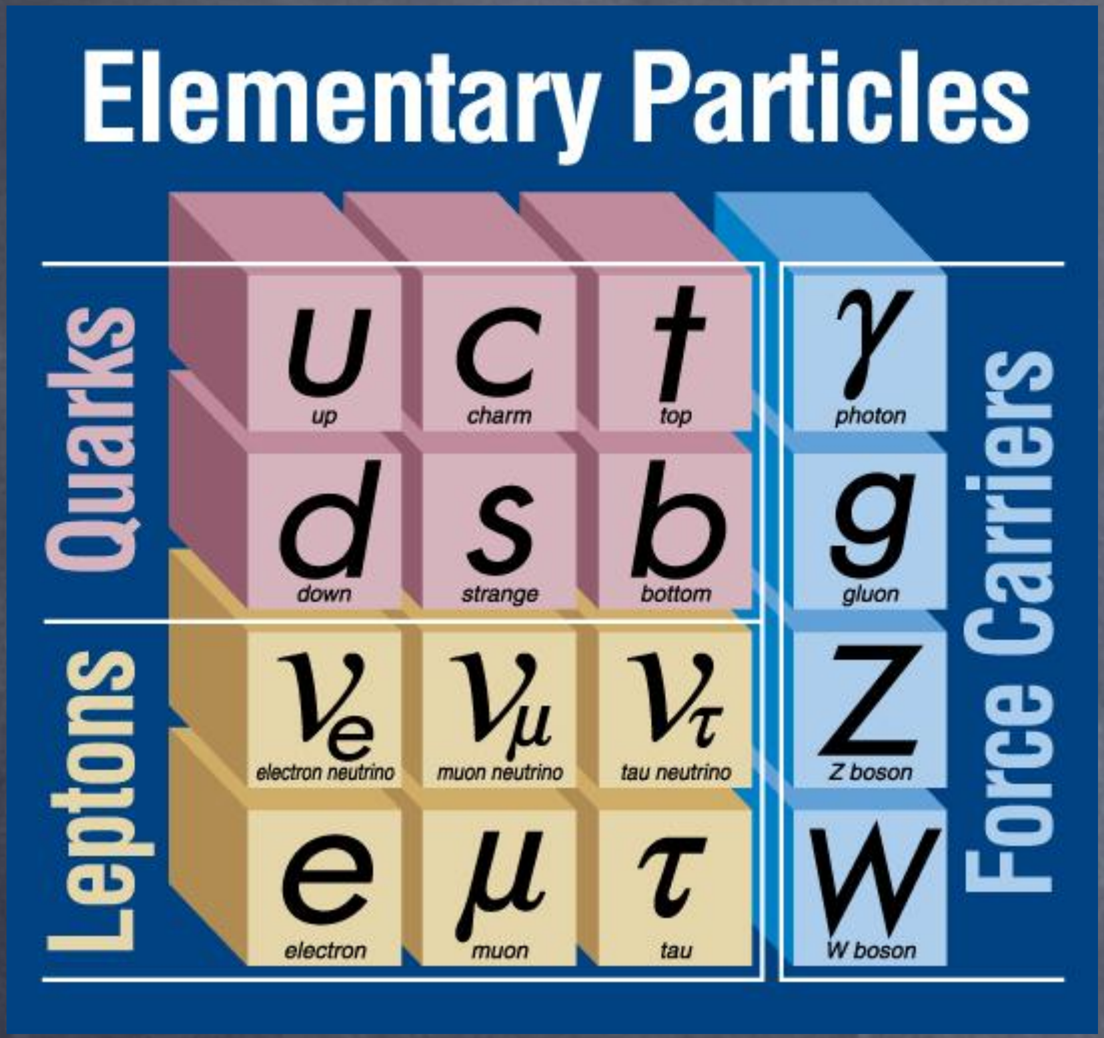
NP in $P_{NP}e^{i\phi p}$ $\Rightarrow A(K^0\pi^0) = -0.15$

NP in $P^C{}_{EW,NP}e^{i\phi EW}$ $\Rightarrow A(K^0\pi^0) = -0.03$

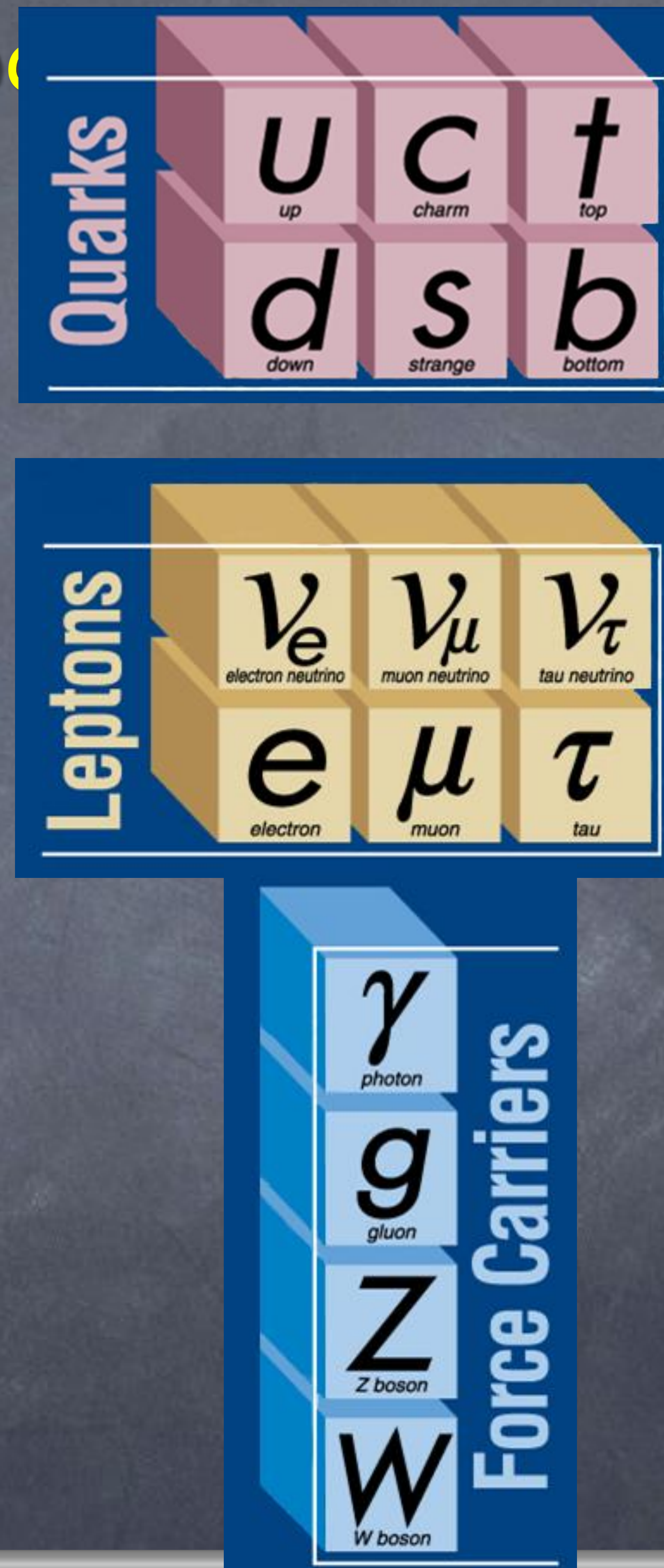
$$\Delta A_{CP} = A(K^+\pi^-) - A(K^+\pi^0)$$

G. Eigen

Is this the Standard Model?



Is this the Standard Mo



Is there a fourth generation?

Is there CP violation in $D^0\bar{D}^0$ mixing?

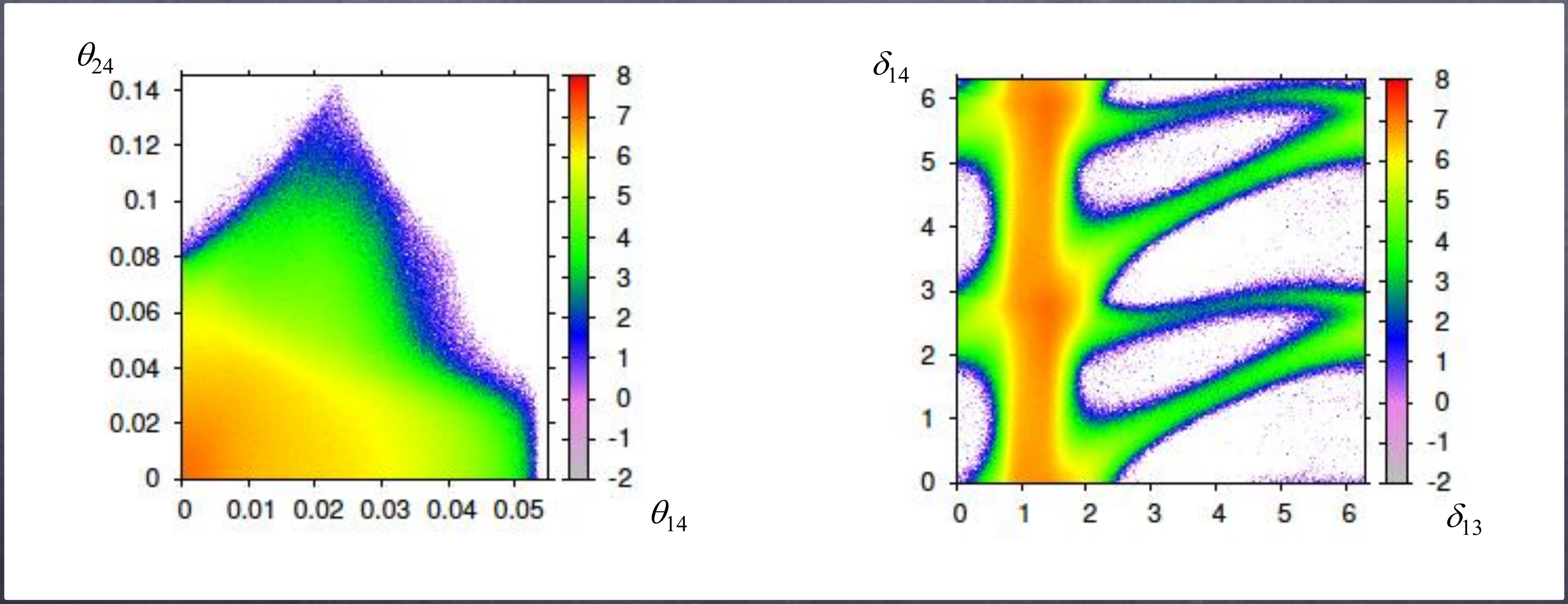
Is there a charged lepton flavor or CP violation?

Is there a Z'?

Is there a fourth quark generation ?

- A fourth generation CKM-like mixing matrix has
  - 2 additional quark masses
  - 3 additional mixing angles
  - 2 additional CP-violating phases
- A recent analysis by Bobrowski, Lenz, Reidl and Rohrwild shows that large regions of the new parameter spaces are still allowed
- Super$B$ will be the primary tool to close down, or, perhaps find, non-zero values of these fourth generation parameters

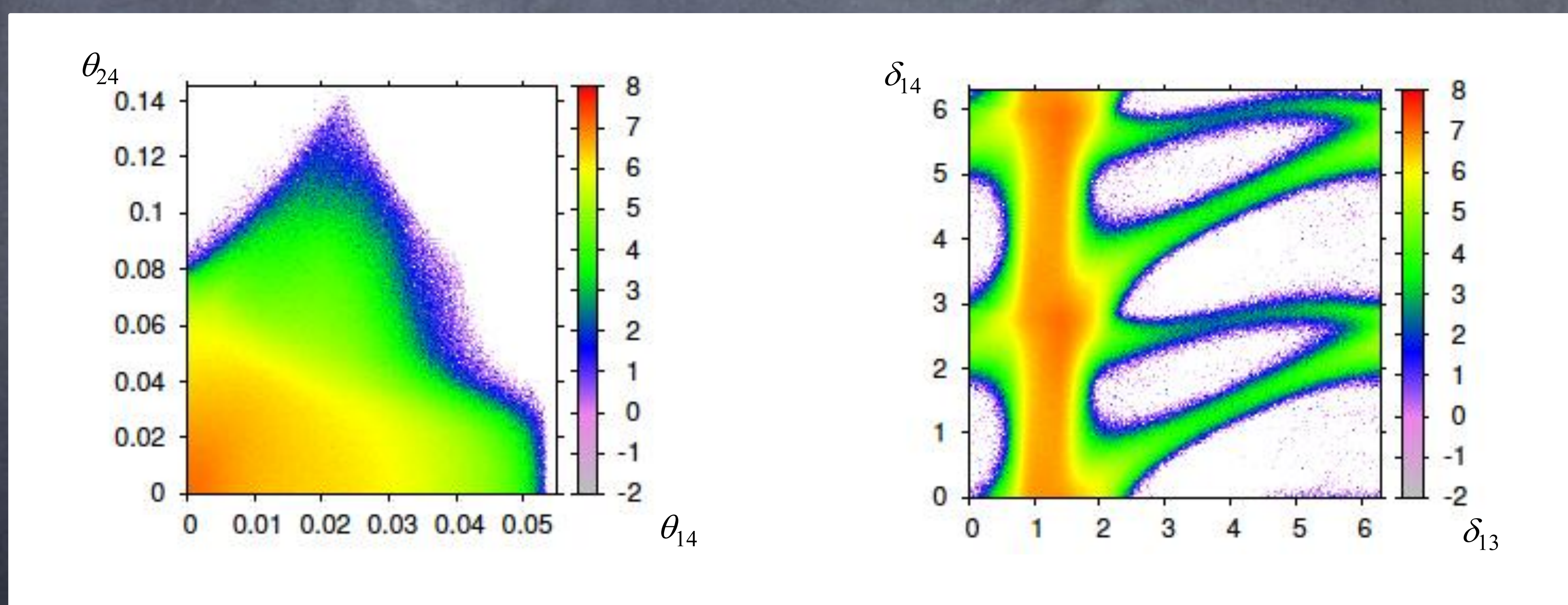
$$V_{CKM}^{(4)} = \begin{pmatrix}
c_{12}c_{13}c_{14} & c_{13}c_{14}s_{12} & c_{14}s_{13}e^{-i\delta_{13}} & s_{14}e^{-i\delta_{14}} \\
\begin{matrix} -c_{23}c_{24}s_{12} - c_{12}c_{24}s_{13}s_{23}e^{i\delta_{13}} \\ -c_{12}c_{13}s_{14}s_{24}e^{i(\delta_{14}-\delta_{24})} \end{matrix} &
\begin{matrix} c_{12}c_{23}c_{24} - c_{24}s_{12}s_{13}s_{23}e^{i\delta_{13}} \\ -c_{13}s_{12}s_{14}s_{24}e^{i(\delta_{14}-\delta_{24})} \end{matrix} &
\begin{matrix} c_{13}c_{24}s_{23} \\ -s_{13}s_{14}s_{24}e^{-i(\delta_{13}+\delta_{24}-\delta_{14})} \end{matrix} &
c_{14}s_{24}e^{-i\delta_{24}} \\
\begin{matrix} -c_{12}c_{23}c_{34}s_{13}e^{i\delta_{13}} + c_{34}s_{12}s_{23} \\ -c_{12}c_{13}c_{24}s_{14}s_{34}e^{i\delta_{14}} \\ +c_{23}s_{12}s_{24}s_{34}e^{i\delta_{24}} \\ +c_{12}s_{13}s_{23}s_{24}s_{34}e^{i(\delta_{13}+\delta_{24})} \end{matrix} &
\begin{matrix} -c_{12}c_{34}s_{23} - c_{23}c_{34}s_{12}s_{13}e^{i\delta_{13}} \\ -c_{12}c_{23}s_{24}s_{34}e^{i\delta_{24}} \\ -c_{13}c_{24}s_{12}s_{14}s_{34}e^{i\delta_{14}} \\ +s_{12}s_{13}s_{23}s_{24}s_{34}e^{i(\delta_{13}+\delta_{24})} \end{matrix} &
\begin{matrix} c_{13}c_{23}c_{34} \\ -c_{13}s_{23}s_{24}s_{34}e^{i\delta_{24}} \\ -c_{24}s_{13}s_{14}s_{34}e^{i(\delta_{14}-\delta_{13})} \end{matrix} &
c_{14}c_{24}s_{34} \\
\begin{matrix} -c_{12}c_{13}c_{24}c_{34}s_{14}e^{i\delta_{14}} \\ +c_{12}c_{23}s_{13}s_{34}e^{i\delta_{13}} \\ +c_{23}c_{34}s_{12}s_{24}e^{i\delta_{24}} - s_{12}s_{23}s_{34} \\ +c_{12}c_{34}s_{13}s_{23}s_{24}e^{i(\delta_{13}+\delta_{24})} \end{matrix} &
\begin{matrix} -c_{12}c_{23}c_{34}s_{24}e^{i\delta_{24}} + c_{12}s_{23}s_{34} \\ -c_{13}c_{24}c_{34}s_{12}s_{14}e^{i\delta_{14}} \\ +c_{23}s_{12}s_{13}s_{34}e^{i\delta_{13}} \\ +c_{34}s_{12}s_{13}s_{23}s_{24}e^{i(\delta_{13}+\delta_{24})} \end{matrix} &
\begin{matrix} -c_{13}c_{23}s_{34} \\ -c_{13}c_{34}s_{23}s_{24}e^{i\delta_{24}} \\ -c_{24}c_{34}s_{13}s_{14}e^{i(\delta_{14}-\delta_{13})} \end{matrix} &
c_{14}c_{24}c_{34}
\end{pmatrix}$$



Is there a fourth quark generation ?

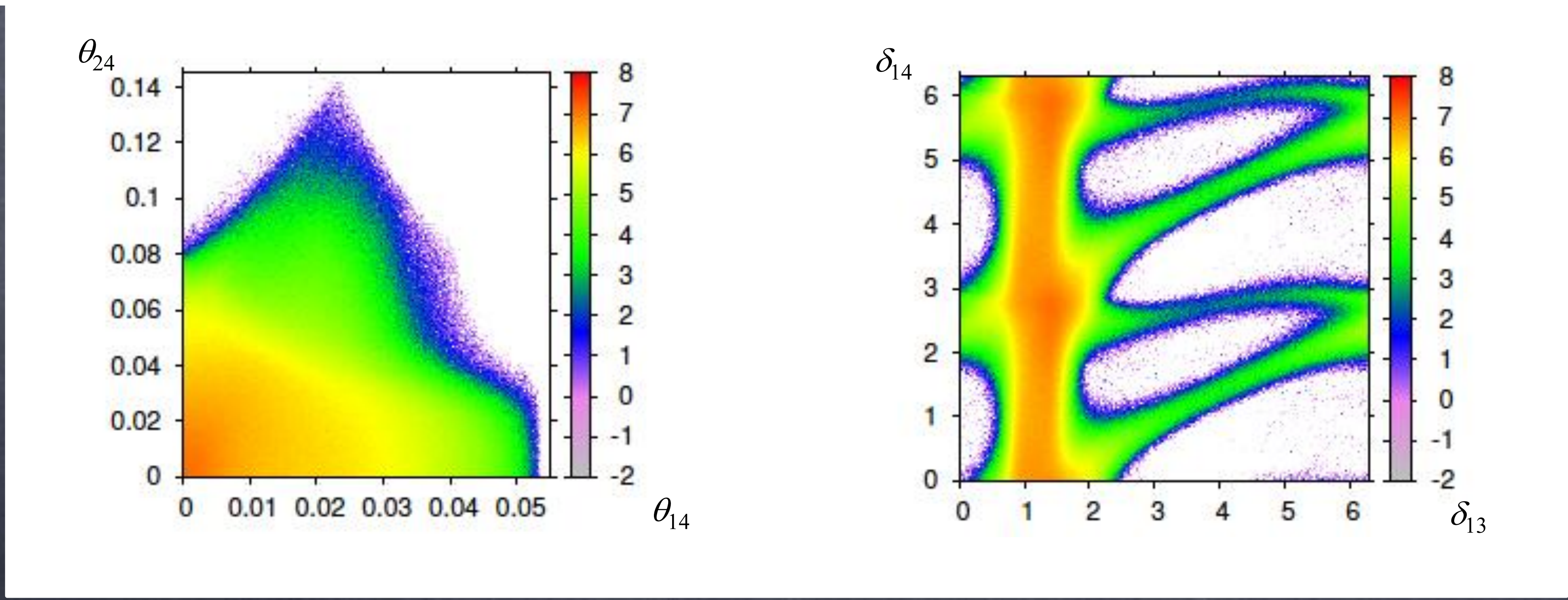
- A fourth generation CKM-like mixing matrix has
  - 2 additional quark masses
  - 3 additional mixing angles
  - 2 additional CP-violating phases
- A recent analysis by Bobrowski, Lenz, Reidl and Rohrwild shows that large regions of the new parameter spaces are still allowed
- Super$B$ will be the primary tool to close down, or, perhaps find, non-zero values of these fourth generation parameters

$$V_{CKM}^{(4)} = \begin{pmatrix} c_{12}c_{13}c_{14} & c_{13}c_{14}s_{12} & c_{14}s_{13}e^{-\imath\delta_{13}} & s_{14}e^{-\imath\delta_{14}} \\ \begin{array}{c} -c_{23}c_{24}s_{12} - c_{12}c_{24}s_{13}s_{23}e^{\imath\delta_{13}} \\ -c_{12}c_{13}s_{14}s_{24}e^{\imath(\delta_{14}-\delta_{24})} \end{array} & \begin{array}{c} c_{12}c_{23}c_{24} - c_{24}s_{12}s_{13}s_{23}e^{\imath\delta_{13}} \\ -c_{13}s_{12}s_{14}s_{24}e^{\imath(\delta_{14}-\delta_{24})} \end{array} & \begin{array}{c} c_{13}c_{24}s_{23} \\ -s_{13}s_{14}s_{24}e^{-\imath(\delta_{13}+\delta_{24}-\delta_{14})} \end{array} & c_{14}s_{24}e^{-\imath\delta_{24}} \\ \begin{array}{c} -c_{12}c_{23}c_{34}s_{13}e^{\imath\delta_{13}} + c_{34}s_{12}s_{23} \\ -c_{12}c_{13}c_{24}s_{14}s_{34}e^{\imath\delta_{14}} \\ +c_{23}s_{12}s_{24}s_{34}e^{\imath\delta_{24}} \\ +c_{12}s_{13}s_{23}s_{24}s_{34}e^{\imath(\delta_{13}+\delta_{24})} \end{array} & \begin{array}{c} -c_{12}c_{34}s_{23} - c_{23}c_{34}s_{12}s_{13}e^{\imath\delta_{13}} \\ -c_{12}c_{23}s_{24}s_{34}e^{\imath\delta_{24}} \\ -c_{13}c_{24}s_{12}s_{14}s_{34}e^{\imath\delta_{14}} \\ +s_{12}s_{13}s_{23}s_{24}s_{34}e^{\imath(\delta_{13}+\delta_{24})} \end{array} & \begin{array}{c} c_{13}c_{23}c_{34} \\ -c_{13}s_{23}s_{24}s_{34}e^{\imath\delta_{24}} \\ -c_{24}s_{13}s_{14}s_{34}e^{\imath(\delta_{14}-\delta_{13})} \end{array} & c_{14}c_{24}s_{34} \\ \begin{array}{c} -c_{12}c_{13}c_{24}c_{34}s_{14}e^{\imath\delta_{14}} \\ +c_{12}c_{23}s_{13}s_{34}e^{\imath\delta_{13}} \\ +c_{23}c_{34}s_{12}s_{24}e^{\imath\delta_{24}} - s_{12}s_{23}s_{34} \\ +c_{12}c_{34}s_{13}s_{23}s_{24}e^{\imath(\delta_{13}+\delta_{24})} \end{array} & \begin{array}{c} -c_{12}c_{23}c_{34}s_{24}e^{\imath\delta_{24}} + c_{12}s_{23}s_{34} \\ -c_{13}c_{24}c_{34}s_{12}s_{14}e^{\imath\delta_{14}} \\ +c_{23}s_{12}s_{13}s_{34}e^{\imath\delta_{13}} \\ +c_{34}s_{12}s_{13}s_{23}s_{24}e^{\imath(\delta_{13}+\delta_{24})} \end{array} & \begin{array}{c} -c_{13}c_{23}s_{34} \\ -c_{13}c_{34}s_{23}s_{24}e^{\imath\delta_{24}} \\ -c_{24}c_{34}s_{13}s_{14}e^{\imath(\delta_{14}-\delta_{13})} \end{array} & c_{14}c_{24}c_{34} \end{pmatrix}$$



Is there a fourth quark generation ?

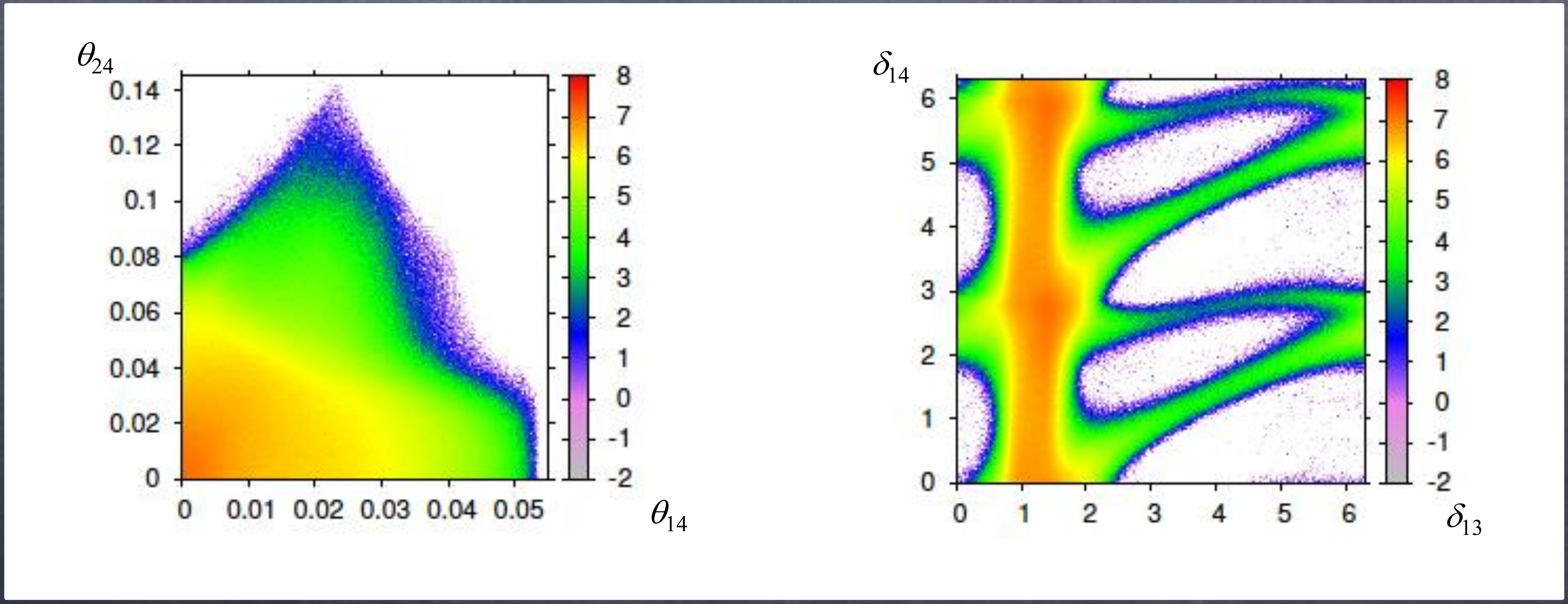
$$V_{CKM}^{(4)} = \begin{pmatrix} c_{12}c_{13}c_{14} & c_{13}c_{14}s_{12} & c_{14}s_{13}e^{-i\delta_{13}} & s_{14}e^{-i\delta_{14}} \\ \begin{array}{c} -c_{23}c_{24}s_{12} - c_{12}c_{24}s_{13}s_{23}e^{i\delta_{13}} \\ -c_{12}c_{13}s_{14}s_{24}e^{i(\delta_{14}-\delta_{24})} \end{array} & \begin{array}{c} c_{12}c_{23}c_{24} - c_{24}s_{12}s_{13}s_{23}e^{i\delta_{13}} \\ -c_{13}s_{12}s_{14}s_{24}e^{i(\delta_{14}-\delta_{24})} \end{array} & \begin{array}{c} c_{13}c_{24}s_{23} \\ -s_{13}s_{14}s_{24}e^{-i(\delta_{13}+\delta_{24}-\delta_{14})} \end{array} & c_{14}s_{24}e^{-i\delta_{24}} \\ \begin{array}{c} -c_{12}c_{23}c_{34}s_{13}e^{i\delta_{13}} + c_{34}s_{12}s_{23} \\ -c_{12}c_{13}c_{24}s_{14}s_{34}e^{i\delta_{14}} \\ +c_{23}s_{12}s_{24}s_{34}e^{i\delta_{24}} \\ +c_{12}s_{13}s_{23}s_{24}s_{34}e^{i(\delta_{13}+\delta_{24})} \end{array} & \begin{array}{c} -c_{12}c_{34}s_{23} - c_{23}c_{34}s_{12}s_{13}e^{i\delta_{13}} \\ -c_{12}c_{23}s_{24}s_{34}e^{i\delta_{24}} \\ -c_{13}c_{24}s_{12}s_{14}s_{34}e^{i\delta_{14}} \\ +s_{12}s_{13}s_{23}s_{24}s_{34}e^{i(\delta_{13}+\delta_{24})} \end{array} & \begin{array}{c} c_{13}c_{23}c_{34} \\ -c_{13}s_{23}s_{24}s_{34}e^{i\delta_{24}} \\ -c_{24}s_{13}s_{14}s_{34}e^{i(\delta_{14}-\delta_{13})} \end{array} & c_{14}c_{24}s_{34} \\ \begin{array}{c} -c_{12}c_{13}c_{24}c_{34}s_{14}e^{i\delta_{14}} \\ +c_{12}c_{23}s_{13}s_{34}e^{i\delta_{13}} \\ +c_{23}c_{34}s_{12}s_{24}e^{i\delta_{24}} - s_{12}s_{23}s_{34} \\ +c_{12}c_{34}s_{13}s_{23}s_{24}e^{i(\delta_{13}+\delta_{24})} \end{array} & \begin{array}{c} -c_{12}c_{23}c_{34}s_{24}e^{i\delta_{24}} + c_{12}s_{23}s_{34} \\ -c_{13}c_{24}c_{34}s_{12}s_{14}e^{i\delta_{14}} \\ +c_{23}s_{12}s_{13}s_{34}e^{i\delta_{13}} \\ +c_{34}s_{12}s_{13}s_{23}s_{24}e^{i(\delta_{13}+\delta_{24})} \end{array} & \begin{array}{c} -c_{13}c_{23}s_{34} \\ -c_{13}c_{34}s_{23}s_{24}e^{i\delta_{24}} \\ -c_{24}c_{34}s_{13}s_{14}e^{i(\delta_{14}-\delta_{13})} \end{array} & c_{14}c_{24}c_{34} \end{pmatrix}$$



Is there a fourth quark generation ?

- A fourth generation CKM-like mixing matrix has
  - 2 additional quark masses
  - 3 additional mixing angles
  - 2 additional CP-violating phases
- A recent analysis by Bobrowski, Lenz, Reidl and Rohrwild shows that large regions of the new parameter spaces are still allowed
- Super$B$ will be the primary tool to close down, or, perhaps find, non-zero values of these fourth generation parameters

$$V_{CKM}^{(4)} = \begin{pmatrix} c_{12}c_{13}c_{14} & c_{13}c_{14}s_{12} & c_{14}s_{13}e^{-i\delta_{13}} & s_{14}e^{-i\delta_{14}} \\ \begin{array}{c} -c_{23}c_{24}s_{12} - c_{12}c_{24}s_{13}s_{23}e^{i\delta_{13}} \\ -c_{12}c_{13}s_{14}s_{24}e^{i(\delta_{14}-\delta_{24})} \end{array} & \begin{array}{c} c_{12}c_{23}c_{24} - c_{24}s_{12}s_{13}s_{23}e^{i\delta_{13}} \\ -c_{13}s_{12}s_{14}s_{24}e^{i(\delta_{14}-\delta_{24})} \end{array} & \begin{array}{c} c_{13}c_{24}s_{23} \\ -s_{13}s_{14}s_{24}e^{-i(\delta_{13}+\delta_{24}-\delta_{14})} \end{array} & c_{14}s_{24}e^{-i\delta_{24}} \\ \begin{array}{c} -c_{12}c_{23}c_{34}s_{13}e^{i\delta_{13}} + c_{34}s_{12}s_{23} \\ -c_{12}c_{13}c_{24}s_{14}s_{34}e^{i\delta_{14}} \\ +c_{23}s_{12}s_{24}s_{34}e^{i\delta_{24}} \\ +c_{12}s_{13}s_{23}s_{24}s_{34}e^{i(\delta_{13}+\delta_{24})} \end{array} & \begin{array}{c} -c_{12}c_{34}s_{23} - c_{23}c_{34}s_{12}s_{13}e^{i\delta_{13}} \\ -c_{12}c_{23}s_{24}s_{34}e^{i\delta_{24}} \\ -c_{13}c_{24}s_{12}s_{14}s_{34}e^{i\delta_{14}} \\ +s_{12}s_{13}s_{23}s_{24}s_{34}e^{i(\delta_{13}+\delta_{24})} \end{array} & \begin{array}{c} c_{13}c_{23}c_{34} \\ -c_{13}s_{23}s_{24}s_{34}e^{i\delta_{24}} \\ -c_{24}s_{13}s_{14}s_{34}e^{i(\delta_{14}-\delta_{13})} \end{array} & c_{14}c_{24}s_{34} \\ \begin{array}{c} -c_{12}c_{13}c_{24}c_{34}s_{14}e^{i\delta_{14}} \\ +c_{12}c_{23}s_{13}s_{34}e^{i\delta_{13}} \\ +c_{23}c_{34}s_{12}s_{24}e^{i\delta_{24}} - s_{12}s_{23}s_{34} \\ +c_{12}c_{34}s_{13}s_{23}s_{24}e^{i(\delta_{13}+\delta_{24})} \end{array} & \begin{array}{c} -c_{12}c_{23}c_{34}s_{24}e^{i\delta_{24}} + c_{12}s_{23}s_{34} \\ -c_{13}c_{24}c_{34}s_{12}s_{14}e^{i\delta_{14}} \\ +c_{23}s_{12}s_{13}s_{34}e^{i\delta_{13}} \\ +c_{34}s_{12}s_{13}s_{23}s_{24}e^{i(\delta_{13}+\delta_{24})} \end{array} & \begin{array}{c} -c_{13}c_{23}s_{34} \\ -c_{13}c_{34}s_{23}s_{24}e^{i\delta_{24}} \\ -c_{24}c_{34}s_{13}s_{14}e^{i(\delta_{14}-\delta_{13})} \end{array} & c_{14}c_{24}c_{34} \end{pmatrix}$$



Tests of the Standard Model Flavor Sector

- Unitarity triangle tests
  - These primarily involve measurements in the B system, but require measurements of the Cabibbo angle, ε_K and theoretical inputs
    - Overconstrained tests of three generation unitarity
    - Does the unitarity triangle close ?
    - Are there extra mixing phases ?
    - Are there extra CP-violating phases ?
- Rare B decays
  - $B \to s\gamma$
  - $B \to \ell\ell$
  - $B \to s\ell\ell$
  - $B \to \tau\nu$
- Rare and polarized τ decays
  - Charged lepton flavor violation
  - CP or T violation in τ production and decay
- $D^0\bar{D}^0$ mixing and CP violation

$D^0\bar{D}^0$ mixing is now well-established

$D^0 \to K^+\pi^-$ decay time analysis	*BABAR:* PRL **98** 211802 (2007)	3.9σ
$D^0 \to K^+K^-, \pi^+\pi^-$ vs $K^+\pi^-$ lifetime difference analysis	Belle: PRL **98** 211803 (2007)	3.2σ
$D^0 \to K_s\pi^+\pi^-$ time dependent amplitude analysis	Belle: PRL **99** 131803 (2007)	2.2σ
$D^0 \to K^+\pi^-$ decay time analysis	*CDF:* PRL **100**, 121802 (2008)	3.8σ
$D^0 \to K^+K^-, \pi^+\pi^-$ vs $K^+\pi^-$ lifetime difference analysis	*BABAR:* PRD **78**, 011105 R (2008)	3.0σ
$D^0 \to K^+\pi^-\pi^0$ time dependent amplitude analysis	*BABAR:* arXiv:0807, 4544 (2008)	3.1σ
$D^0 \to K^+\pi^-$ relative strong phase using quantum-correlated measurements in $e^+e^- \to D^0\bar{D}^0$	CLEO-*c*: PRD 78, 012001, (2008)	
$D^0 \to K^-\pi^+$ *and* K^+K^- lifetime ratios	*BABAR*: EPS	4.1σ

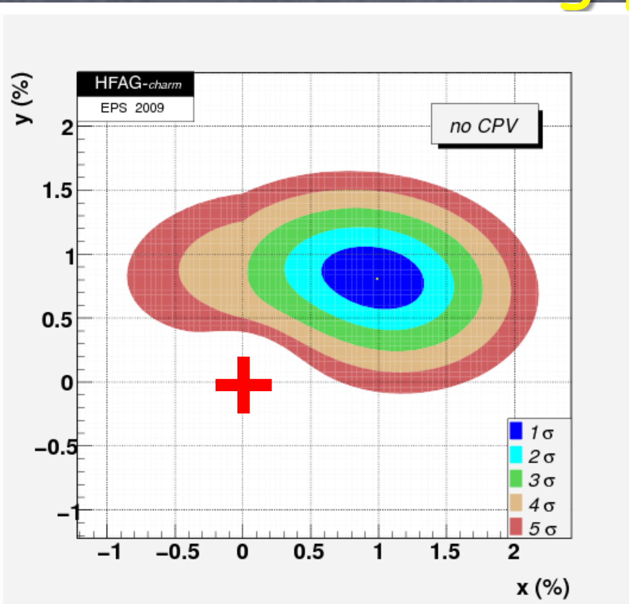
Significance of all mixing results (HFAG Preliminary– EPS2009): 10.2σ

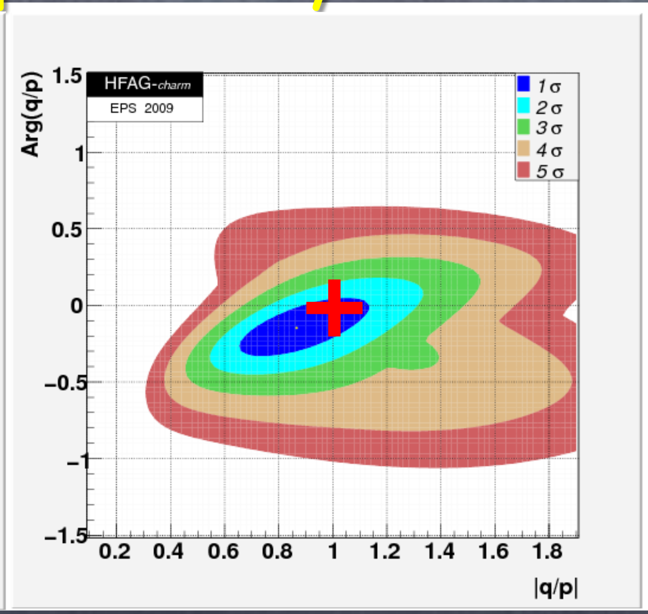
This raises the exciting possibility of searching for *CP* violation

$$x = \frac{\Delta M}{\Gamma},$$

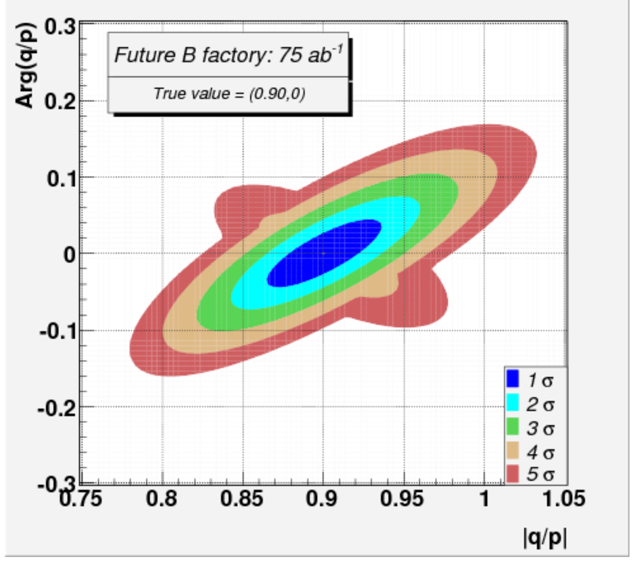
$$y = \frac{\Delta\Gamma}{2\Gamma}$$

$$\Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$$

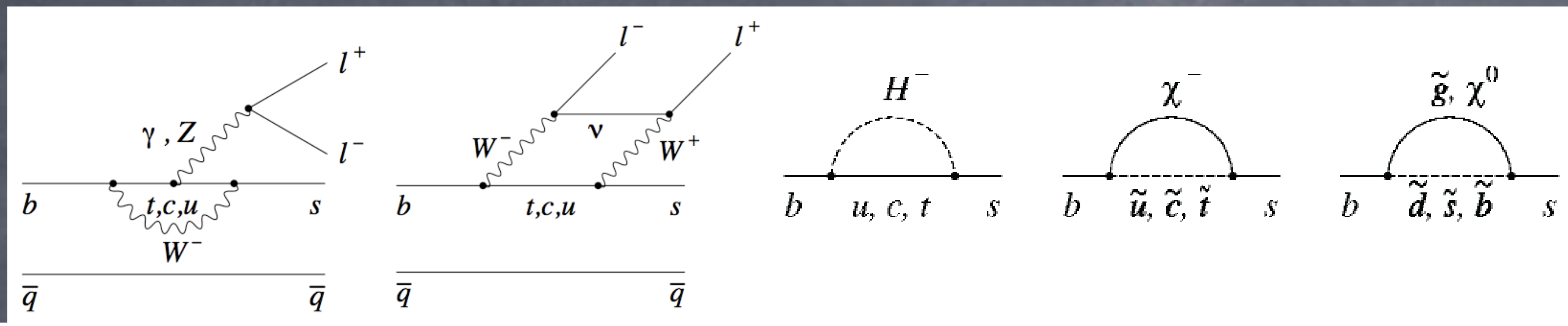


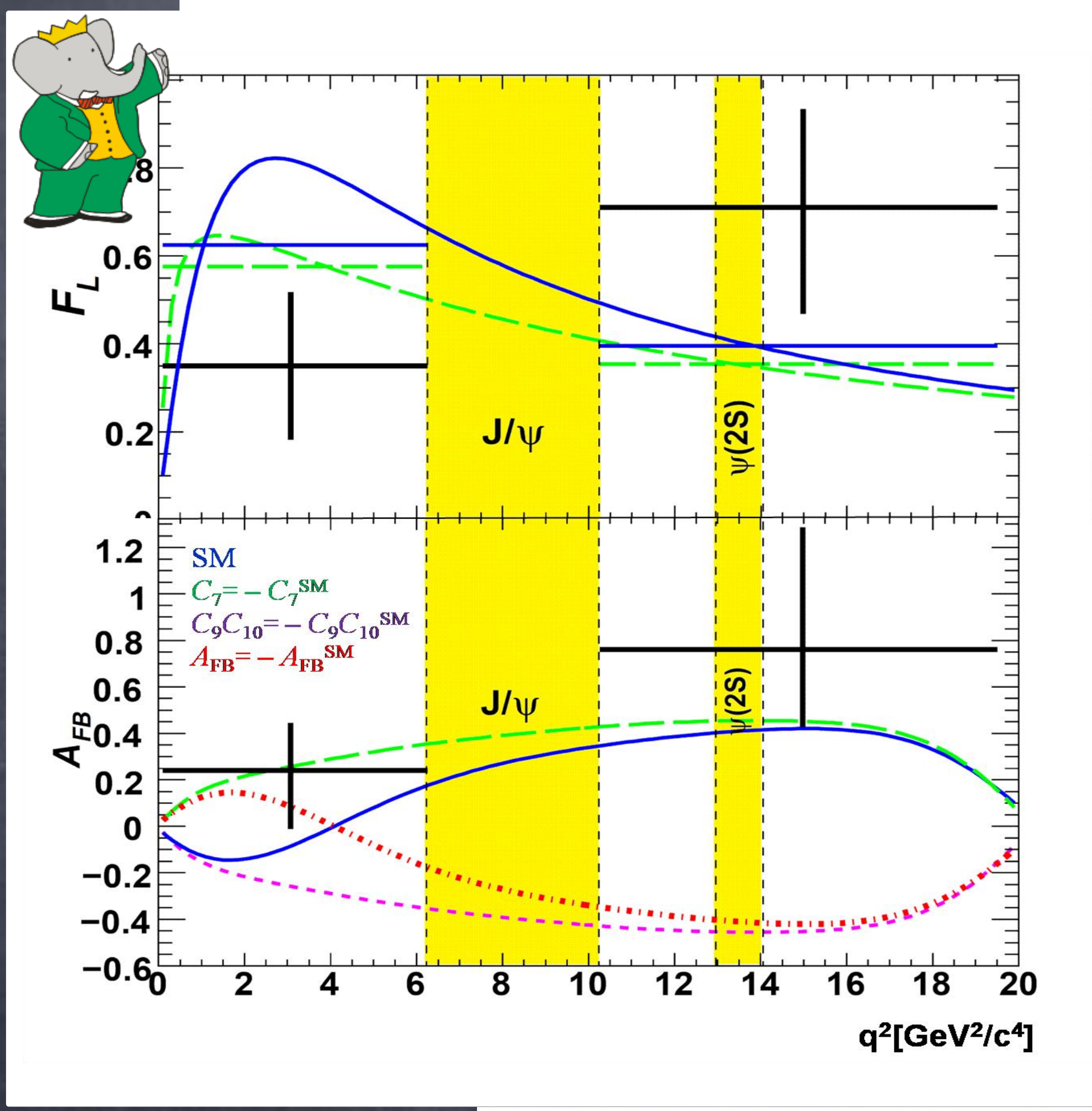


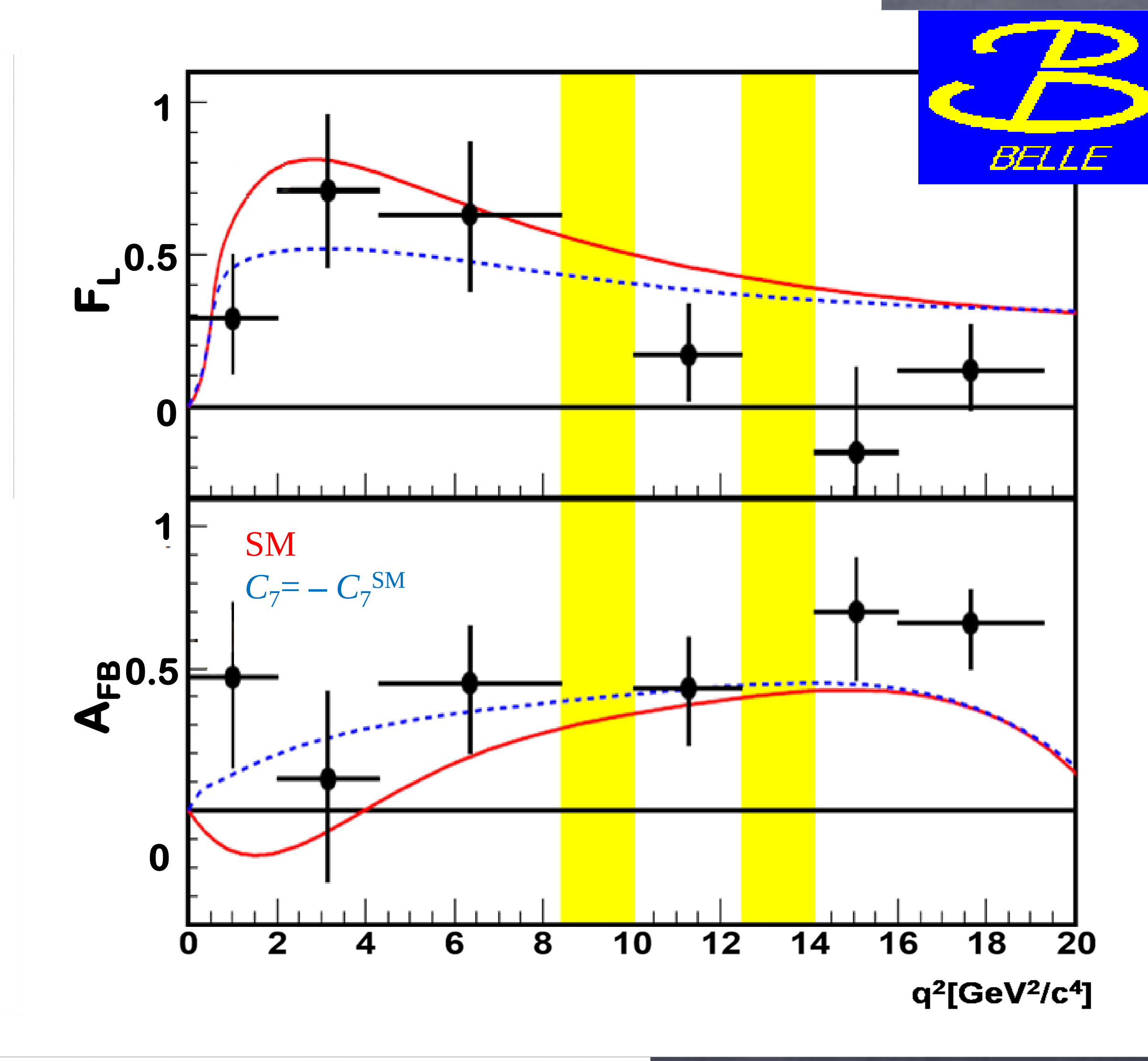
Super*B* @ 75 ab^{-1}



Kinematic distributions in $B \to K^{(*)}\ell^+\ell^-$



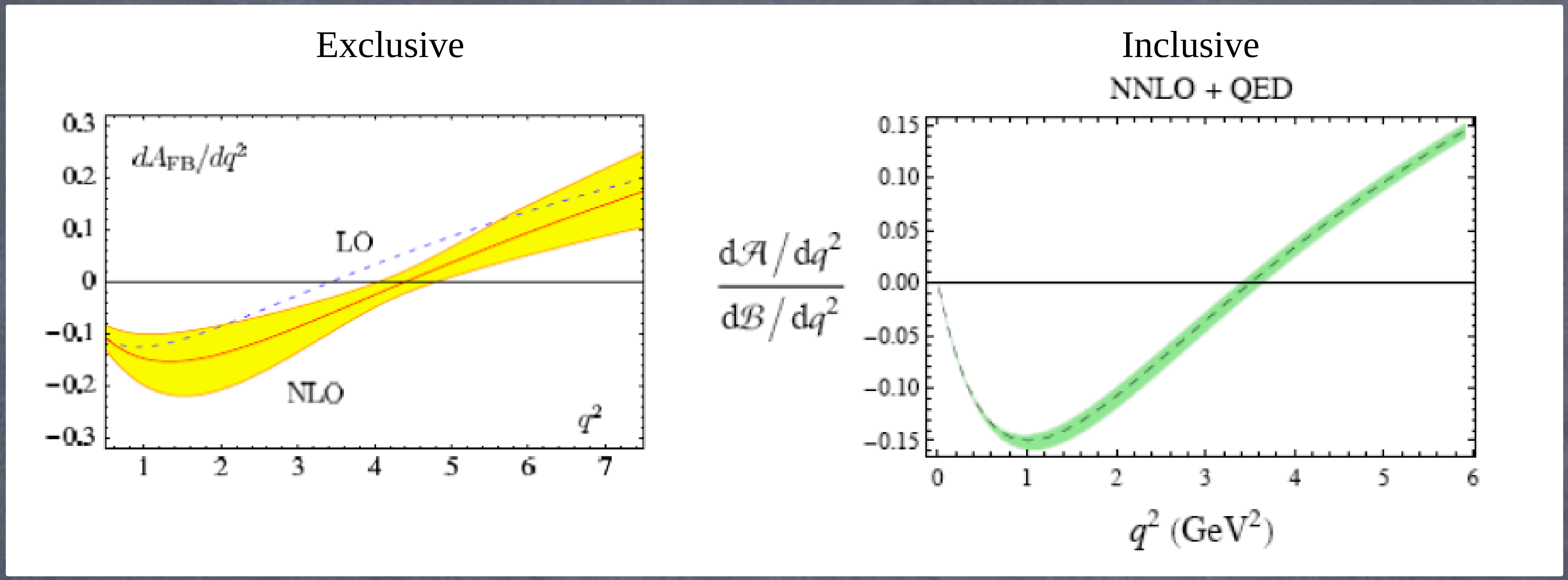




$$A_{\rm FB}(q^2) = -C_{10}^{\rm eff}\xi(q^2)\left[Re(C_9^{\rm eff})F_1 + \frac{1}{q^2}C_7^{\rm eff}F_2\right]$$

Much more data is required for a definitive result

- Can be pursued with exclusive $B \to K^{(*)}\ell^+\ell^-$ or inclusive $B \to x_s\ell^+\ell^-$ reconstruction
- A measure of the relative merits is the precision in determination of the zero



Theory error: 9% + $O(\Lambda/m_b)$ uncertainty
Egede, Hurth, Matias, Ramon, Reece
arxiv:0807.2589

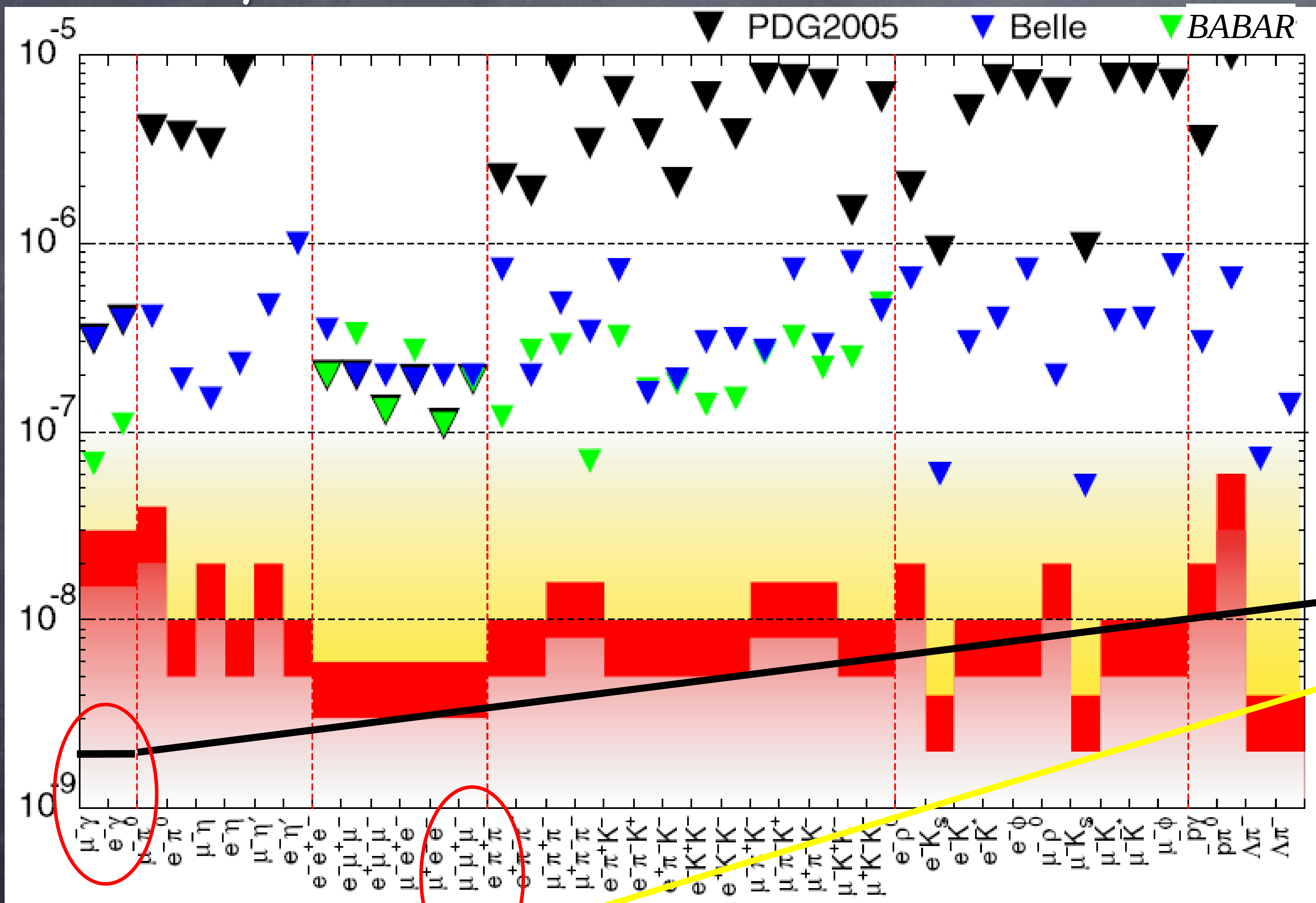
Theory error: ~5%
Huber, Hurth, Lunghi
arxiv:0712.3009

Experimental error (SHLC): 2.1%

Experimental error (Super$B$): 4-6%

Lepton Flavor Violation in τ decays

SuperB sensitivity directly confronts many New Physics models



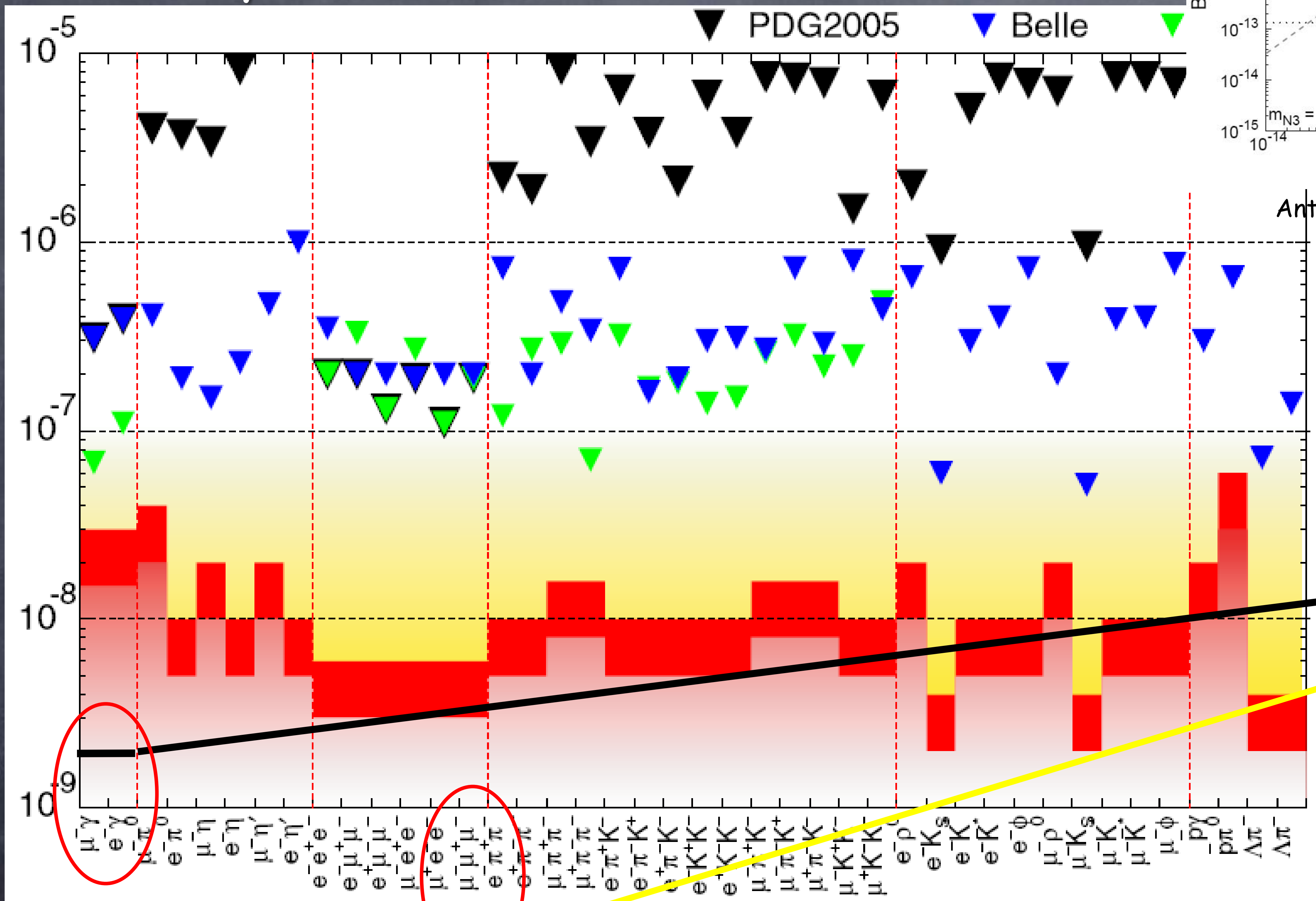
SuperB sensitivity For 75 ab^{-1}

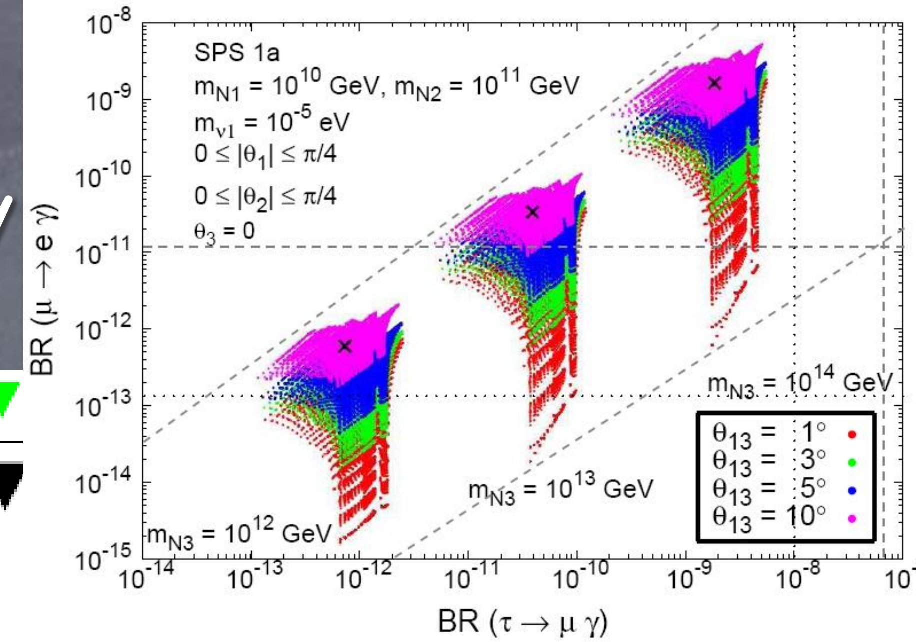
Process	Sensitivity
$\mathcal{B}(\tau \to \mu\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell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

We expect to see LFV events, not just improve limits

Lepton Flavor Violation in τ decays

SuperB sensitivity directly confronts many New Physics models





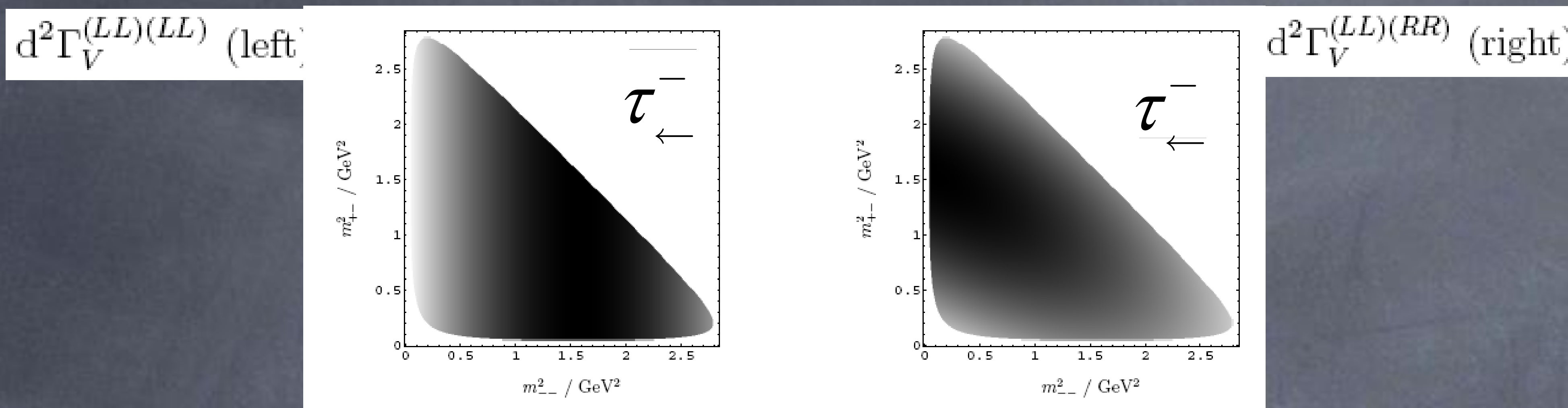
Antusch, Arganda, Herrero, Teixeira, 2006

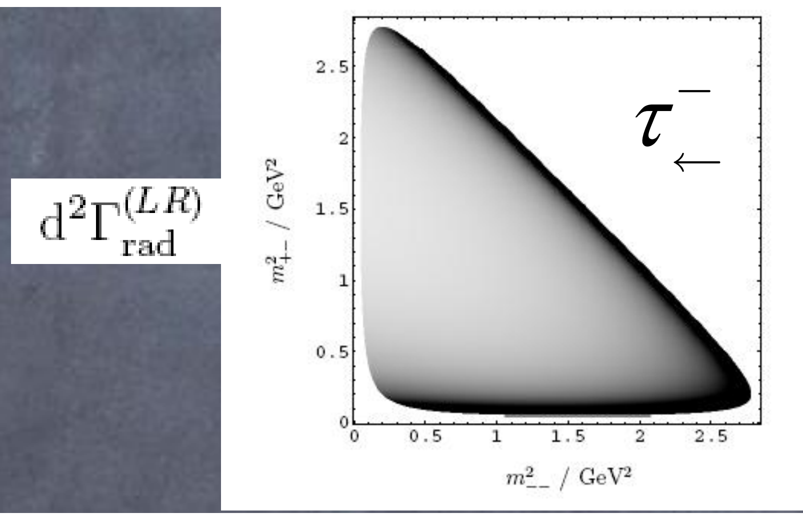
SuperB sensitivity For 75 ab^{-1}

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}

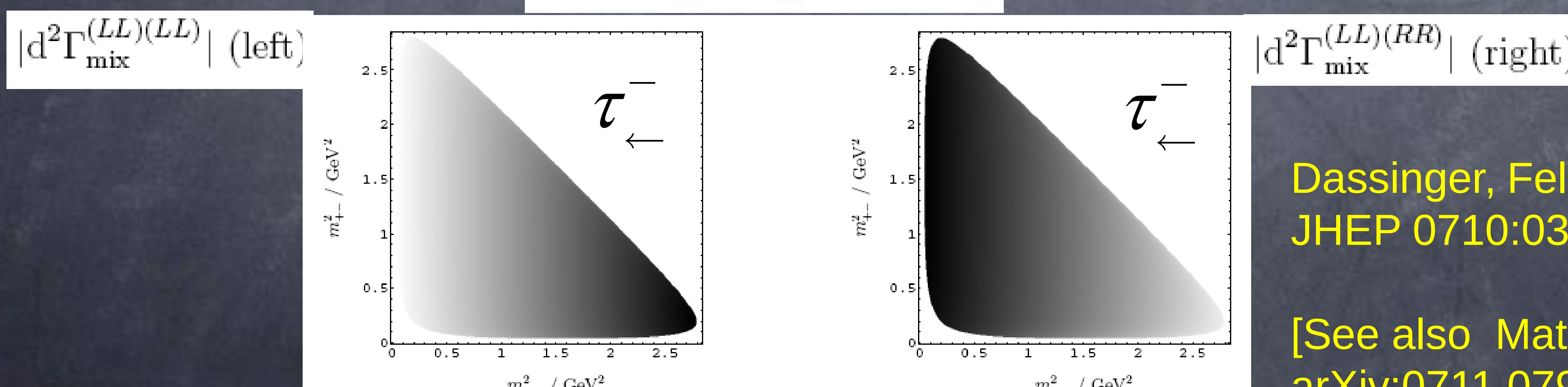
We expect to see LFV events, not just improve limits

Polarized τ's can probe the chiral structure of LFV





Flipping the helicity of the polarized electron beam allows us to determine the chiral structure of dimension 6 four fermion lepton flavor-violating interactions

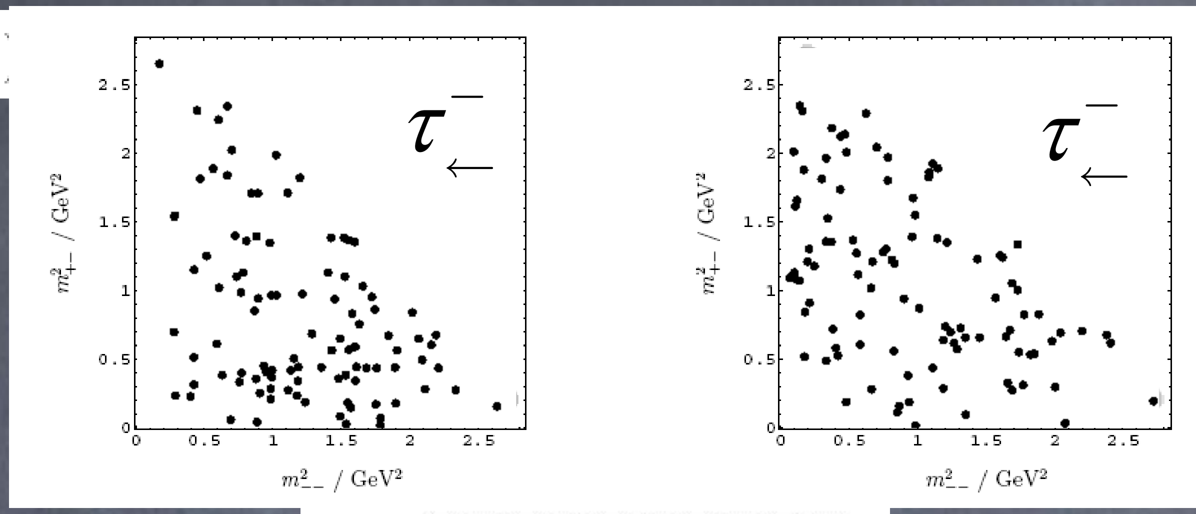


Dassinger, Feldmann, Mannel, and Turczyk JHEP 0710:039,2007;

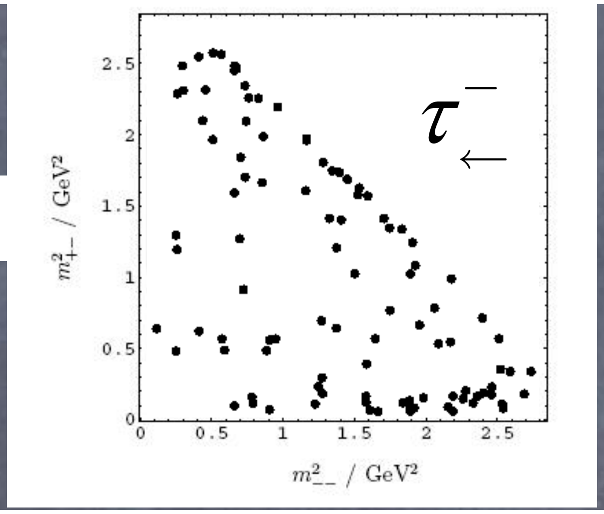
[See also Matsuzaki and Sanda arXiv:0711.0792 [hep-ph]

Polarized τ's can probe the chiral structure of LFV

$d^2\Gamma_V^{(LL)(LL)}$ (left) $\qquad$ $d^2\Gamma_V^{(LL)(RR)}$ (right)

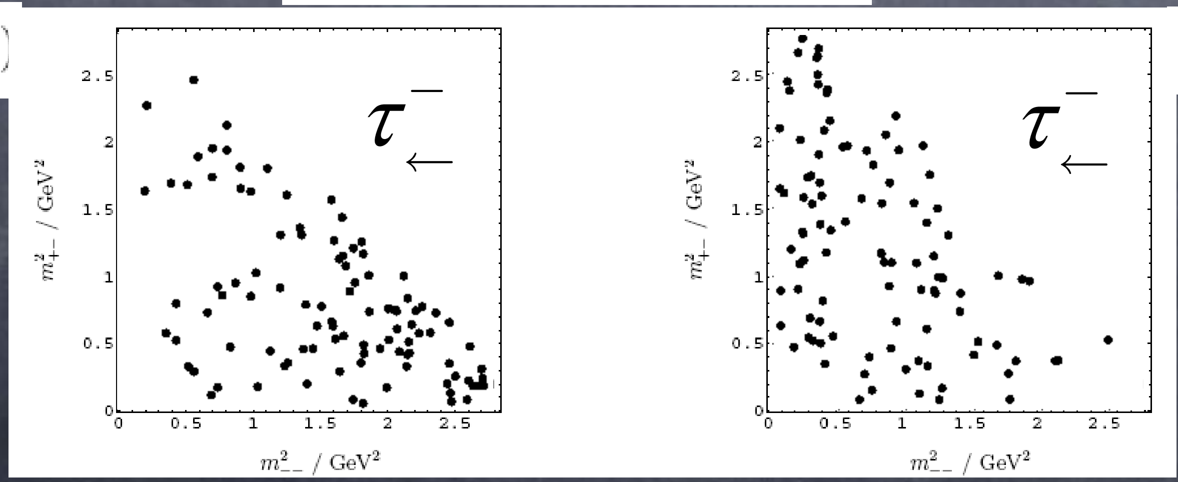


$d^2\Gamma_{\rm rad}^{(LR)}$



Flipping the helicity of the polarized electron beam allows us to determine the chiral structure of dimension 6 four fermion lepton flavor-violating interactions

$|d^2\Gamma_{\rm mix}^{(LL)(LL)}|$ (left) $\qquad$ $|d^2\Gamma_{\rm mix}^{(LL)(RR)}|$ (right)



Dassinger, Feldmann, Mannel, and Turczyk JHEP 0710:039,2007;

[See also Matsuzaki and Sanda arXiv:0711.0792 [hep-ph]]

Summary: “Flavor DNA”

Agashe, Carone
Ross, Velasco-Sevilla, Vives
WA, Buras, Paradisi

	GMSSM	AC	RVV	δ_{LL} only	FBMSSM
$D^0 - \bar{D}^0$ mixing	★★★	★★★	★	★	★
ϵ_K	★★★	★	★★★	★	★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★
$S_{\phi K_S}$, $S_{\eta' K_S}$	★★★	★★★	★★	★★★	★★★
$A_{CP}^{bs\gamma}$	★★★	★	★	★★★	★★★
$\langle A_{7,8} \rangle (B \to K^* \mu^+ \mu^-)$	★★★	★	★★	★★★	★★★
$\langle A_9 \rangle (B \to K^* \mu^+ \mu^-)$	★★★	★	★★	★	★
$B_s \to \mu^+ \mu^-$	★★★	★★★	★★★	★★★	★★★
$B \to K^{(*)} \nu \bar{\nu}$	★★	★	★	★	★
$K \to \pi \nu \bar{\nu}$	★★★	★	★★	★	★
d_e, d_n	★★★	★★★	★★	★★	★★★

★★★: large effects, ★★: medium effects, ★: small effects

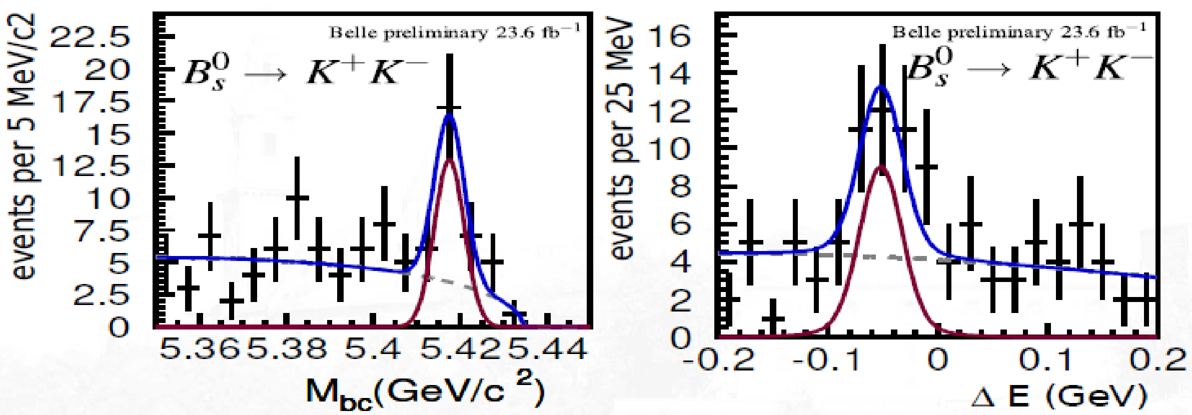
Many other flavor-related experimental results

- B_s studies in e^+e^- at Belle
- New b baryons at the Tevatron
- New states in the 4 GeV region

Belle $\Upsilon(5S)$ results

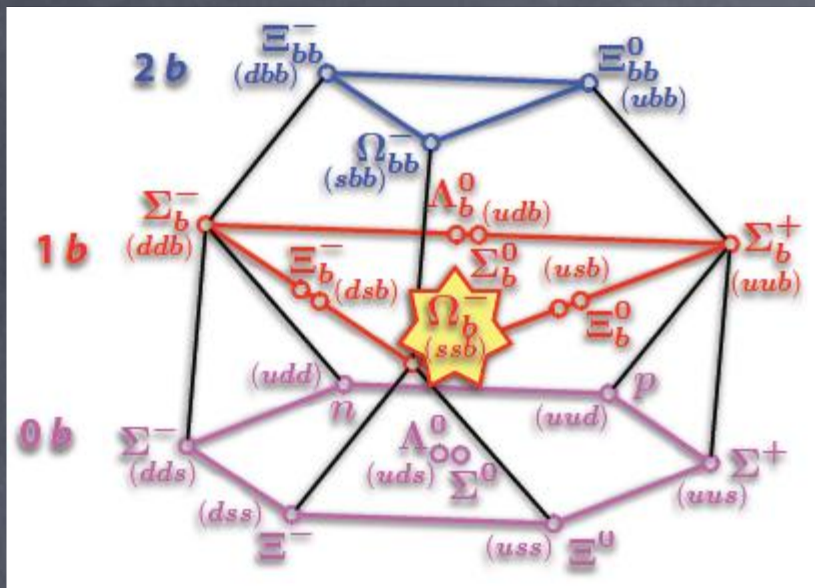
- In $23.6\,\text{fb}^{-1}$ of $\Upsilon(5S)$ data: new results:
  - CKM-favored (First observations):
    - $\mathcal{B}(B_s^0 \to D_s^{*-}\pi^+) = (2.4^{+0.5}_{-0.4}(\text{stat.}) \pm 0.3(\text{syst.}) \pm 0.4(f_s)) \times 10^{-3}$
    - $\mathcal{B}(B_s^0 \to D_s^{-}\rho^+) = (8.5^{+1.3}_{-1.2}(\text{stat.}) \pm 1.1(\text{syst.}) \pm 1.3(f_s)) \times 10^{-3}$
    - $\mathcal{B}(B_s^0 \to D_s^{*-}\rho^+) =$ $(13.0^{+2.3}_{-2.1}(\text{stat.}) \pm 1.7(\text{syst.}) \pm 1.7(\text{pol.}) \pm 1.9(f_s)) \times 10^{-3}$
  - $B_s^0 \to CP$ eigenstate + charmless decays
    - $\mathcal{B}(B_s^0 \to J/\psi\,\eta) = (3.69 \pm 0.95^{+0.65}_{-0.95}) \times 10^{-4}$ (First observation)
    - $\mathcal{B}(B_s^0 \to K^+K^-) = (3.8^{+1.0}_{-0.9} \pm 0.7) \times 10^{-5}$
    - $\mathcal{B}(B_s^0 \to \pi^+\pi^-) < 1.2 \times 10^{-5}$ (90% C.L.)
    - $\mathcal{B}(B_s^0 \to K^0\bar{K}^0) < 3.3 \times 10^{-5}$ (90% C.L.)
    - $\mathcal{B}(B_s^0 \to K^+\pi^-) < 2.6 \times 10^{-5}$ (90% C.L.)
- $100\,\text{fb}^{-1}$ of data are now available

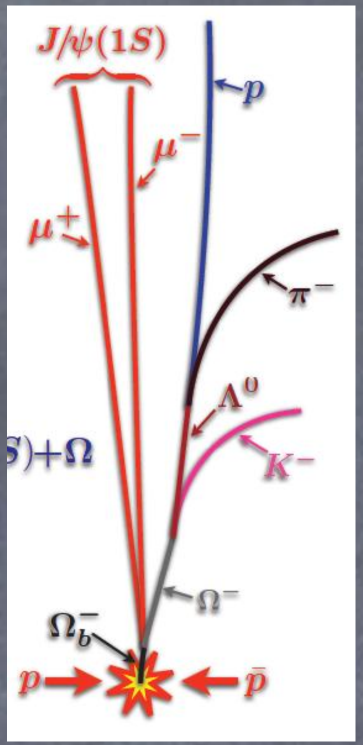
- Observation of 23 $B_s^0 \to K^+K^-$ events (5.8σ)

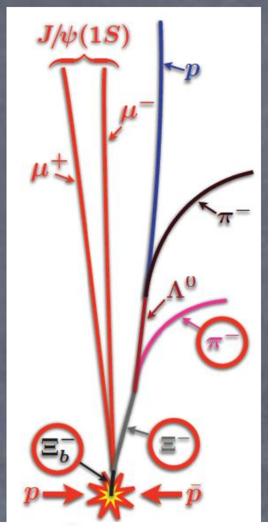


R. Louvot – EPS 2009

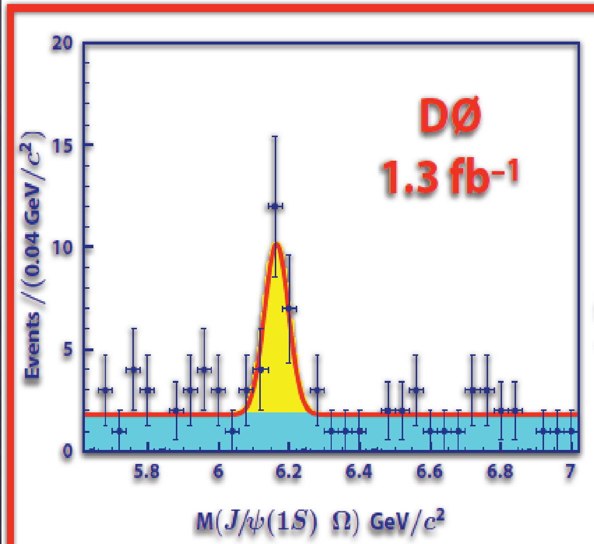
Observation of the doubly strange b baryon Ω_b^-







DØ and CDF, 2007



17.8 ± 4.9 (stat) ± 0.8 (syst)

6.165 ± 0.010 (stat) ± 0.013 (syst) GeV/c^2

5.4 σ

$$\frac{f(b\to\Omega_b^-)Br(\Omega_b^-\to J/\psi(1S)\ \Omega^-)}{f(b\to\Xi_b^-)Br(\Xi_b^-\to J/\psi(1S)\ \Xi^-)} = 0.80\pm0.32\ (\text{stat})^{+0.14}_{-0.22}\ (\text{syst})$$

A new b−Baryon observed! ☺

CDF

$$\frac{\sigma B(\Omega_b^- \to J/\psi\Omega^-)}{\sigma B(\Lambda_b^0 \to J/\psi\Lambda)} = 0.045^{+0.017}_{-0.012}(stat.) \pm 0.004(syst.)$$

$$\frac{\sigma B(\Xi_b^- \to J/\psi\Xi^-)}{\sigma B(\Lambda_b^0 \to J/\psi\Lambda)} = 0.167^{+0.037}_{-0.025}(stat.) \pm 0.012(syst.)$$

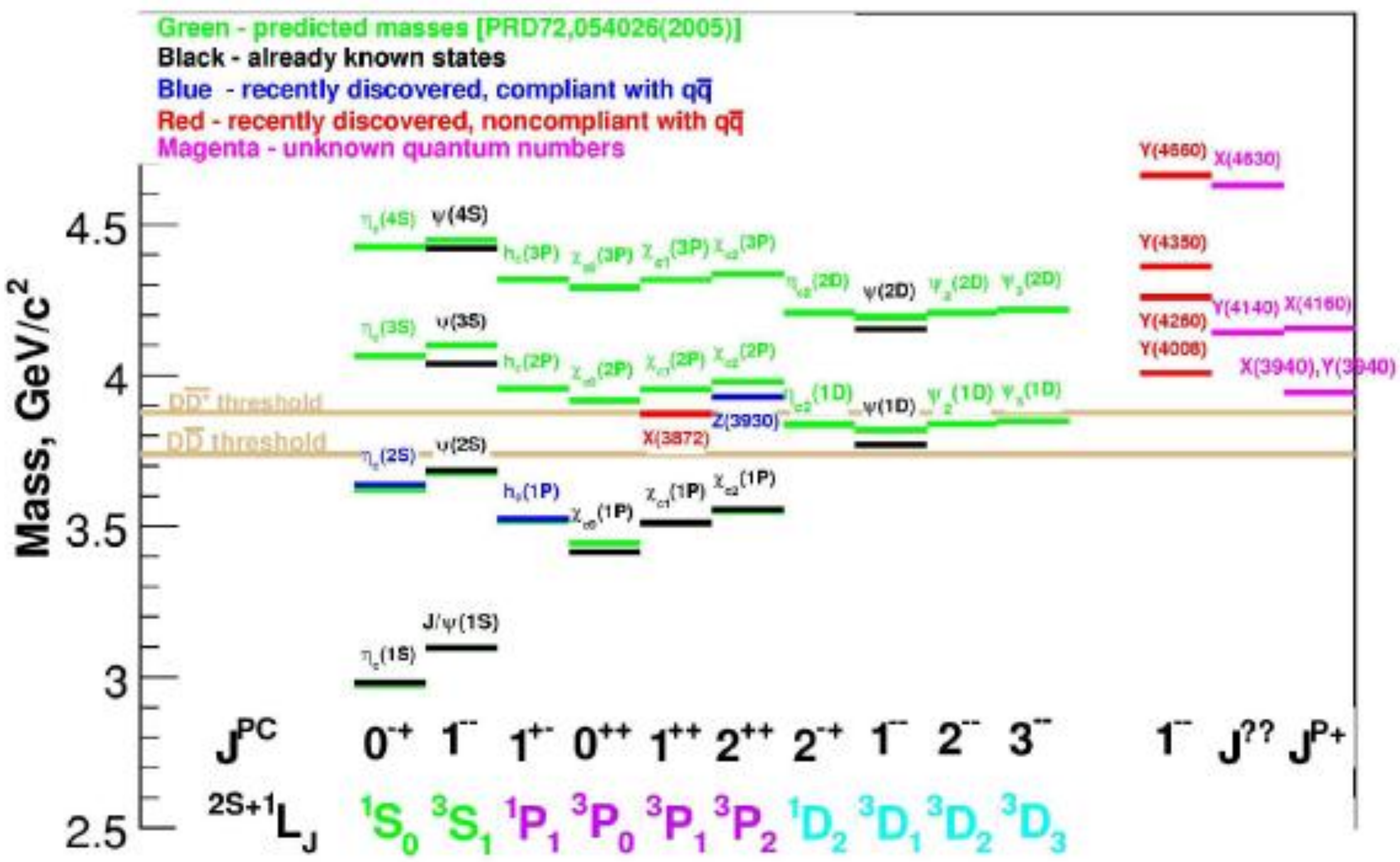
	Mass (MeV/c²)			τ_0(ps)			$\sigma B/\sigma B(\Lambda_b^0)$		
Ξ_b^-	5790.9	± 2.6	± 0.9	1.56	+0.27 −0.25	± 0.02	0.167	+0.037 −0.025	± 0.012
Ω_b^-	6054.4	± 6.8	± 0.9	1.13	+0.53 −0.40	± 0.02	0.045	0.017 −0.012	± 0.004

New charmonium states above threshold

State	EXP	M + i Γ (MeV)	J^{PC}	Decay Modes Observed	Production Modes Observed
X(3872)	Belle, CDF, D0, BaBar	$3871.2 \pm 0.5 + i(<2.3)$	1^{++}	$\pi^+\pi^- J/\psi$, $\pi^+\pi^-\pi^0 J/\psi$, $\gamma J/\psi$	B decays, ppbar
	Belle BaBar	$3872.6^{+0.5}_{-0.4} \pm 0.4 + i(3.9^{+2.5}_{-1.3}{}^{+0.8}_{-0.3})$ $3875.1^{+0.7}_{-0.5} \pm 0.5 + i(3.0^{+1.9}_{-1.4} \pm 0.9)$		$D^0 D^{*0}$	B decays
Z(3930)	Belle	$3929 \pm 5 \pm 2 + i(29 \pm 10 \pm 2)$	2^{++}	$D^0 D^0$, $D^+ D^-$	$\gamma\gamma$
Y(3940)	Belle BaBar	$3943 \pm 11 \pm 13 + i(87 \pm 22 \pm 26)$ $3914.3^{+3.8}_{-3.4} \pm 1.6 + i(33^{+12}_{-8} \pm 0.60)$	J^{P+}	$\omega J/\psi$	B decays
X(3940)	Belle	$3942^{+7}_{-6} \pm 6 + i(37^{+26}_{-15} \pm 8)$	J^{P+}	DD^*	e^+e^- (recoil against J/ψ)
Y(4008)	Belle BaBar	$4008 \pm 40^{+72}_{-28} + i(226 \pm 44^{+87}_{-79})$ (not seen)	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^- (ISR)
Y(4140)	CDF	$4143.0 \pm 2.9 \pm 1.2 + i(11.7^{+8.3}_{-5.0} \pm 3.7)$	J^{P+}	$\phi\ J/\psi$	ppbar
X(4160)	Belle	$4156^{+25}_{-20} \pm 15 + i(139^{+111}_{-61} \pm 21)$	J^{P+}	$D^* D^*$	e^+e^- (recoil against J/ψ)
Y(4260)	BaBar Cleo Belle	$4259 \pm 6^{+2}_{-3} + i(105 \pm 18^{+4}_{-6})$ $4284^{+17}_{-16} \pm 4 + i(73^{+39}_{-25} \pm 5)$ $4247 \pm 12^{+17}_{-32} + i(108 \pm 19 \pm 10)$	1^{--}	$\pi^+\pi^- J/\psi$, $\pi^0\pi^0 J/\psi$, $K^+K^- J/\psi$	e^+e^- (ISR), e^+e^-
Y(4350)	BaBar Belle	$4324 \pm 24 + i(172 \pm 33)$ $4361 \pm 9 \pm 9 + i(74 \pm 15 \pm 10)$	1^{--}	$\pi^+\pi^- \psi(2S)$	e^+e^- (ISR)
$Z^+(4430)$	Belle BaBar	$4433 \pm 4 \pm 1 + i(44^{+17}_{-13}{}^{+30}_{-11})$ (not seen)	J^P	$\pi^+ \psi(2S)$	B decays
Y(4660)	Belle	$4664 \pm 11 \pm 5 + i(48 \pm 15 \pm 3)$	1^{--}	$\pi^+\pi^- \psi(2S)$	e^+e^- (ISR)

More than a dozen new charmonium-like states have been reported

X(3872), Y(3940), Y(4260), η_c(2S), Z(3930),...



Too many states to be accommodated by the quark model !!!

Looking forward

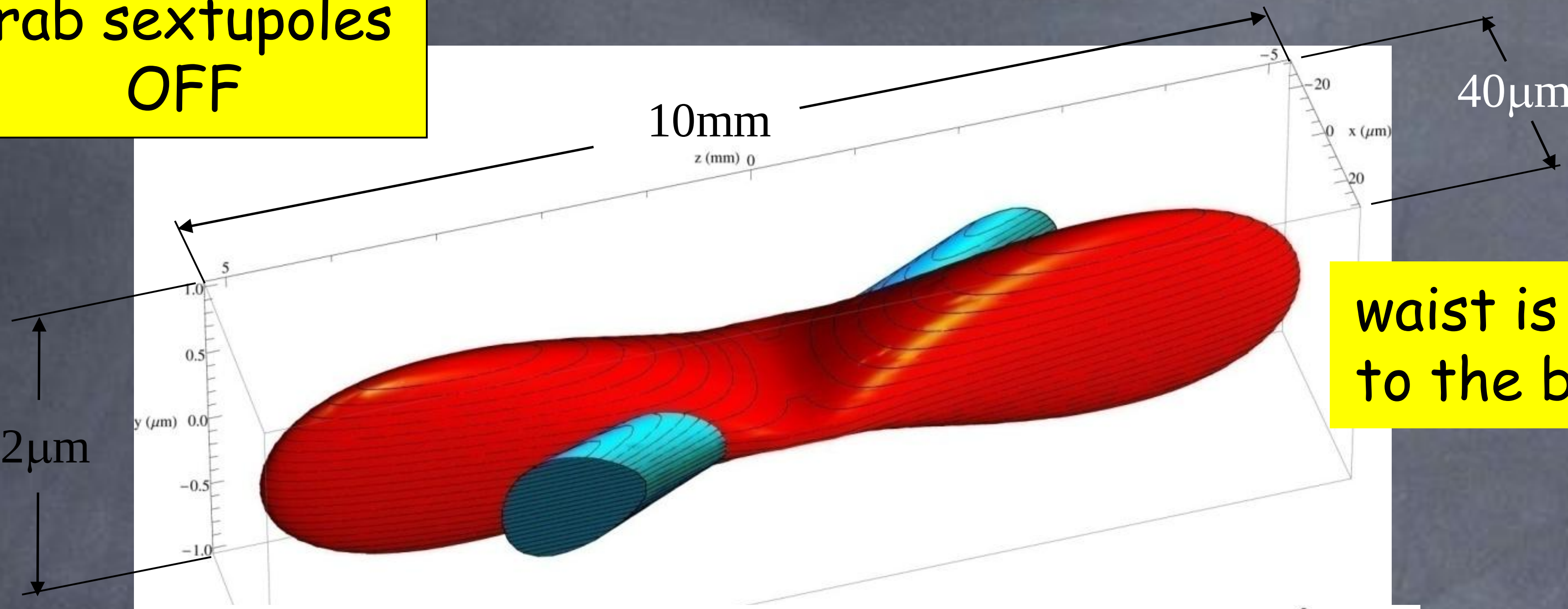
- Much remains to be done in flavor experiments - at both hadron and e+e- machines
  - Clarify UT anomalies – is there evidence of new physics ?
  - Access very rare b, c and τ decays that can through branching fractions, CP asymmetries and kinematic distributions, provide information on new physics uncovered at the LHC
  - Search for charged lepton flavor violation and perhaps study details of the coupling
- Experiments the LHC and the new Super B Factories will have the sensitivity to establish or refute the current anomalies seen in heavy flavor experiments and provide constraints and guidance on physics beyond the Standard Model

Super*B* One Pager

- Super*B* is an e^+e^- Super Flavor Factory
  - very high initial luminosity, 10^{36} $cm^{-2}s^{-1}$ by 2015/2016
    - upgradeable to $4x10^{36}$ in a straightforward manner
  - It is an asymmetric collider : 4 on 7 GeV
  - The low energy beam can be linearly polarized to ~85% , using the SLC laser gun
    - Polarization is particularly important for exploring new physics in τ decays
  - The primary E_{CM} will be the $\Upsilon(4S)$, but Super*B* can run elsewhere in the Υ region, and in the charm & tau threshold regions as well, with a luminosity above 10^{35}
    - One month at the $\psi(3770)$, for example, yields 10x the total data sample that will be produced by BEPCII
- Super*B* will be built on the campus of the Rome II University at Tor Vergata
  - An alternate site at LNF is also being explored
  - Most of the ring magnets can re reused from PEP-II, as can the RF systems, many vacuum components, linac and injection components – as well as *BABAR* as the basis for an upgraded detector
- Super*B* is included in the roadmap of the CERN Strategy Group
- INFN is working for approval of Super*B* with the Italian government and other European and EU agencies
  - Tunneling, funded by Regione Lazio, will commence soon after approval

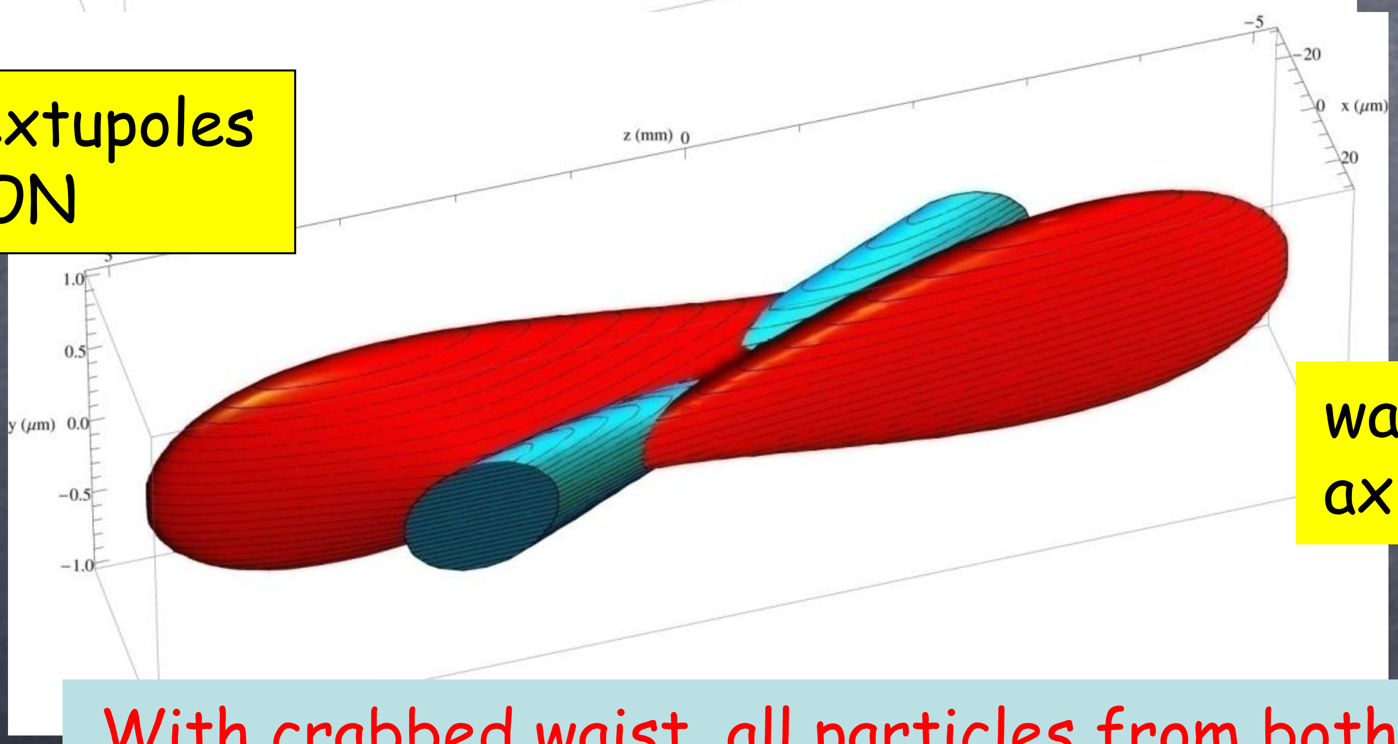
Super*B* crabbed waist beam distribution at the IP
4 GeV on 7 GeV

Crab sextupoles OFF



waist is orthogonal to the bunch axis

Crab sextupoles ON



waist moves to the axis of other beam

Note anamorphic scales

E. Paoloni

With crabbed waist, all particles from both beams collide in the minimum β_y region, producing a net gain in luminosity and a broad tune plane


26 Mag 2008
1:56pm
Due Torri
© 2008 Cnes/Spot Image
Image © 2008 DigitalGlobe
© 2008 Tele Atlas
Image NASA
Google
©2008
41°50'39.90" N
12°38'45.38" E
98 m elev
1.07 km Alt