The role of Super*B* in unraveling the nature of physics beyond the SM

ICHEP 2012

David Hitlin
Caltech

Scenarios – the relevance of flavor

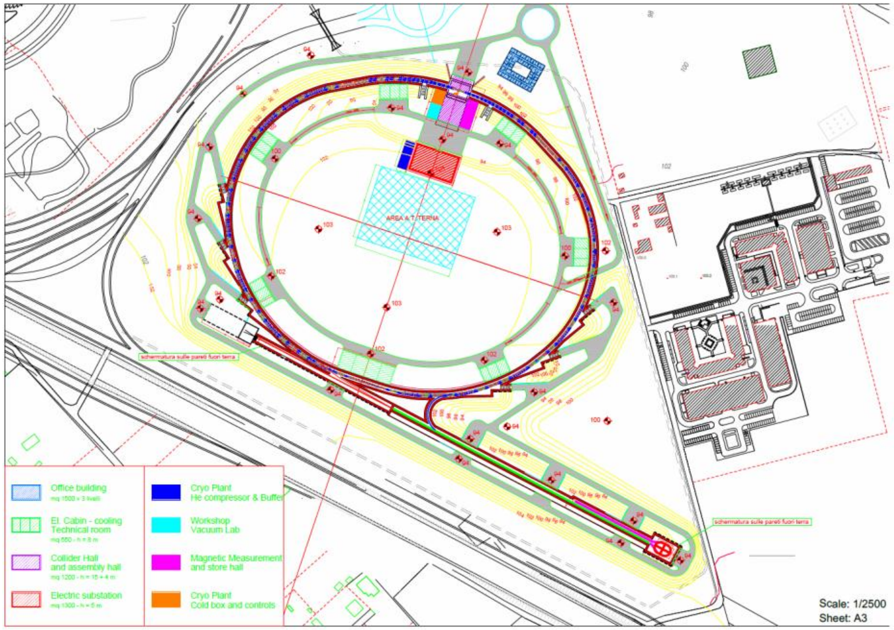
1. LHC finds NP compatible with flavor data - flavor data constrains couplings
2. LHC finds NP incompatible with flavor data – modify the theory
3. LHC finds nothing – flavor studies indirectly probe high energy effects

Flavor measurements – from Super τ/charm factories, Super *B* factories, LHC and rare muon and kaon decays are crucial to sorting through the large number of still viable New Physics models

- Both the quark and lepton sectors are important
  - Quark sector
    - Precision Unitarity Triangle measurements
    - Rare decay *b, c decay* branching fractions
    - New sources of *CP* violation in *b* and *c* decays
    - Modifcations to kinematic distributions
  - Lepton sector
    - Charged lepton flavor violation in τ decay
    - *CP* violation in τ decay
    - τ *g*-2 and EDM limits

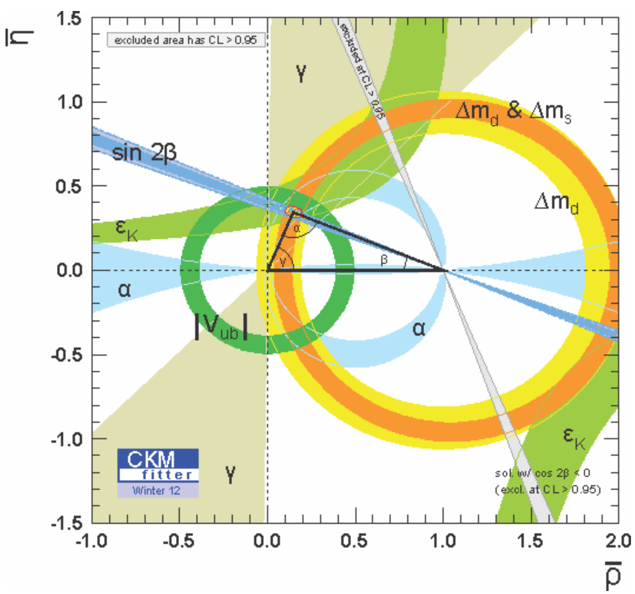
Super*B* at the Nicola Cabibbo Lab in Tor Vergata

- $\mathcal{L} = 10^{36}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ at $\Upsilon(4S)$ (with headroom for higher $\mathcal{L}$)
  - Will integrate 75 ab^{-1} in ~5 years
  - Crabbed waist scheme produces high luminosity (50x PEP-II) with very small beam sizes and currents, and therefore wall plug power, similar to PEP-II
  - Circumference ~1350m
  - Electron beam is polarized (60-80%)
  - Can run in τ/charm region with $\mathcal{L} = 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - Many components from PEP-II
  - Uses upgraded *BABAR* detector
  - Linac can function as FEL
  - Incorporates synchrotron radiation beamlines



How will current stresses in the Unitarity Triangle resolve?

~ 1 ab^{-1}

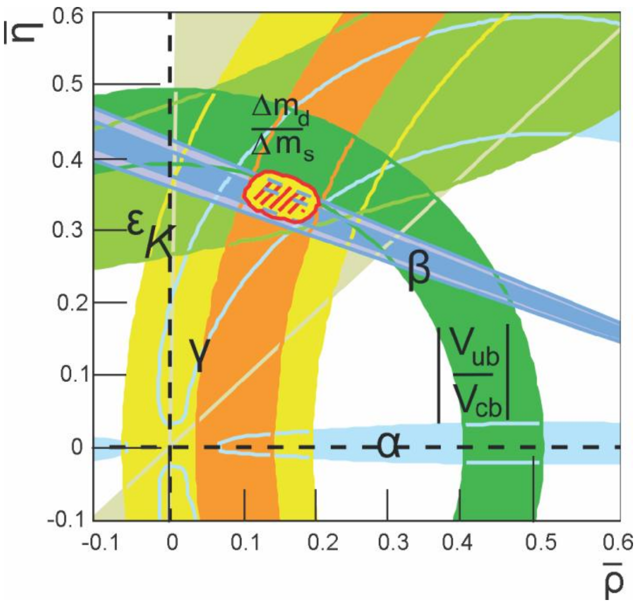


Observable/mode Luminosity	Current $\sim 1\,\mathrm{ab}^{-1}$	LHCb (2017) $5\,\mathrm{fb}^{-1}$	Super$B$ (5 years) $75\,\mathrm{ab}^{-1}$	LHCb upgrade $50\,\mathrm{fb}^{-1}$	Theory
α					
β from $b \to c\bar{c}s$					
$B_d \to J/\psi\,\pi^0$					
$B_s \to J/\psi\,K^0_S$					
γ					
$\lvert V_{ub}\rvert$ inclusive					
$\lvert V_{ub}\rvert$ exclusive					
$\lvert V_{cb}\rvert$ inclusive					
$\lvert V_{cb}\rvert$ exclusive					

Experiment	Theory
No result	
Moderately precise	Moderately clean
Precise	Clean – needs lattice
Very precise	Clean

How will current stresses in the Unitarity Triangle resolve?

~ 1 ab^{-1}

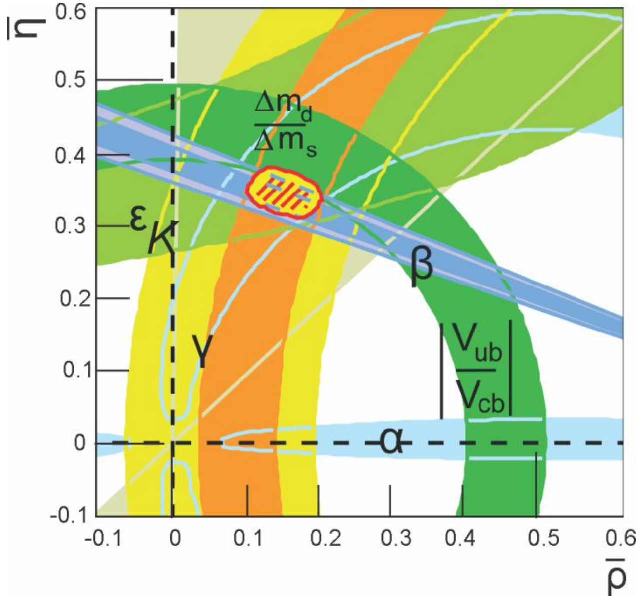


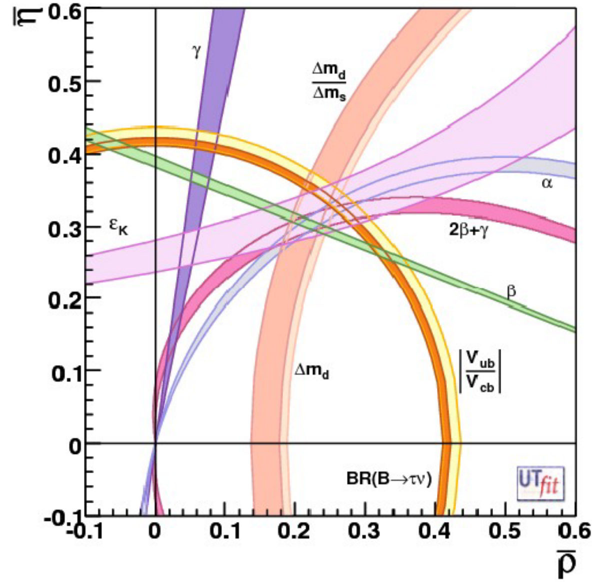
Observable/mode Luminosity	Current $\sim 1\,\mathrm{ab}^{-1}$	LHCb (2017) $5\,\mathrm{fb}^{-1}$	Super$B$ (5 years) $75\,\mathrm{ab}^{-1}$	LHCb upgrade $50\,\mathrm{fb}^{-1}$	Theory
α					
β from $b \to c\bar{c}s$					
$B_d \to J/\psi\,\pi^0$					
$B_s \to J/\psi\,K^0_S$					
γ					
$\lvert V_{ub}\rvert$ inclusive					
$\lvert V_{ub}\rvert$ exclusive					
$\lvert V_{cb}\rvert$ inclusive					
$\lvert V_{cb}\rvert$ exclusive					

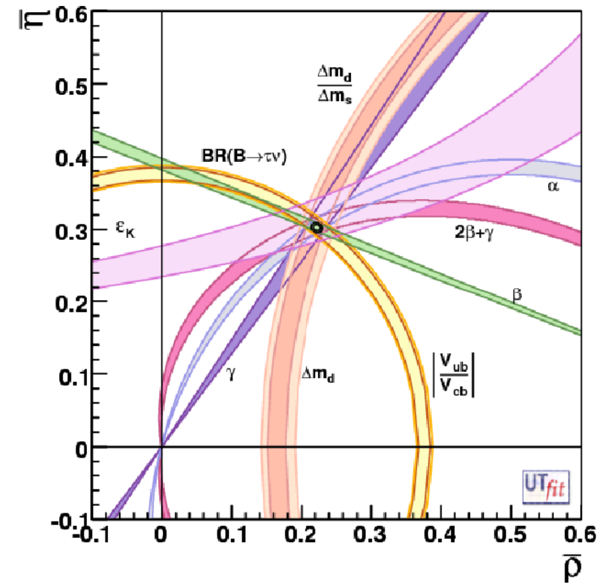
Experiment	**Theory**
No result	
Moderately precise	Moderately clean
Precise	Clean – needs lattice
Very precise	Clean

How will current stresses in the Unitarity Triangle resolve?

~ 1 ab^{-1} ~ 100 ab^{-1}







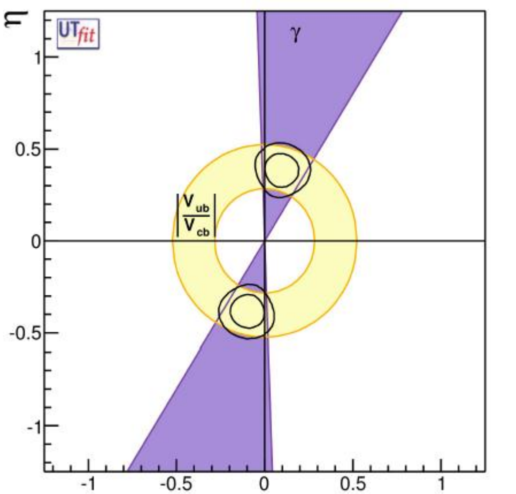
Observable/mode Luminosity	Current $\sim 1\,ab^{-1}$	LHCb (2017) $5\,fb^{-1}$	Super*B* (5 years) $75\,ab^{-1}$	LHCb upgrade $50\,fb^{-1}$	Theory
α					
β from $b \to c\bar{c}s$					
$B_d \to J/\psi\,\pi^0$					
$B_s \to J/\psi\,K_S^0$					
γ					
$\|V_{ub}\|$ inclusive					
$\|V_{ub}\|$ exclusive					
$\|V_{cb}\|$ inclusive					
$\|V_{cb}\|$ exclusive					

Experiment	**Theory**
No result	
Moderately precise	Moderately clean
Precise	Clean – needs lattice
Very precise	Clean

Improvement in precision of γ and V_{ub} provides a strong constraint

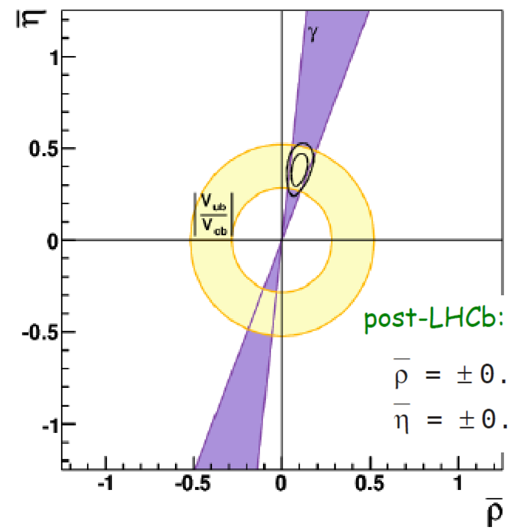
Assuming only 1) three generation unitarity
2) no New Physics at tree level

This constraint must be obeyed by any New Physics model:



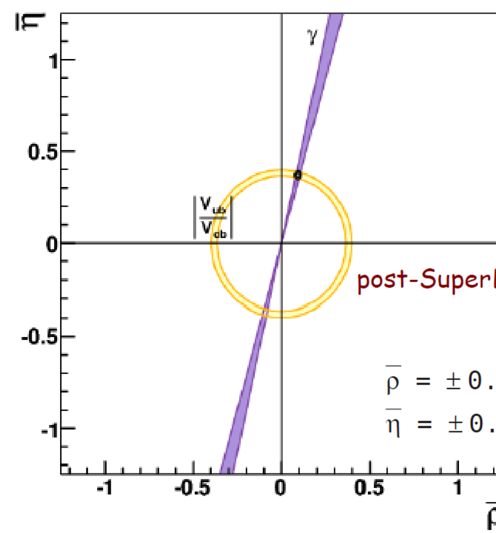
γ = $(-103.9 \pm 9.2)°$
$(75.7 \pm 9.2)°$
$|V_{cb}|$ = $(41.0 \pm 1.0)\times10^{-3}$
$|V_{ub}|$ = $(3.82 \pm 0.52)\times10^{-3}$

$\bar{\rho} = \pm 0.089 \pm 0.061\ (69\%)$
$\bar{\eta} = \pm 0.385 \pm 0.057\ (15\%)$



post-LHCb: $\delta\gamma \sim 4°$, $|V_{cb,ub}|$ unchanged

$\bar{\rho} = \pm 0.098 \pm 0.031\ (32\%)$
$\bar{\eta} = \pm 0.386 \pm 0.056\ (15\%)$



post-SuperB: $\delta\gamma \sim 1°$, $\delta|V_{cb}|/|V_{cb}| \sim 1\%$
$\delta|V_{ub}|/|V_{ub}| \sim 2\%$

$\bar{\rho} = \pm 0.093 \pm 0.007\ (8\%)$
$\bar{\eta} = \pm 0.371 \pm 0.009\ (2.5\%)$

Marco Ciuchini

Squark mass matrices and the mass scale Λ_{NP}

SuperB, LHCb

$$m^2_{\tilde d} \sim \begin{pmatrix} m^2_{\tilde d_L} & m_d(A_d - \mu\tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\ & m^2_{\tilde d_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\ & & m^2_{\tilde s_L} & m_s(A_s - \mu\tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\ & & & m^2_{\tilde s_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\ & & & & m^2_{\tilde b_L} & m_b(A_b - \mu\tan\beta) \\ & & & & & m^2_{\tilde b_R} \end{pmatrix}$$

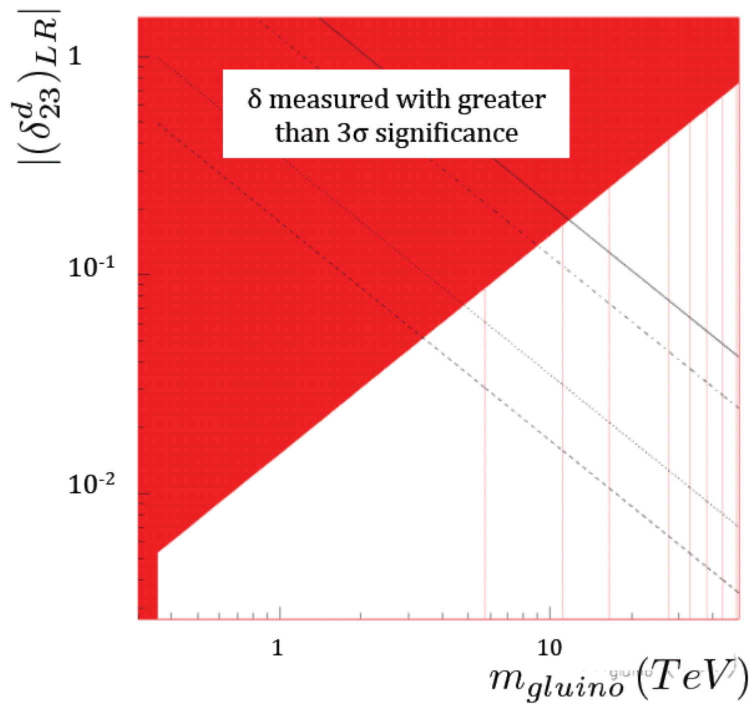
LHC

Example: the MSSM with generic squark mass matrices:
Use the mass insertion approximation with $m_{\tilde q} \sim m_{\tilde g}$ to constrain couplings:

$$(\delta^q_{ij})_{AB} = \frac{(\Delta_{ij})^q_{AB}}{m^2_{\tilde q}}$$

Can constrain the δ^d_{ij}'s using

$$\mathcal{B}(B \to X_s \gamma)$$
$$\mathcal{B}(B \to X_s \ell^+ \ell^-)$$
$$\mathcal{A}_{CP}(B \to X_s \gamma)$$



Squark mass matrices and the mass scale Λ_{NP}

$$m^2_{\tilde d} \sim \begin{pmatrix} m^2_{\tilde d_L} & m_d(A_d - \mu\tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\ & m^2_{\tilde d_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\ & & m^2_{\tilde s_L} & m_s(A_s - \mu\tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\ & & & m^2_{\tilde s_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\ & & & & m^2_{\tilde b_L} & m_b(A_b - \mu\tan\beta) \\ & & & & & m^2_{\tilde b_R} \end{pmatrix}$$

LHC

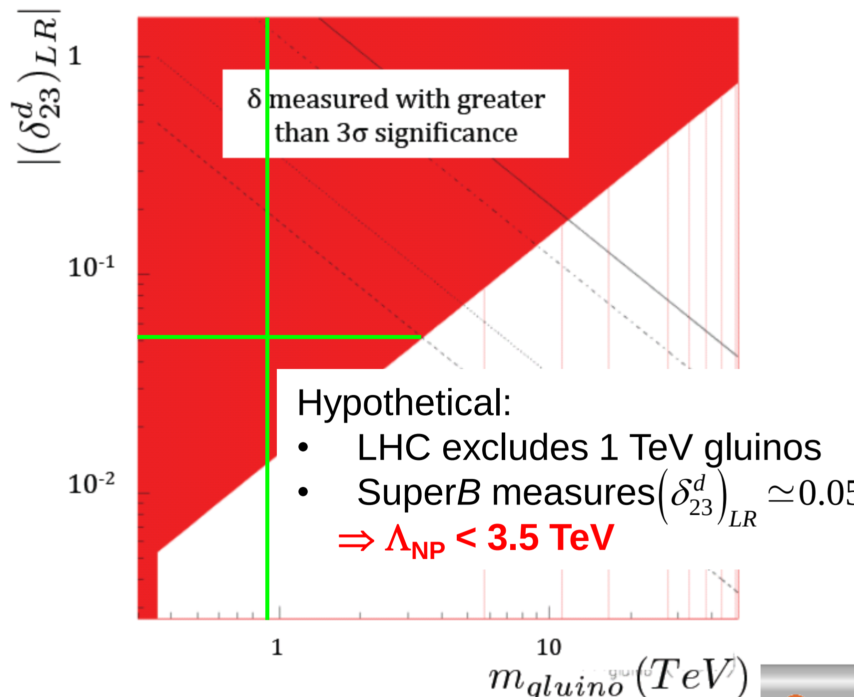
Super*B*, LHC*b*

Example: the MSSM with generic squark mass matrices:
Use the mass insertion approximation with $m_{\tilde q} \sim m_{\tilde g}$ to constrain couplings:

$$(\delta^q_{ij})_{AB} = \frac{(\Delta_{ij})^q_{AB}}{m^2_{\tilde q}}$$

Can constrain the δ^d_{ij}'s using

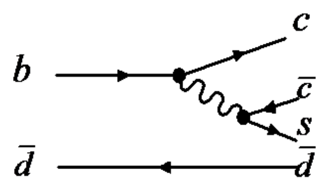
$$\mathcal{B}(B \to X_s\gamma)$$
$$\mathcal{B}(B \to X_s\ell^+\ell^-)$$
$$\mathcal{A}_{CP}(B \to X_s\gamma)$$



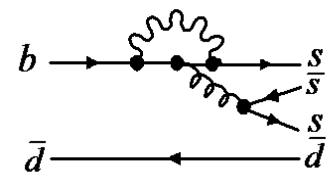
Probes of New Physics – *CP*V in exclusive modes

- 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 models of SUSY breaking or extra dimensions, or …. 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

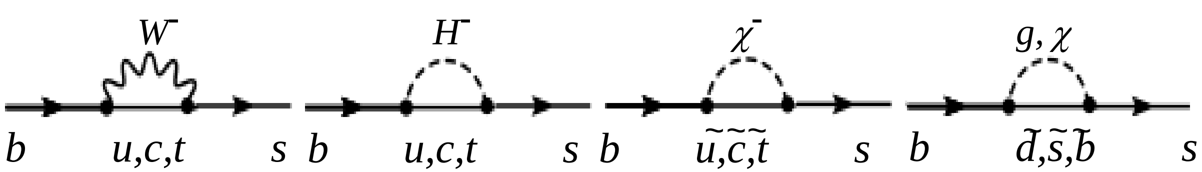
$B^0 \to J/\psi K_S^0$



$B^0 \to \eta' K_S^0,\ \phi K_S^0, \ldots$

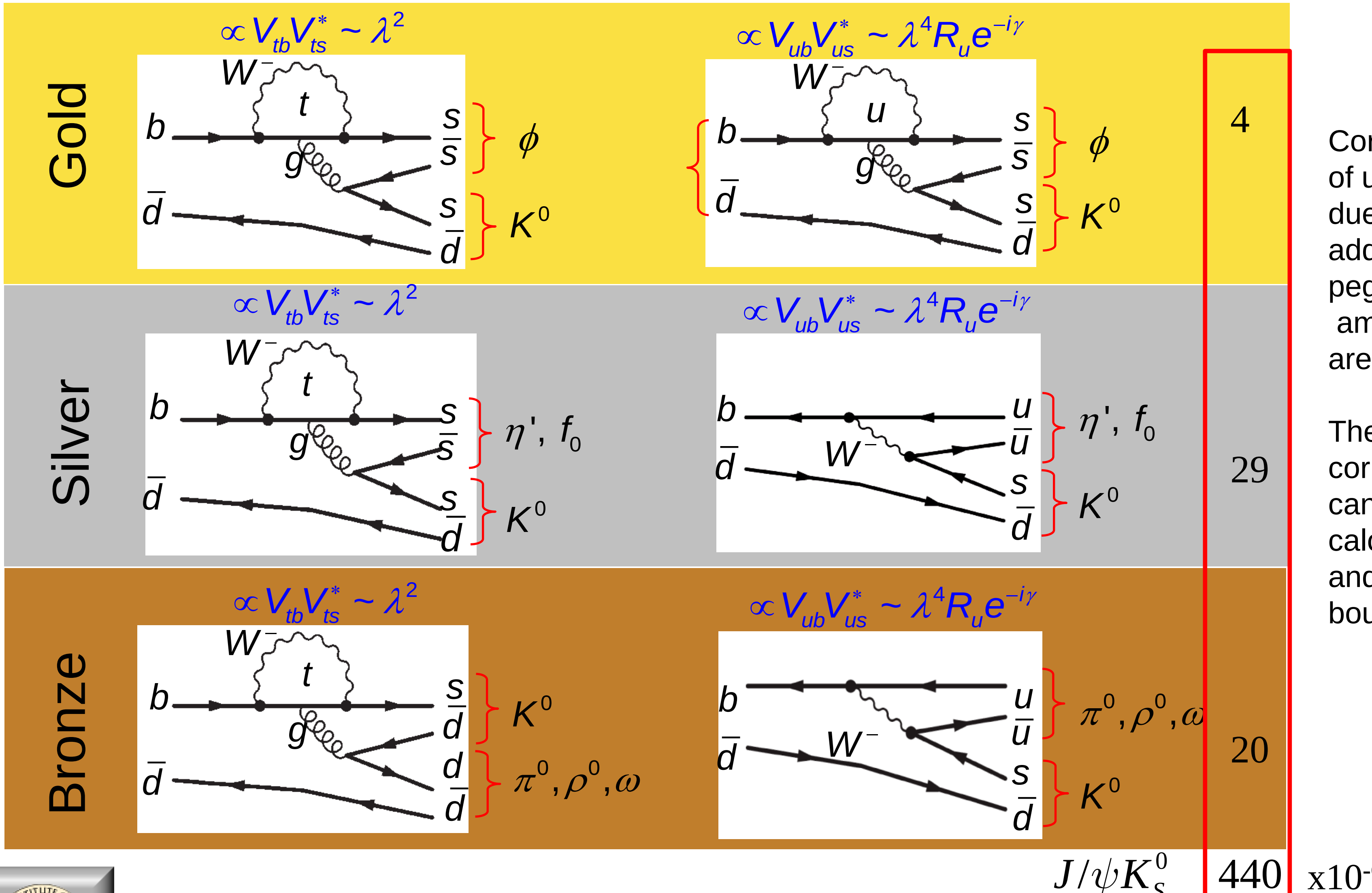


$$\lambda_{tree} = \frac{q}{p}\frac{\bar{A}}{A} = \eta \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \frac{V_{cb} V_{cs}^*}{V_{cb}^* V_{cs}} = (-1) e^{-2i\beta} \qquad \lambda_{penguin} = \frac{q}{p}\frac{\bar{A}}{A} = \eta \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \frac{V_{tb} V_{ts}^*}{V_{tb}^* V_{ts}} = (-1)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



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

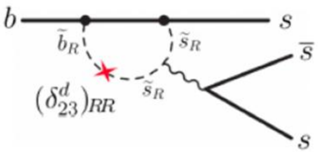
$b \to s\bar{s}s$ decays have 1 to 5% the rate of $b \to c\bar{c}s$ decays

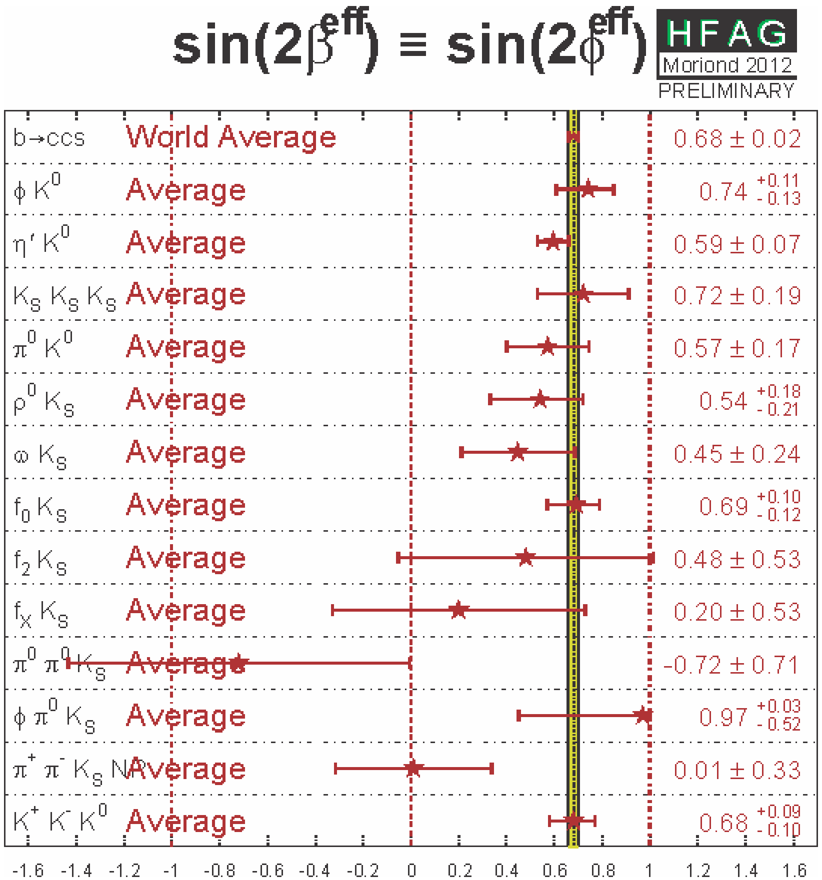


Corrections of up to 20% due to additional pegin or tree amplitudes are possible

These corrections can be calculated and/or bounded

Search for new sources of *CP* violation in *s* penguin modes





- With 1 ab^{-1}, there is insufficient sensitivity to see NP effects
- At 75ab^{-1}, statistical uncertainty in many of these *s*-penguin modes will be comparable to current precision for $B^0 \to J/\psi K^0_S$, providing mass insertion scale sensitivity approaching 1 TeV at standard coupling

	1 ab^{-1}			75 ab^{-1}		
Mode	Stat	Syst	Th	Stat	Syst	Th
ψK^0_S	0.022	0.010	0.01	0.002	0.005	0.001
$\eta' K^0_S$	0.08	0.02	0.015±0.015	0.006	0.005	tbd
ϕK^0_S	0.26	0.03	0.03±0.02	0.020	0.005	
$f_0 K^0_S$	0.18	0.04	0.0±0.02+LD	0.012	0.003	
$K^0_S K^0_S K^0_S$	0.19	0.03	0.02±0.01	0.015	0.020	

Heavy flavor studies provide a "DNA Chip" for New Physics

W. Altmannshofer, A.J. Buras, S. Gori, P. Paradisi and D.M. Straub

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\mathrm{CP}}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

The pattern of measurement:
★★★ large effects
★★ visible but small effects
★ unobservable effects
is characteristic,
often uniquely so,
of a particular model

GLOSSARY	
AC [10]	RH currents & U(1) flavor symmetry
RVV2 [11]	SU(3)-flavored MSSM
AKM [12]	RH currents & SU(3) family symmetry
δLL [13]	CKM-like currents
FBMSSM [14]	Flavor-blind MSSSM
LHT [15]	Little Higgs with T Parity
RS [16]	Warped Extra Dimensions

These are a subset of a subset listed by Buras and Girrbach
MFV, CMFV, $2HDM_{\overline{MFV}}$, LHT, SM4, SUSY flavor. SO(10) – GUT, $SSU(5)_{HN}$, FBMSSM, RHMFV, L-R, RS_0, gauge flavor, ……….

Observable/mode Luminosity	Current $\sim 1\,\mathrm{ab}^{-1}$	LHCb (2017) $5\,\mathrm{fb}^{-1}$	Super$B$ (5 years) $75\,\mathrm{ab}^{-1}$	LHCb upgrade $50\,\mathrm{fb}^{-1}$	Theory
τ Decays					
$\tau \to \mu\gamma$	Moderately precise	Moderately precise	Very precise	Moderately precise	Clean
$\tau \to e\gamma$	Moderately precise	Moderately precise	Very precise	Moderately precise	Clean
$B_{u,d}$ Decays					
$B \to \tau\nu, \mu\nu$	Moderately precise	No Result	Precise	No Result	Clean, needs Lattice
$B \to K^{(*)+}\nu\overline{\nu}$	No Result	No Result	Very precise	No Result	Clean
S in $B \to K_S^0\pi^0\gamma$	Moderately precise	No Result	Very precise	No Result	Moderately clean
S (other penguin modes)	Moderately precise	Moderately precise	Very precise	Precise	Moderately clean
$A_{CP}\ (B \to X_s\gamma)$	Precise	Moderately precise	Very precise	Moderately precise	Clean
$\mathrm{BR}(B \to X_s\gamma)$	Precise	Moderately precise	Very precise	Moderately precise	Moderately clean
$\mathrm{BR}(B \to X_s ll)$	Moderately precise	No Result	Very precise	No Result	Clean
$\mathrm{BR}(B \to K^{(*)} ll)$	Moderately precise	Precise	Very precise	Very precise	Moderately clean
B_s Decays					
$B_s \to \mu\mu$	No Result	Precise	No Result	Very precise	Clean
β_S from $B_s \to J/\psi\,\phi$	No Result	Precise	No Result	Very precise	Clean
$B_s \to \gamma\gamma$	No Result	No Result	Precise	No Result	Clean
a_{sl}	No Result	Precise	Very precise	Very precise	Clean
D Decays					
Mixing parameters	Moderately precise	Precise	Very precise	Very precise	Clean
CP Violation	No Result	Precise	Very precise	Very precise	Clean
Precision Electroweak					
$\sin^2\theta_W$ at $\Upsilon(4S)$	No Result	No Result	Very precise	No Result	Clean
$\sin^2\theta_W$ at Z-Pole	Very precise	Precise	No Result	Very precise	Moderately clean

Experiment:	No Result	Moderately precise	Precise	Very precise
Theory:		Moderately clean	Clean, needs Lattice	Clean

Rare processes in a U(2)^3 model

- Weakly coupled 3rd generation

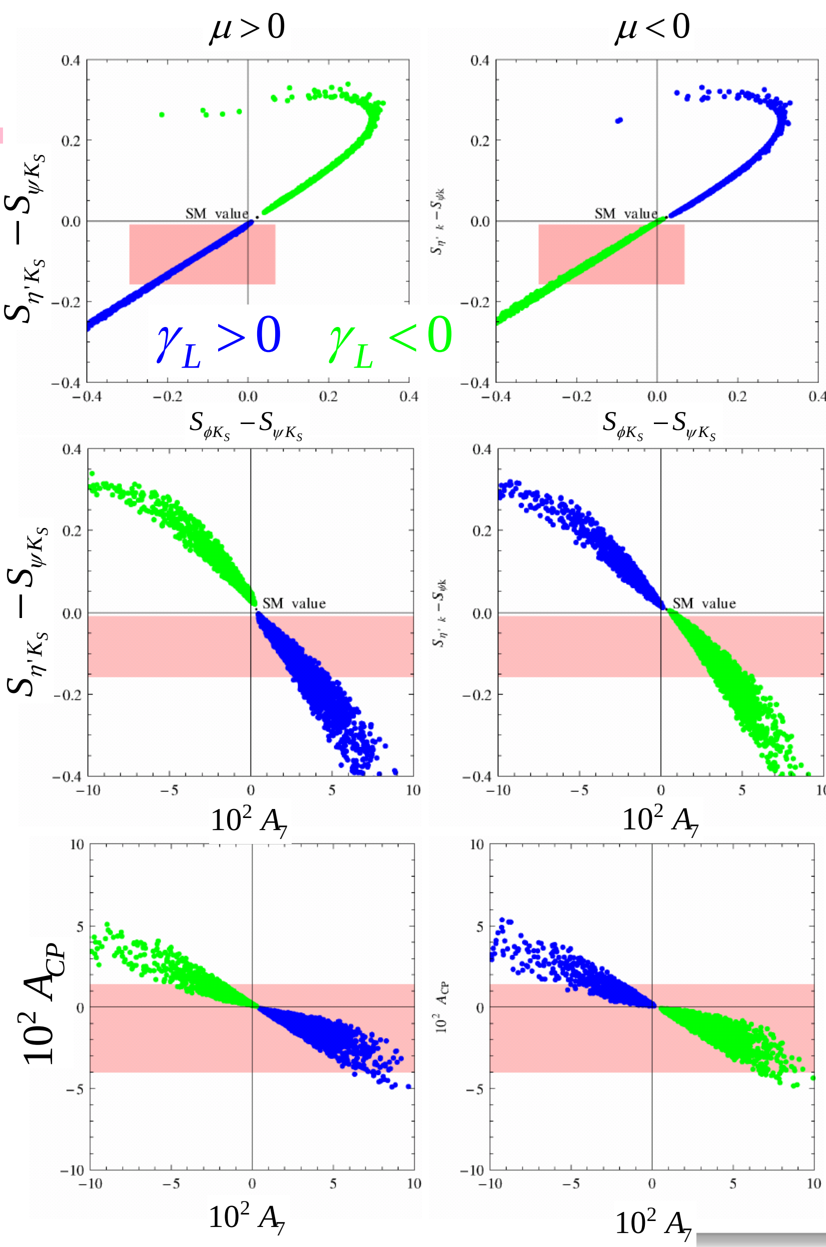
$$(\bar{d}_{L,R} W^d_{L,R} \tilde{d}_{L,R})\tilde{g}$$

$$W^d_L = \begin{pmatrix} c_d & \kappa^* & -\kappa^* s_L e^{i\gamma_L} \\ -\kappa & c_d & -c_d s_L e^{i\gamma_L} \\ 0 & s_L e^{-i\gamma_L} & 1 \end{pmatrix}$$

- Correlations in a variety of rare processes (ΔF=1):

$$S_{\eta' K_S} - S_{\psi K_S}, S_{\phi K_S} - S_{\psi K_S}, A_{CP}(b \to s\gamma), A_7$$

- Also consistent with recent $B_{d,s}$ mixing results

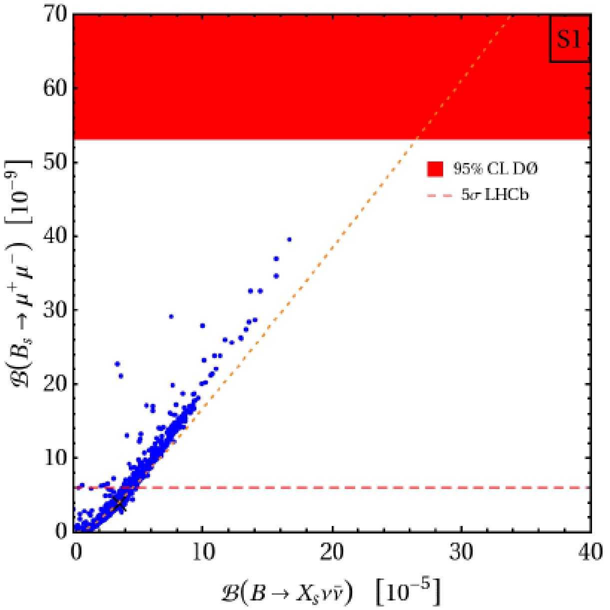


Barbieri, Campli, Isidori, Sala & Straub

Beyond the Unitarity Triangle

- Super*B* has the needed sensitivity

Observable	SM prediction	Experiment	Future sensitivity
$\mathrm{BR}(B \to X_s\gamma)$	$(3.15 \pm 0.23) \times 10^{-4}$ [14]	$(3.52 \pm 0.25) \times 10^{-4}$	$\pm 0.15 \times 10^{-4}$
$A_{\mathrm{CP}}(b \to s\gamma)$	$(-0.6 \div 2.8)\%$ [15]	$(-1.2 \pm 2.8)\%$	$\pm 0.5\%$
$\mathrm{BR}(B \to X_d\gamma)$	$(1.54^{+0.26}_{-0.31}) \times 10^{-5}$ [16]	$(1.41 \pm 0.49) \times 10^{-5}$	
$S_{\phi K_S}$	0.68 ± 0.04 [17, 18]	$0.56^{+0.16}_{-0.18}$	± 0.02
$S_{\eta' K_S}$	0.66 ± 0.03 [17, 18]	0.59 ± 0.07	± 0.01
$\langle A_7 \rangle$	$(3.4 \pm 0.5) \times 10^{-3}$ [19]	–	
$\langle A_8 \rangle$	$(-2.6 \pm 0.4) \times 10^{-3}$ [19]	–	



Correlation between the branching ratios for $B_s \to \mu^+\mu^-$ and $B \to X_s \nu\nu$ in the minimal RS model
M. Bauer *et al.*, arXiv:0912.1625 [hep-ph]

Charged lepton flavor violation

- Charged lepton flavor violation can be large in SUSY GUTs
- LFV branching fractions are very sensitive to the details of the Yukawa couplings and the mass scale of a heavy ν_R

$$A(\ell_i \to \ell_j \gamma) =$$

$$a[Y_e Y_\nu^\dagger Y_\gamma]_{ij} + b[Y_U^\dagger Y_U Y_D]_{ij}$$

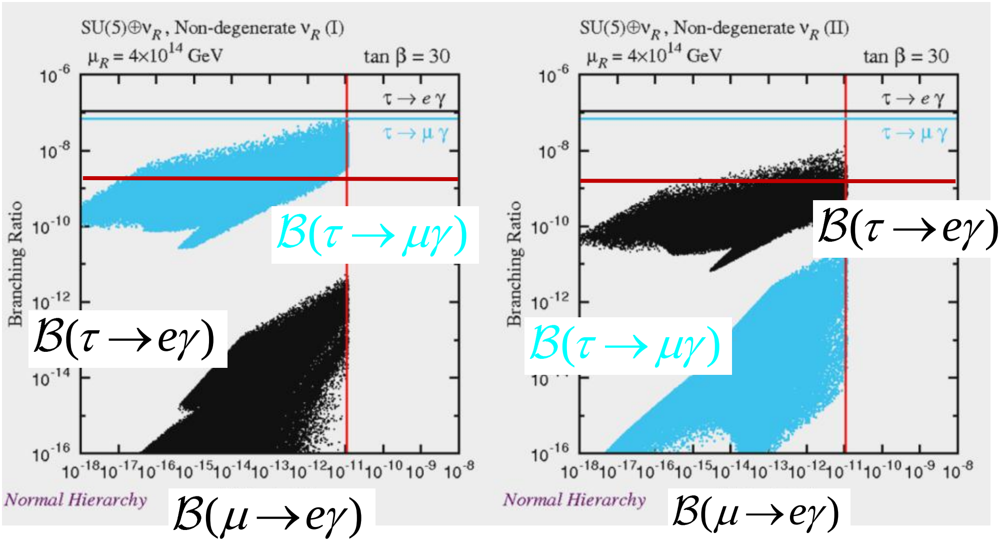
PMNS mixing	CKM mixing
dominant if	dominant if
$M_{\nu_R} > 10^{12}$ GeV	$M_{\nu_R} < 10^{12}$ GeV

$$\boxed{\mathcal{B}(\tau \to \mu\gamma) : \mathcal{B}(\tau \to e\gamma) : \mathcal{B}(\mu \to e\gamma)}$$

$[500-10]:1:1$	$10^4:500:1$

SU(5)$\oplus\nu_R$ (non-degenerate)

[Goto et al.]

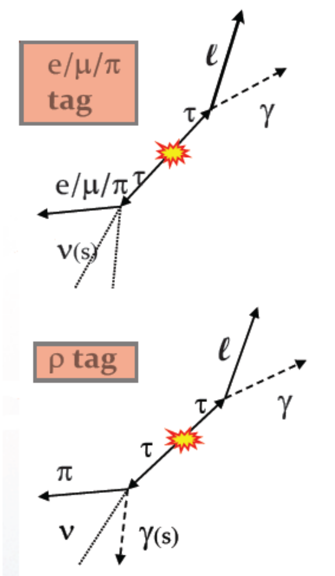


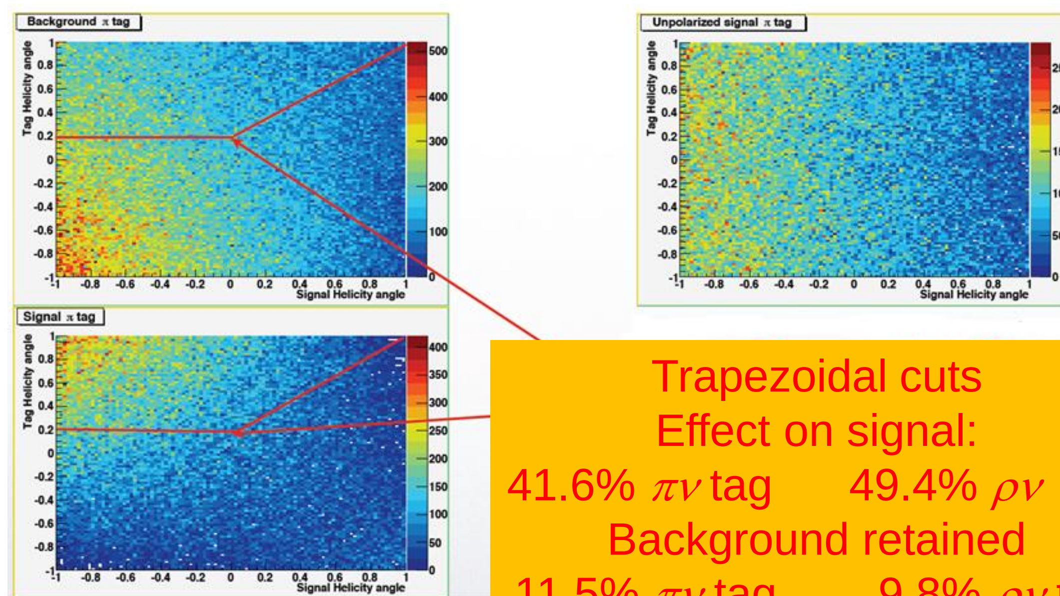
Correlations between $\mathcal{B}(\mu \to e\gamma)$ and $\mathcal{B}(\tau \to \mu\gamma)$, $\mathcal{B}(\tau \to e\gamma)$ in an SU(5) model with right-handed neutrinos, with different structures for the neutrino Yukawa couplings (I and II)

T. Goto et al., Phys.Rev. D77, 095010 (2008)

Sensitivity of $\tau\to\mu\gamma$ decay searches

- $\tau\to\mu\gamma$ searches suffer from irreducible backgrounds:
  Thus sensitivity improves as $1/\sqrt{\int L\,dt}$
  $e^+e^-\to\tau\tau\gamma$ backgrounds are reduced by a hadronic tag, leaving
  $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$ as the main background
- A polarized electron beam can reduce this background by exploiting the correlation between the ν direction in hadronic tag and the helicity of the polarized τ, leading to an improvement in sensitivity of a factor of ~2





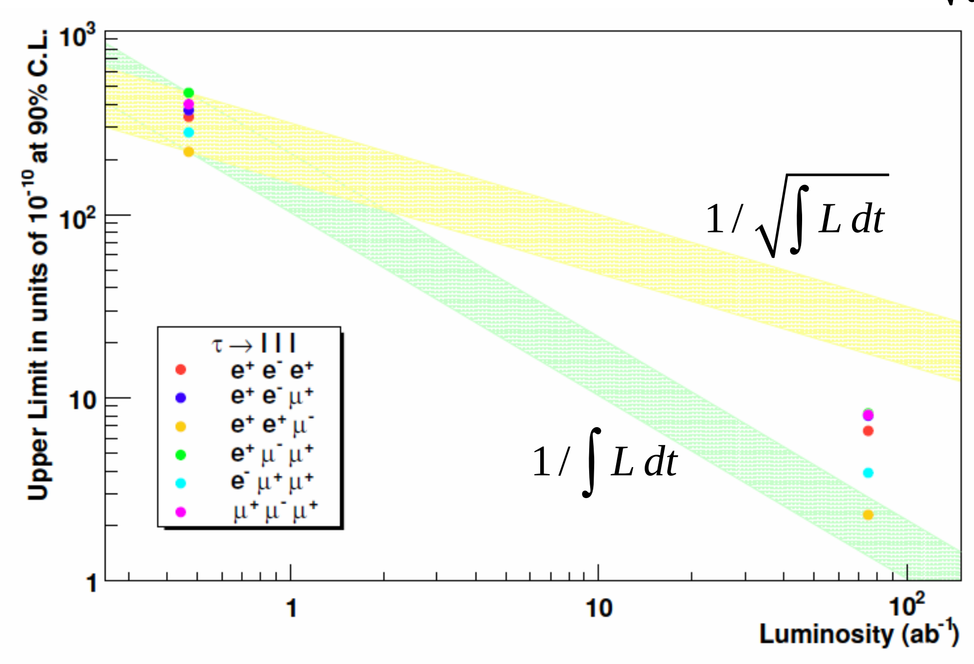
Trapezoidal cuts
Effect on signal:
41.6% $\pi\nu$ tag 49.4% $\rho\nu$ tag
Background retained
11.5% $\pi\nu$ tag 9.8% $\rho\nu$ tag

Sensitivity of $\tau \to \ell\ell\ell$ decay searches

- Current branching fraction limits, typically in the several x10^{-8} range, don't have measurable backgrounds. Is this the case with 100× the data?

❑ It is difficult to do a realistic Monte Carlo simulation of potential backgrounds at a Super *B* Factory. Simulations are underway

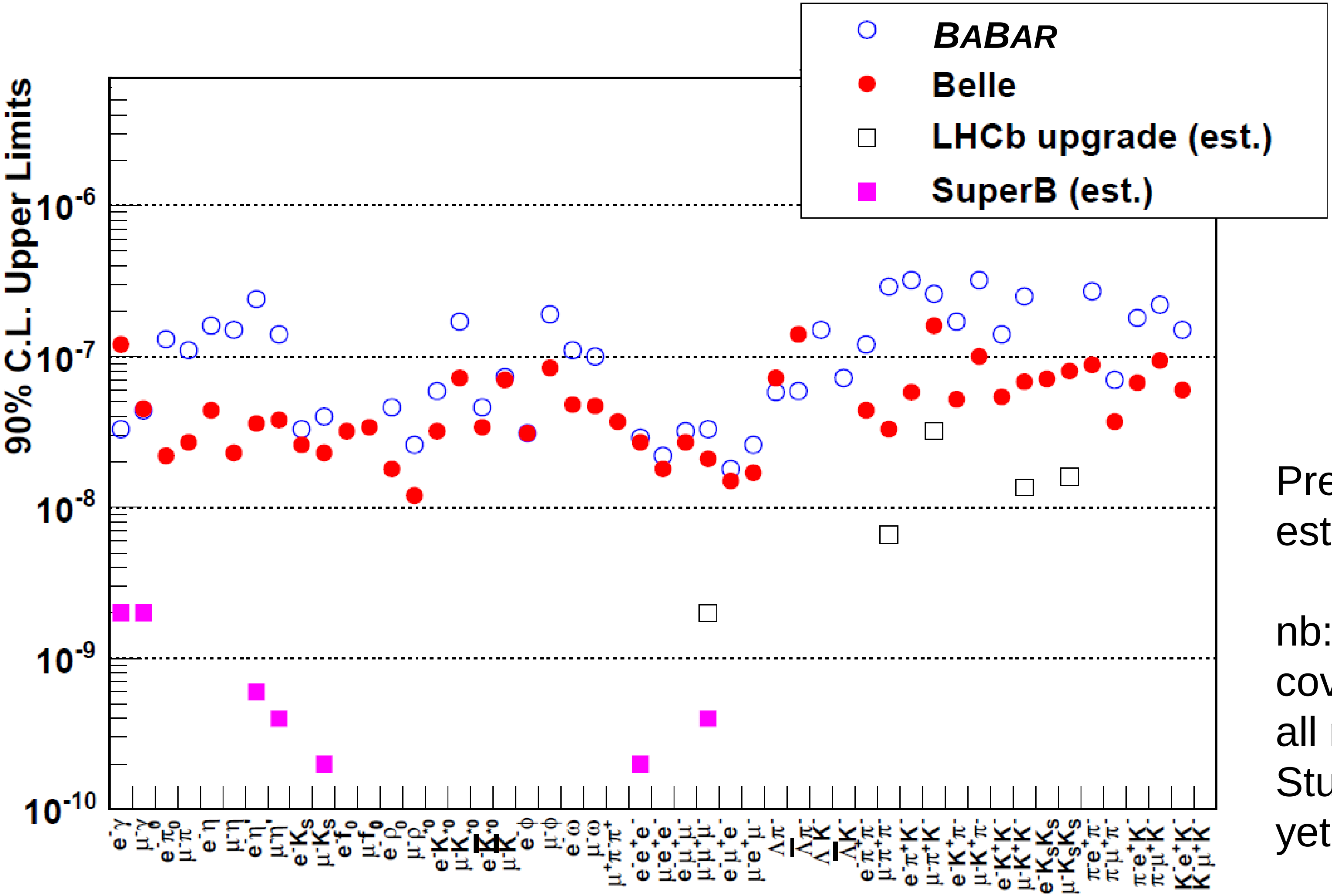
- The no-background regime improves as $1/\int L\,dt$
- If there are background events, the improvement is $1/\sqrt{\int L\,dt}$



Studies ongoing

Polarization not yet incorporated

Super*B* sensitivity directly confronts New Physics models of τ CLFV

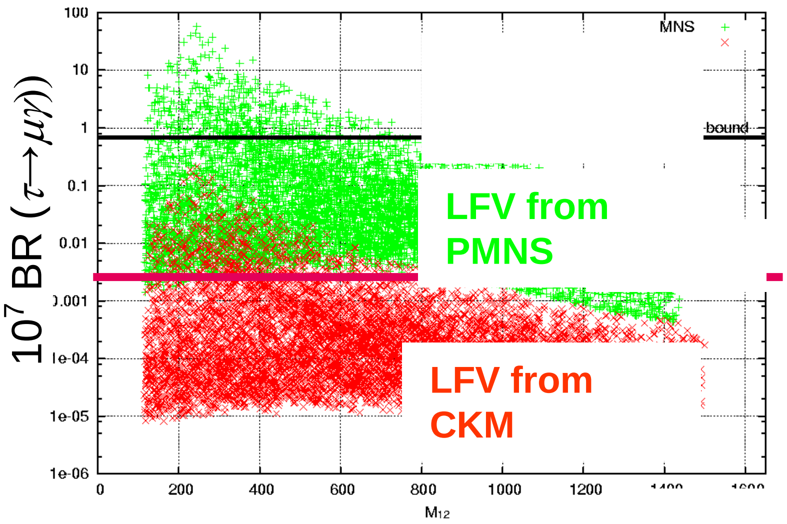


Preliminary estimates

nb: there is coverage in all modes. Studies not yet complete

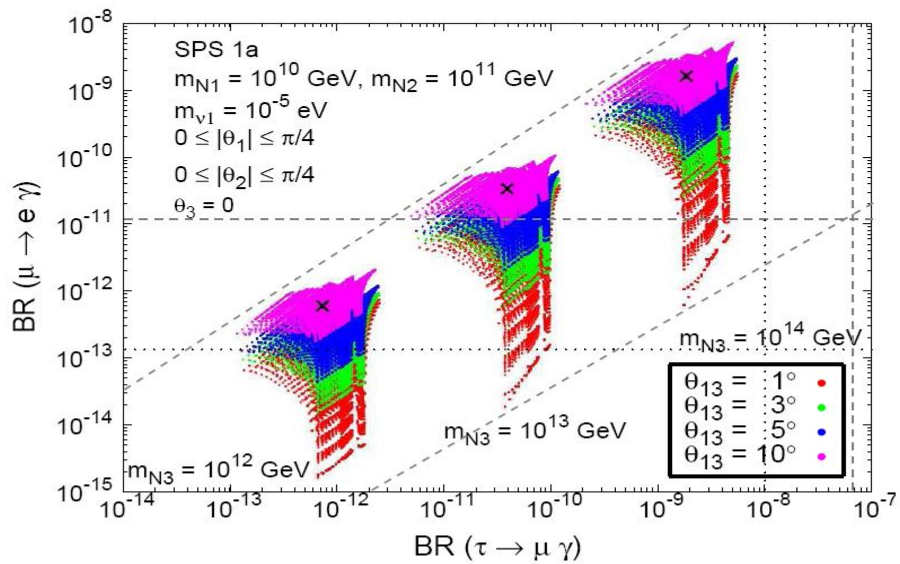
LFV rates discriminate between models

SO(10) GUT



Calibbi, Faccia, Masiero and Vempati

Impact of θ_{13} in a SUSY seesaw model

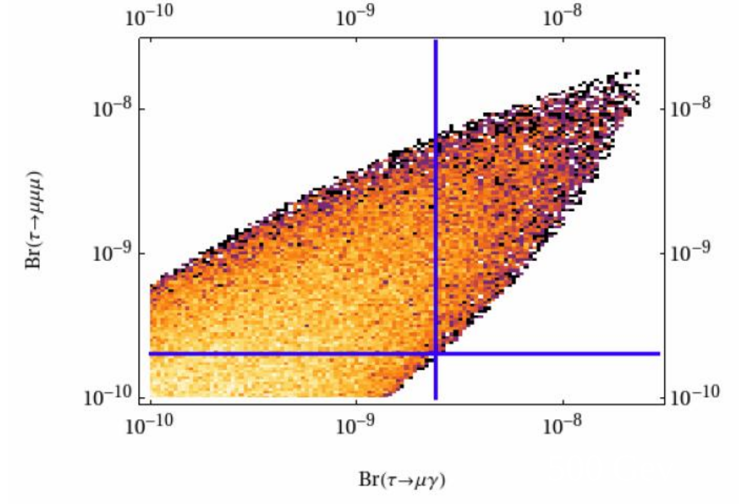


Antusch, Arganda, Herrero and Teixeira

nb: only [magenta box] area is now relevant

LFV rates discriminate between models

ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{Br(\mu^- \to e^- e^+ e^-)}{Br(\mu \to e\gamma)}$	$0.02 \ldots 1$	$\sim 6 \cdot 10^{-3}$	$\sim 6 \cdot 10^{-3}$
$\frac{Br(\tau^- \to e^- e^+ e^-)}{Br(\tau \to e\gamma)}$	$0.04 \ldots 0.4$	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$
$\frac{Br(\tau^- \to \mu^- \mu^+ \mu^-)}{Br(\tau \to \mu\gamma)}$	$0.04 \ldots 0.4$	$\sim 2 \cdot 10^{-3}$	$0.06 \ldots 0.1$
$\frac{Br(\tau^- \to e^- \mu^+ \mu^-)}{Br(\tau \to e\gamma)}$	$0.04 \ldots 0.3$	$\sim 2 \cdot 10^{-3}$	$0.02 \ldots 0.04$
$\frac{Br(\tau^- \to \mu^- e^+ e^-)}{Br(\tau \to \mu\gamma)}$	$0.04 \ldots 0.3$	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$
$\frac{Br(\tau^- \to e^- e^+ e^-)}{Br(\tau^- \to e^- \mu^+ \mu^-)}$	$0.8 \ldots 2.0$	~ 5	$0.3 \ldots 0.5$
$\frac{Br(\tau^- \to \mu^- \mu^+ \mu^-)}{Br(\tau^- \to \mu^- e^+ e^-)}$	$0.7 \ldots 1.6$	~ 0.2	$5 \ldots 10$
$\frac{R(\mu \mathrm{Ti} \to e \mathrm{Ti})}{Br(\mu \to e\gamma)}$	$10^{-3} \ldots 10^{2}$	$\sim 5 \cdot 10^{-3}$	$0.08 \ldots 0.15$

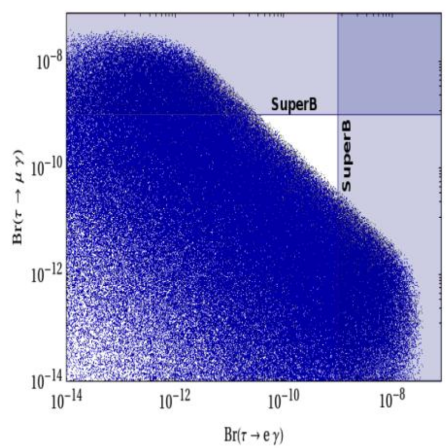


NP scale 500GeV

There are correlations in the $\tau \to \mu\gamma$ and $\ell\ell\ell$ branching fractions

Blanke, Buras, Duling, Recksiegel & Tarantino

$\mathcal{B}(\tau \to \mu\gamma)$ vs. $\mathcal{B}(\tau \to e\gamma)$ in a general fourth generation scenario (Buras)



$\mathcal{B}(\tau \to \mu\gamma)$ vs. $\mathcal{B}(\tau \to e\gamma)$ are anti-correlated.
Observation of both modes would be evidence against a fourth generation

CPV in τ decay

Unpolarized τs

- Measure asymmetries in decay rates of tagged τ decays with two or more hadrons

$\mathcal{B}(\tau^- \to \pi^-\pi^0\nu_\tau) \neq \mathcal{B}(\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau)$	CLEO
$\mathcal{B}(\tau^- \to K^-\pi^0\nu_\tau) \neq \mathcal{B}(\tau^+ \to K^+\pi^0\bar{\nu}_\tau)$	CLEO
$\mathcal{B}(\tau^- \to \pi^\pm\pi^\mp\pi^-\nu_\tau) \neq \mathcal{B}(\tau^+ \to \pi^\pm\pi^\mp\pi^+\bar{\nu}_\tau)$	*Belle*
$\mathcal{B}(\tau^- \to K_S^0\pi^-(\geq 0\pi^0)\nu_\tau) \neq \mathcal{B}(\tau^+ \to K_S^0\pi^+(\geq 0\pi^0)\bar{\nu}_\tau)$	*BABAR*

- The $\tau^- \to K_S^0\pi^-(\geq 0\pi^0)\nu_\tau)$ mode is interesting for two reasons:
  1) Due to the K_S^0 it has an SM *CP* asymmetry of (0.36 ± 0.01)%
  2) *BABAR* has recently measured an asymmetry of opposite sign:
     $(-0.45 \pm 0.24 \pm 0.11)\%$ 3σ from the Standard Model

Interpretation of any observed *CP*V requires understanding of final state interactions

- Measure *CP*-violating or *T*-odd correlations in $\tau^+\tau^-$ decays

Polarized τs – new, more sensitive, observables

- Search for *T*-odd rotationally invariant products, *e.g.* $w_{e^-} \cdot \left(p_{\pi^+} \times p_{\pi^0}\right)$ in τ^+ and τ^- decays such as $\tau^- \to K_S^0\pi^-\nu_\tau,\ K^-\pi^0\nu_\tau, K^-\pi^+\pi^-\nu_\tau, \pi^-\pi^0\nu_\tau, \pi^-\pi^+\pi^-\nu_\tau$

The sensitivity of Super*B* with 75 ab^{-1} should approach 2×10^{-5} in the $\tau^- \to K^-\pi^0\nu_\tau$ mode

- Search for *T*-odd correlation between τ polarization and μ polarization in $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$

τ magnetic moment and EDM

τ magnetic moment

SM prediction: $a_\tau^{SM} = (g-2)/2 = 1177.21(5) \times 10^{-6}$. SUSY contribution $\frac{\Delta a_\tau}{\Delta a_\mu} = \frac{m_\tau^2}{m_\mu^2} \approx 300$

Model-independent bound on New Physics contributions (LEP):

$$-0.007 < a_\tau^{NP} < 0.005 \text{ @ } 95\ \%\ \text{CL}$$

- a_τ measurement can be done in $e^+e^- \to \tau^+\tau^-$ with unpolarized beams
  - The real part of the form factor $F_2(0) = \mathrm{Re}\{F_2(0)\} = a_\tau = (g-2)/2$ needs the measurement of correlations on the τ decay products of *both* polarized τ s

$$\frac{d\sigma(e^+e^- \to \tau^+\tau^-)}{d\cos\theta_{\tau^-}} = \frac{\pi\alpha^2}{2s}\beta\left[(2-\beta^2\sin^2\theta_{\tau^-})\left|F_1(s)\right|^2 + 4\mathrm{Re}\,F_2(s)\right]$$

- Super*B* has the sensitivity to improve this measurement by three orders of magnitude using a polarized electron beam

$$A_T^{\pm} = \frac{\sigma_R^{\pm}|P_e - \sigma_L^{\pm}|P_e}{\sigma} = \mp\alpha_{\pm}\frac{3\pi}{8(3-\beta^2)\gamma}\left[\left|F_1\right|^2 + (2-\beta^2)\gamma^2\,\mathrm{Re}\{F_2\}\right]$$

$$A_L^{\pm} = \frac{\sigma_{FB}^{\pm}(+)|P_e - \sigma_{FB}^{\pm}(-)|P_e}{\sigma} = \mp\alpha_{\pm}\frac{3}{4(3-\beta^2)}\left[\left|F_1\right|^2 + 2\,\mathrm{Re}\{F_2\}\right]$$

$$\mathrm{Re}\{F_2(s)\} = \mp\frac{8(3-\beta^2)}{3\pi\gamma\beta^2}\frac{1}{\alpha_{\pm}}\left(A_T^{\pm} - \frac{\pi}{2\gamma}A_L^{\pm}\right)$$

Sensitivity

	15 ab^{-1}		75 ab^{-1}	
	Re{F_2}	Im{F_2}	Re{F_2}	Im{F_2}
Super$B$ at $\Upsilon(4S)$ unpolarized beams	1.1×10^{-5}	7.8×10^{-6}	4.7×10^{-6}	3.5×10^{-6}
Super$B$ at $\Upsilon(4S)$ polarized e^- beam	3.7×10^{-6}	7.8×10^{-6}	1.7×10^{-6}	3.5×10^{-6}

Caveats:
perfect tracking
100% e^- polarization.
$\pi\nu$ and $\rho\nu$ modes only

Systematic error ~10% of statistical error

J. Bernabéu, G.A. González-Sprinberg and J. Vidal
J. Bernabéu, G.A. González-Sprinberg, J. Papavassiliou and J. Vidal

- A more recent evaluation, made using an 80% polarized beam, a more recent detector performance simulation and all τ decay modes, yields

$\Delta a_\tau = (1.0\text{–}2.6) \times 10^{-6}$, depending on decay modes included

τ EDM

New Physics sensitivity for a τ EDM is boosted by $\sim m_\tau / m_e$ = 3.5 × 10^3

Some predictions in the 10^{-19} range (SM < 10^{-34} *e*cm)

Can be done with unpolarized beams

$$-0.22\, e\mathrm{cm} < \mathrm{Re}\{d_\tau^\gamma\} \times 10^{16} < 0.45\, e\mathrm{cm} \; @ \; 95\% \; CL$$ Belle

Polarized τ s provide a new, more sensitive *CP*-odd *T*-odd observable:

$$A_N^{CP} = \frac{1}{2}\left(A_N^+ + A_N^-\right) = \alpha_h \frac{3\pi\gamma\beta}{8(3-\beta^2)} \frac{2m_\tau}{e} \mathrm{Re}\left\{d_\tau^\gamma\right\}$$

where the azimuthal asymmetry for the two polarizations is

$$A_N^\mp = \frac{\sigma_L^\mp - \sigma_R^\mp}{\sigma} = \alpha_\mp \frac{3\pi\gamma\beta}{8(3-\beta^2)} \frac{2m_\tau}{e} \mathrm{Re}\left\{d_\tau^\gamma\right\}$$

This allows the use of single τ polarization observables, improving sensitivity

Sensitivity estimate for Super*B* (Bernabéu *et al.)* :

$$\left|\mathrm{Re}\{d_\tau^\gamma\}\right| \le 7.2 \times 10^{-20} \, e\,\mathrm{cm} \text{ for } 75\,\mathrm{ab}^{-1} \; @ \; 95\%\,\mathrm{CL} \quad \text{using } \tau^- \to \pi^- \bar{\nu}_\tau,\ \rho^- \bar{\nu}_\tau \text{ decay modes}$$

$$\text{Belle II: } \sigma\left(\mathrm{Re}\{d_\tau^\gamma\}\right) \sim 3 \times 10^{-19} \, e\,\mathrm{cm} \text{ for } 50\,\mathrm{ab}^{-1} \text{ using } \tau^- \to \pi^- \bar{\nu}_\tau,\ \rho^- \bar{\nu}_\tau \text{ decay modes}$$

Either estimate brings the sensitivity into the regime of New Physics predictions

Conclusions

- High precision, high sensitivity flavor physics measurements, from the next generation of experiments, Super*B* in particular, will be crucial to relating new phenomena found at the LHC to particular New Physics models
- The goal, reconstructing the NP Lagrangian, will require explicit production of new particles and comprehending the detailed pattern of departures from, or adherence to, precise SM predictions in the flavor sector
  - This interplay will continue over the next decade, combining discovered new particles, SM discrepancies found in flavor measurements and/or constraints from the quark and lepton decay sector.

THE END