The Super*B* physics programme

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(on behalf of the Super*B* collaboration)

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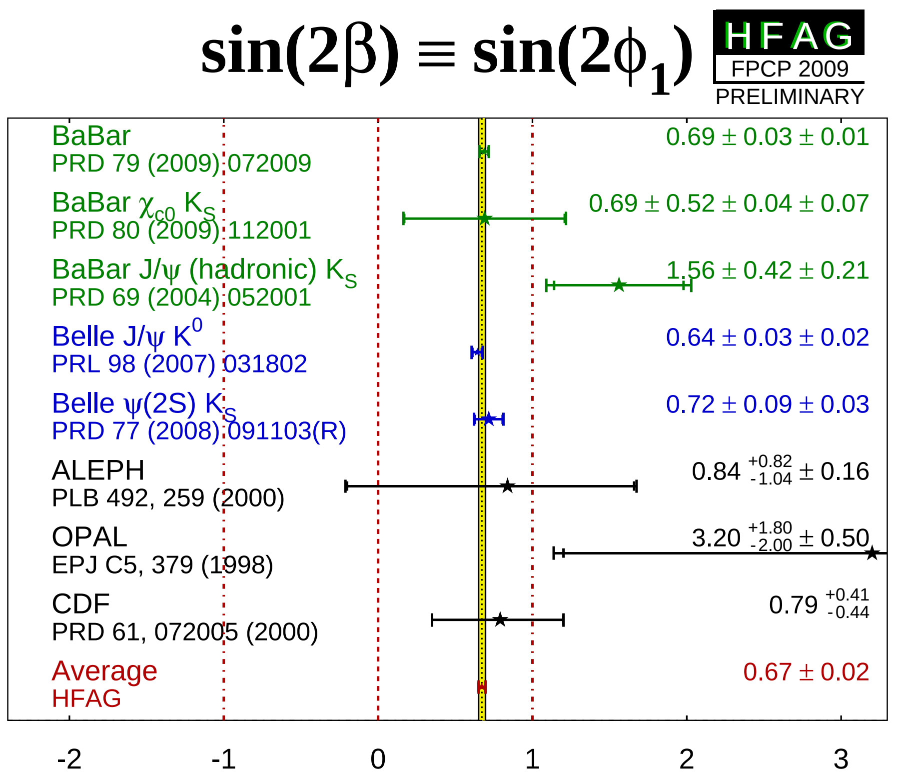
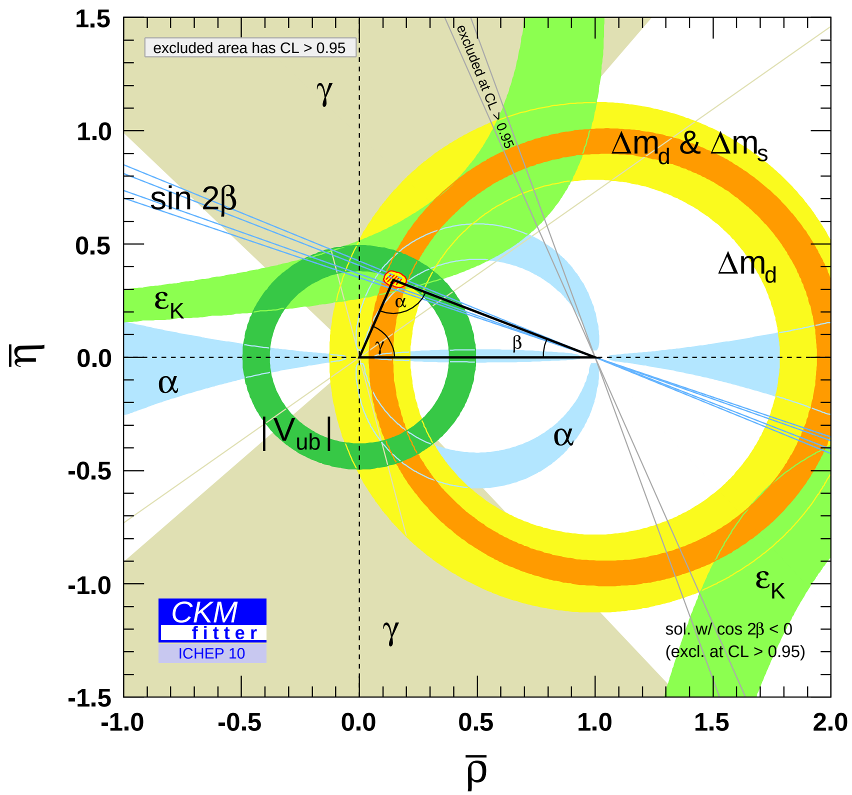
B-factories overconstrained Standard Model & searched for New Physics





- **CKM matrix phase main source of CP violation** (2008 Nobel prize to M.Kobayashi & T.Maskawa)
- no evidence (but perhaps few glimpses) of Physics beyond the Standard Model

The Super*B* project

- $\Upsilon(4S)$-peak asymmetric energy e^+e^- **Super Flavor Factory**
- flexible design will also allow **running at the charm threshold**
- **80% polarized electron beam** further defines the already clean initial e^+e^- state
- accelerator: **100× B-factories luminosity** with same power by squeezing beams (ILC)
- detector: moderately improved *BABAR* detector (e.g. vertex detector closer to the beam)
- $\boldsymbol{L = 10^{36}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}}$ around the $\Upsilon(4S)$, 10 times less at the charm threshold
  - $\Upsilon(4S)$: **coherent *B* mesons** & time-dep. measurements, charm hadrons, **tau leptons**
  - charm threshold: **coherent *D* mesons** & time-dep. measurements, tau leptons
- Physics program
  - topics: bottom and charm physics, tau LFV, precision EW, light new physics
  - emphasis: new physics sensitivity **competitive** and **complementary** with LHC experiments
  - don't forget: e^+e^- clean data for precision measurements in almost every energy-accessible topic
- data-taking: beginning of 2017
  - plan: $75\,\mathrm{ab}^{-1}$ around $\Upsilon(4S)$ (+ continuum), $0.5\,\mathrm{ab}^{-1}$ at charm threshold, $1\,\mathrm{ab}^{-1}$ at $\Upsilon(5S)$

Physics case for Super*B*

New Physics (NP) expected beyond Standard Model, perhaps at $\Lambda \sim 1$ TeV

Super*B* can search for NP, in a complementary & competivive way with LHC, MEG and other expts

case 1 **LHC finds New Physics (therefore determining Λ)**

- ► Super*B* can study NP flavour structure, but can also be sensitive to larger scales than LHC

case 2 **the NP scale is beyond the LHC reach**

- ► Super*B* can look for indirect NP signals up to $\Lambda \sim 10$ TeV and more

♦ LHCb and MEG have similar abilities but

- ► some *B* final states are only measurable by Super*B* (with neutrals or missing momentum)
- ► Super*B* can test tau LFV, *CPV*, EDM, *g*–2, can search for light new physics
- ► Super*B* can do useful measurements on entangled charm mesons decays

♦ productive competition with Belle2, but Super*B* has also unique features

- ► Super*B* can run at the charm threshold and will have a polarized electron beam
- ► plus it is designed to take $75\,\text{ab}^{-1}$ rather than $50\,\text{ab}^{-1}$ of data

Super*B* physics studies started in ∼2005

2005 Hewett et al., The Discovery Potential of a Super B factory, **hep-ph/0503261**

2007 Conceptual Design Report, **arXiv:0709.0451 [hep-ex]**

2008 Valencia retreat proceedings, **arXiv:0810.1312 [hep-ex]**

2010 SuperB white paper: Physics, **arXiv:1008.1541 [hep-ex]**

Super*B* golden modes

(indirect searches for NP need 1) good exp. precision & 2) good theory understanding)

$B_{u,d}$ Physics

- $B^+ \to \tau^+\nu$, $B^+ \to \mu^+\nu$, $B^+ \to K^{(*)+}\nu\bar{\nu}$, $b \to s\gamma$, $b \to s\ell\ell$
- precision $\sin 2\beta$ measurements, in particular $B \to \eta' K^0_S, \to K^0_S\pi^0\gamma$

τ Physics

- Lepton flavour violation in tau decays: especially $\tau \to \mu\gamma$ and $\tau \to 3\ell$

Charm Physics

- mixing parameters and *CP* violation.

B_s Physics

- Semi-leptonic *CP* asymmetry A^s_{SL}.
- $B_s \to \gamma\gamma$.

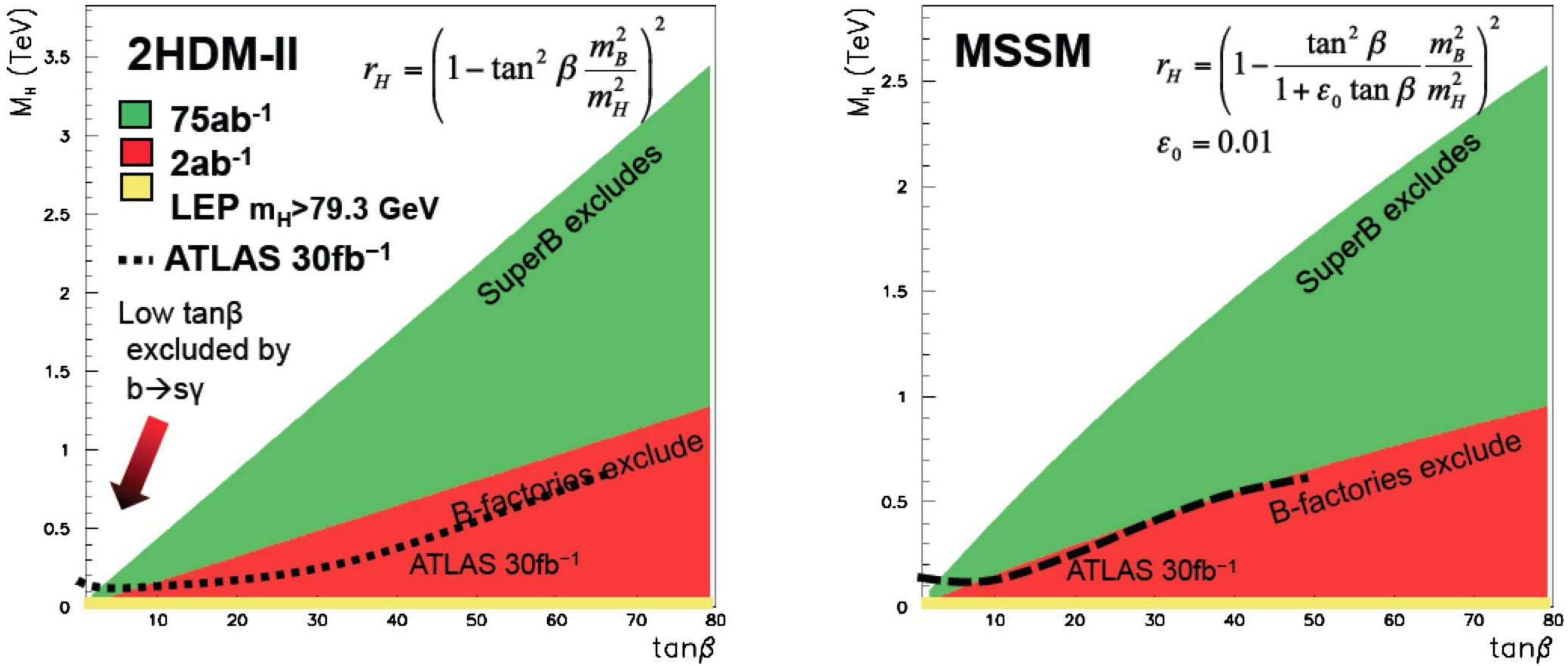
Other Physics

- Precision measurement of $\sin^2\theta_W$ at $\sqrt{s} = 10.58$ GeV/c^2.
- Direct searches for non-standard light Higgs bosons, Dark Matter and Dark Forces

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

- helicity suppressed, reasonably clean SM prediction
  - (within the SM, BR proportional to $|V_{ub}|^2$ and f_B^2. Now tension with other $|V_{ub}|$ determinations)
- negative interference from charged Higgs amplitude (favoring tau over muon)
- non trivial selection and bkg suppression because of neutrinos in final state
- Super*B* offers ideal conditions
  - clean events, hermetic detector, well defined initial state, just 2 *B*s
  - → tag other side with reconstructed *B*
  - → study “extra-energy” distribution with data for bkg subtraction
- 3% measurement is possible

$\mathcal{B}(B \to \tau\nu)$ effective constraint on charged Higgs NP



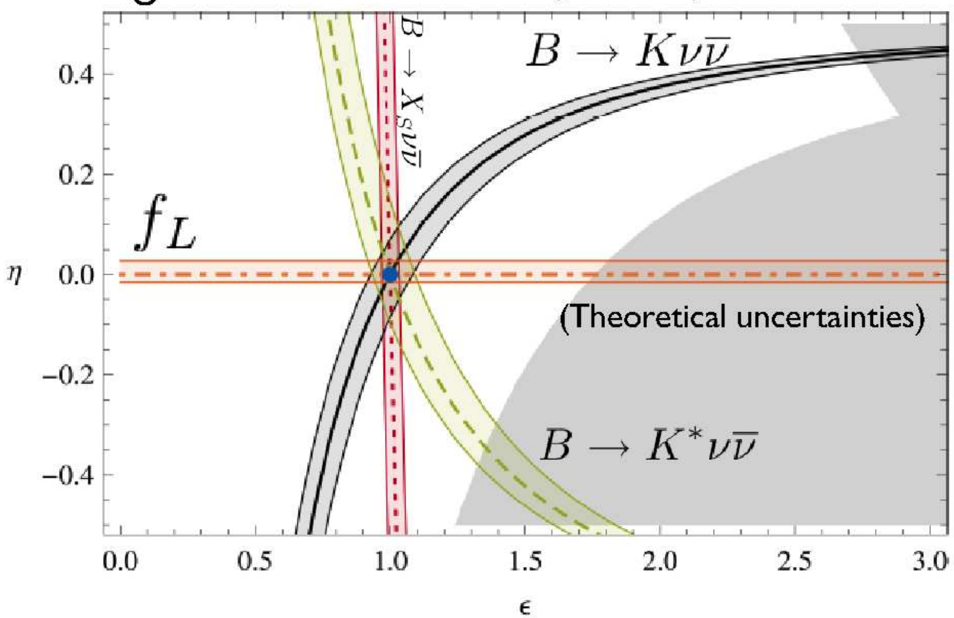
- $r_H = \mathcal{B}(B \to \tau\nu)/\mathcal{B}_{SM}(B \to \tau\nu)$ limits assuming the SM value is measured
- ATLAS exclusion limit for 30 fb^{-1} at 14 TeV computed using arXiv:0901.0512

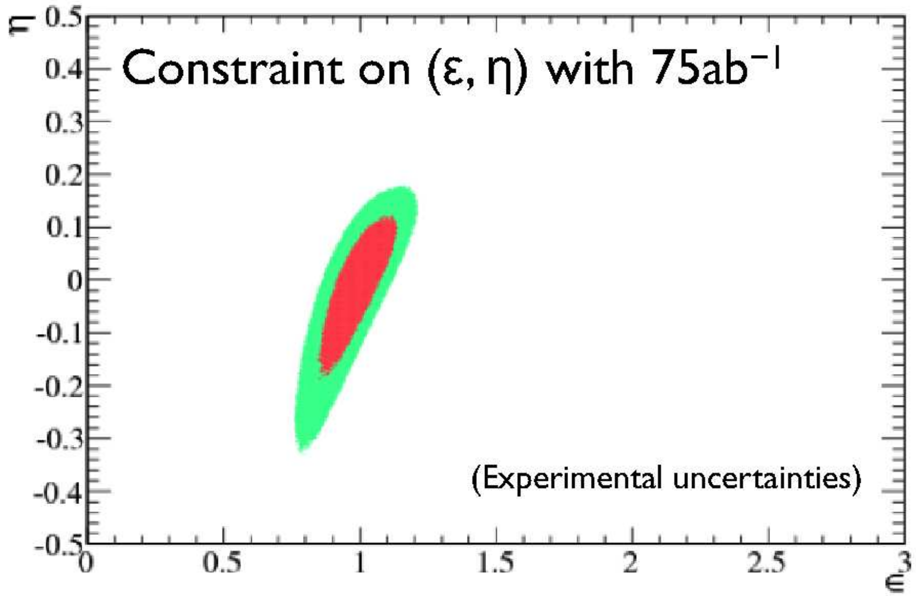
$\mathcal{B}(B^+ \to K^{*+}\nu\bar{\nu})$ and $\mathcal{B}(B^+ \to K^+\nu\bar{\nu})$

$$\epsilon = \frac{\sqrt{|C_L^\nu|^2 + |C_R^\nu|^2}}{|(C_L^\nu)^{\mathrm{SM}}|}\,, \qquad \eta = \frac{-\mathrm{Re}\,(C_L^\nu C_R^{\nu *})}{|C_L^\nu|^2 + |C_R^\nu|^2}$$

Sensitive to models with Z penguins and RH currents.

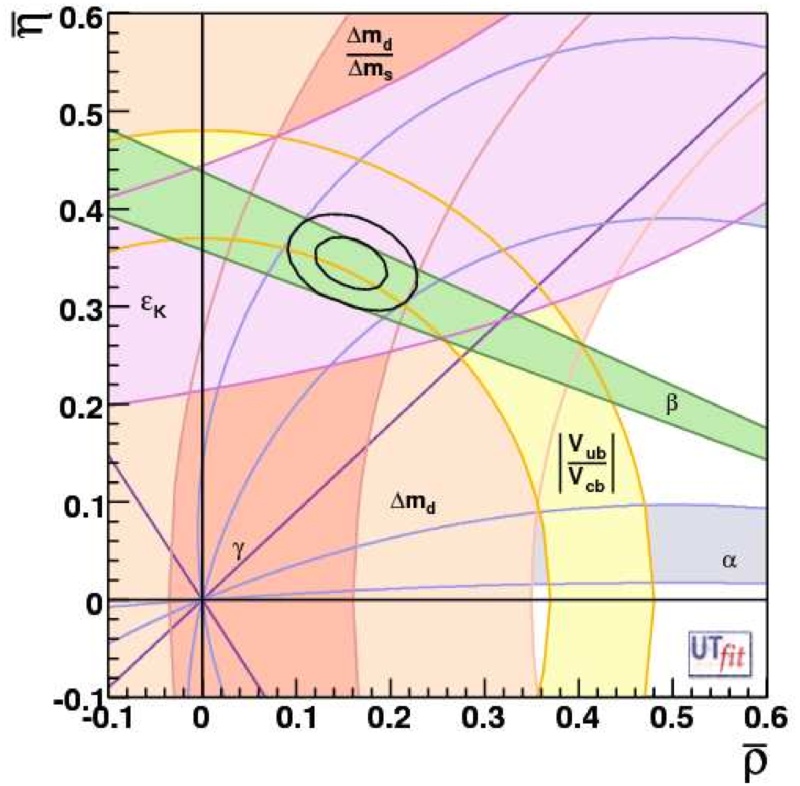
e.g. see Altmannshofer, Buras, & Straub



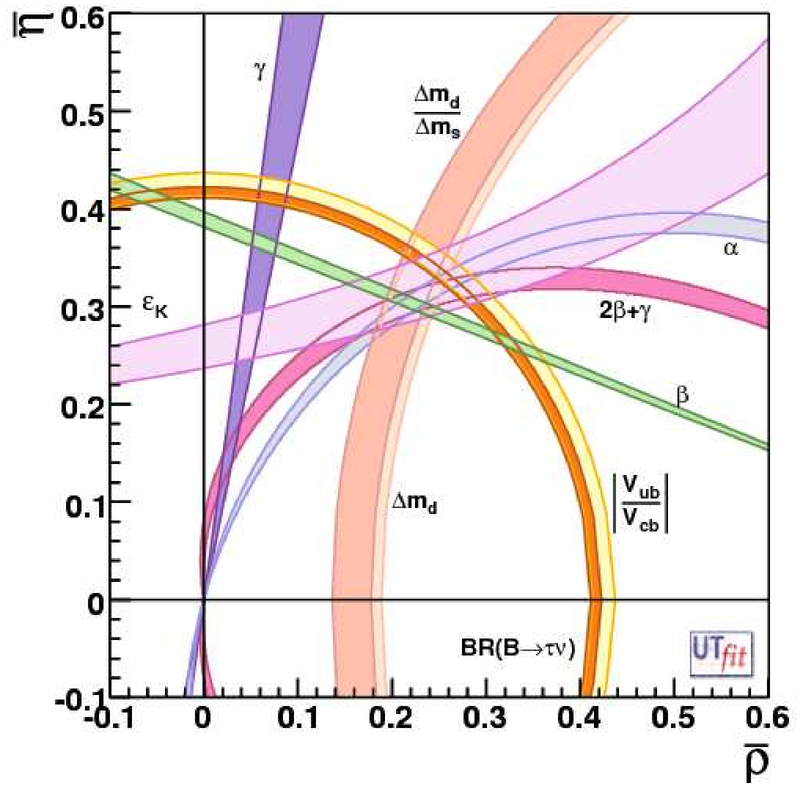


From ∼10% to ∼1% experimental precision on CKM

CKM fit in 2006



possible fit with Super*B* & improved lattice QCD

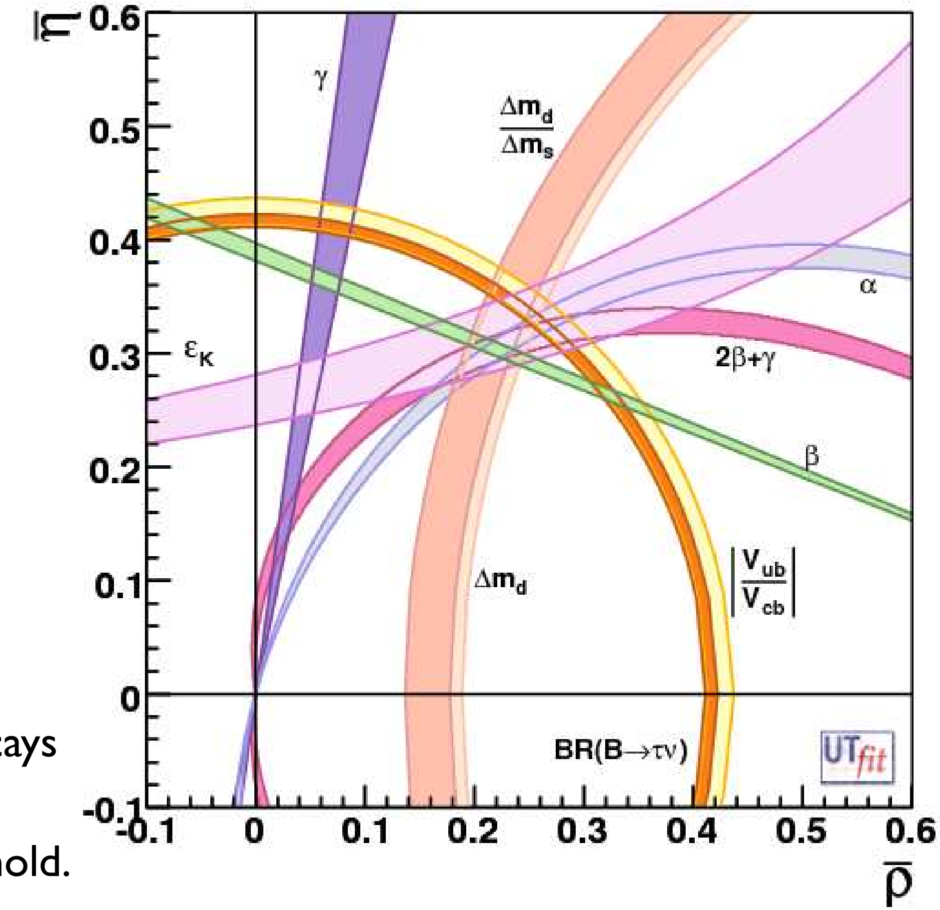


- bands show 95% constraints, 2006 values assumed for the Super*B* fit

From ~10% to ~1% experimental precision on CKM

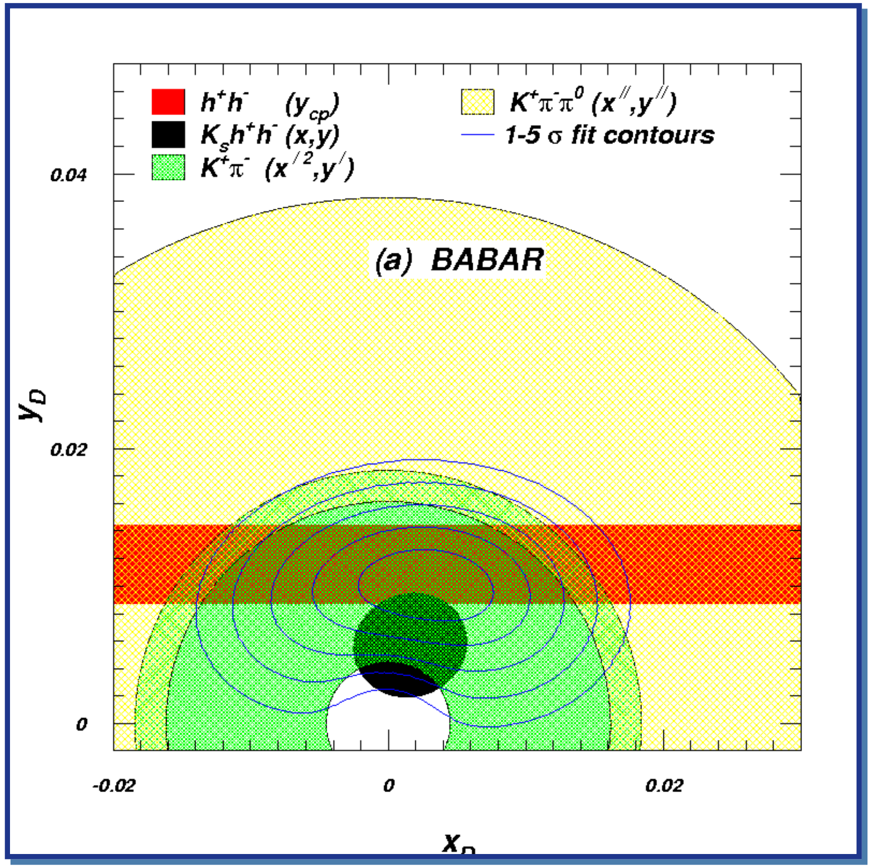
- Unitarity Triangle Angles
  - $\sigma(\alpha)$ = 1−2°
  - $\sigma(\beta)$ = 0.1°
  - $\sigma(\gamma)$ = 1−2°
- CKM Matrix Elements
  - $|V_{ub}|$
    - Inclusive σ = 2%
    - Exclusive σ = 3%
  - $|V_{cb}|$
    - Inclusive σ = 1%
    - Exclusive σ = 1%
  - $|V_{us}|$
    - Can be measured precisely using τ decays
  - $|V_{cd}|$ and $|V_{cs}|$
    - can be measured at/near charm threshold.

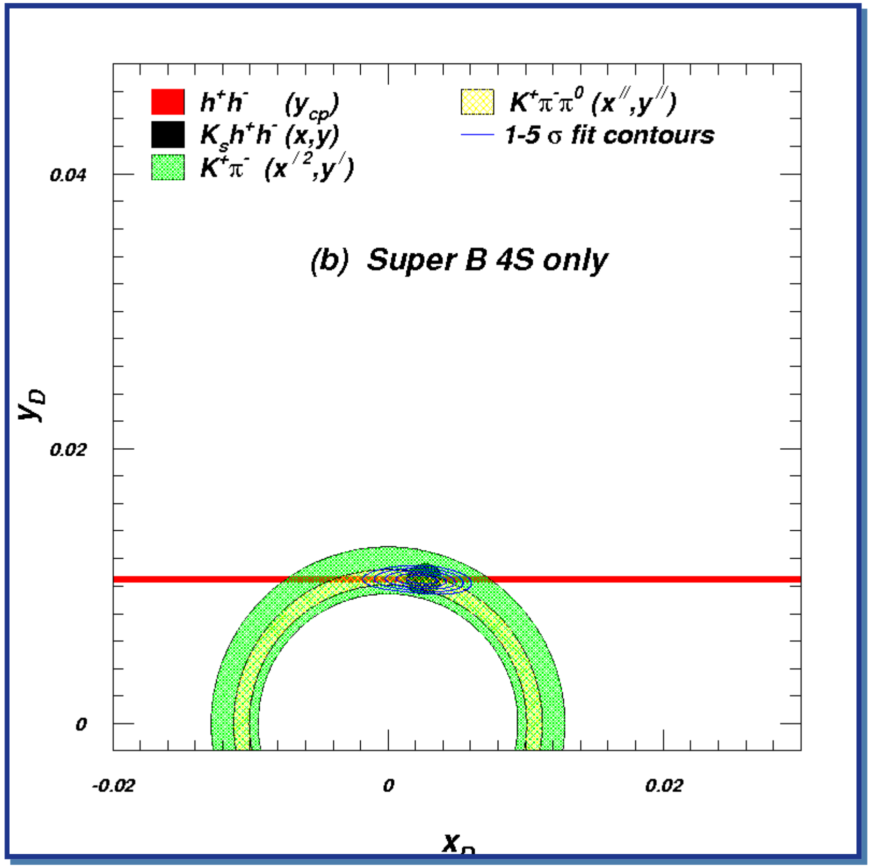
The "dream" scenario with $75ab^{-1}$



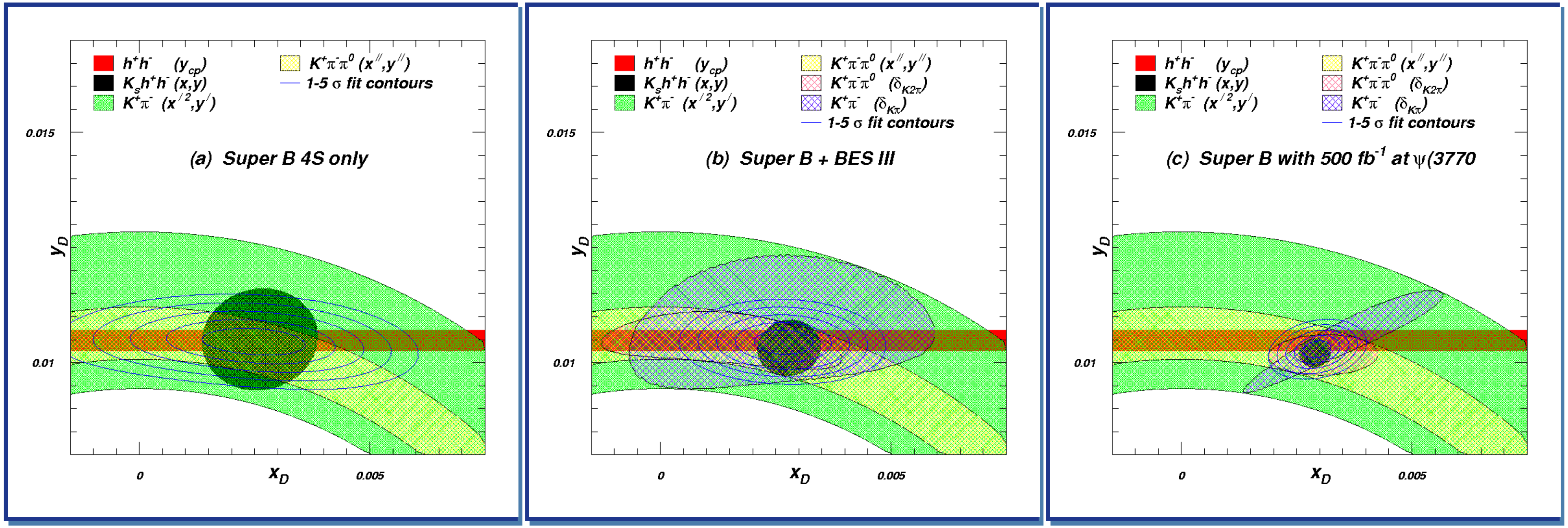
- SuperB Measures the sides and angles of the Unitarity Triangle

SuperB D^0–mixing reach, using only $\Upsilon(4S)$ data





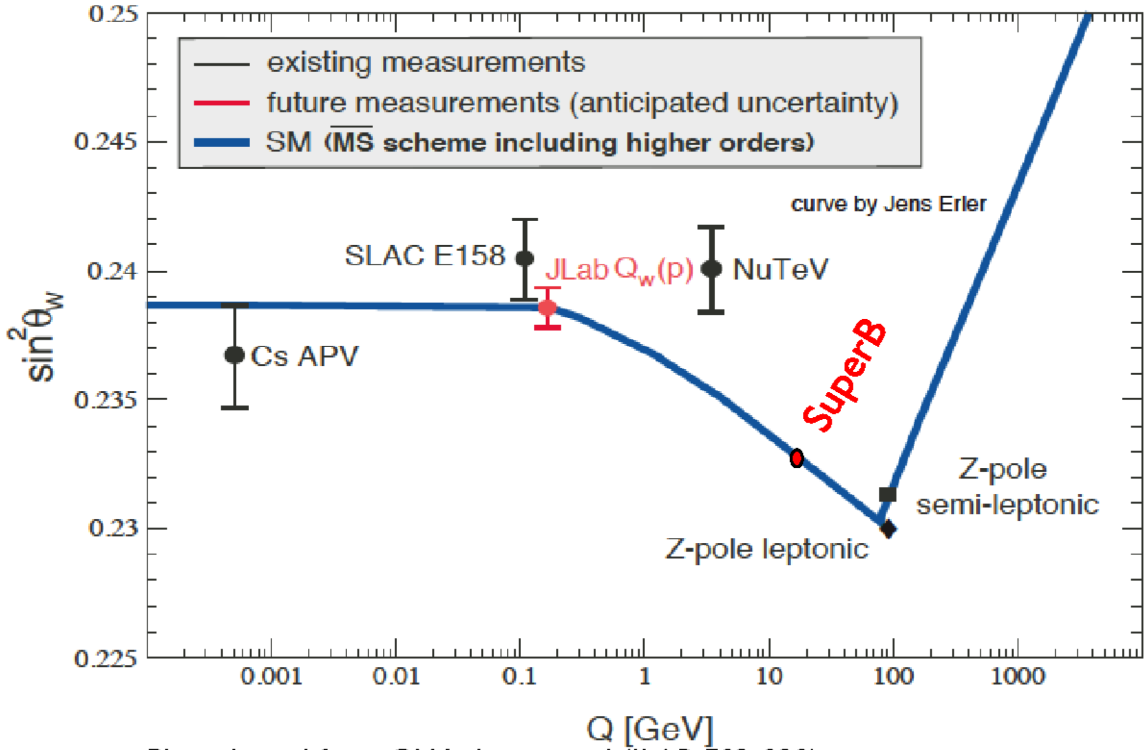
Super*B* D^0–mixing reach, using also charm threshold data



- entangled *D* mesons produced at threshold used to measure Dalitz strong phases

Precision electroweak measurements

- $\sin^2\theta_W$ can be measured with polarised e^- beam
  - $\sqrt{s}=\Upsilon(4S)$ is theoretically clean, c.f. b-fragmentation at Z pole



Plot adapted from QWeak proposal (JLAB E02-020)

Measure LR asymmetry in

$$e^+e^- \to c\bar{c}$$
$$e^+e^- \to \mu^+\mu^-$$
$$e^+e^- \to \tau^+\tau^-$$

at the $\Upsilon(4S)$ to same precision as LEP/SLC at the Z-pole.

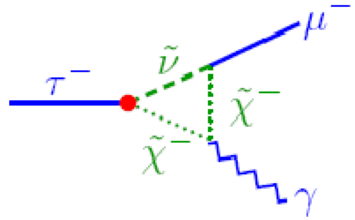
Can also perform crosscheck at $\psi(3770)$.

Super*B* Tau Physics NP probes

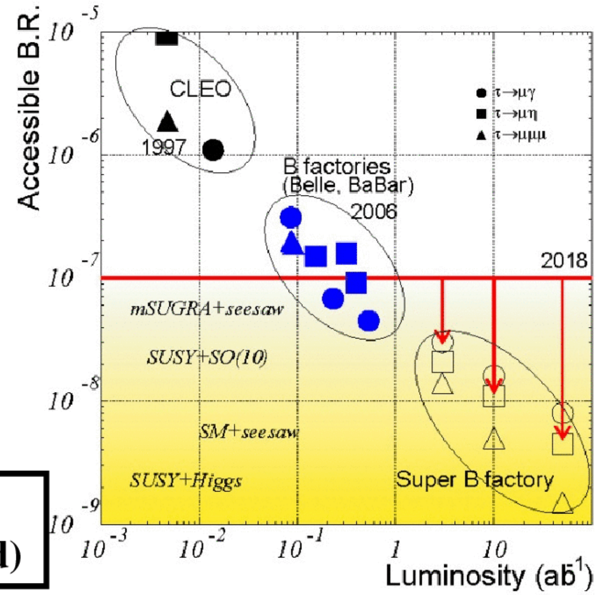
- Lepton Flavor violation in tau decays
  - many NP models predict tau LFV within Super*B* sensitivity
  - unambiguous NP probe, negligible theory uncertainties
  - Super*B* is complementary with MEG
    ($\mu \to e\gamma$ can be accidentally suppressed, tau measurements are complementary)
  - best channels: $\boldsymbol{\tau \to \mu\gamma, \tau \to 3\ell, \tau \to \mu\rho, \tau \to \mu\eta}$
- Tau *g*–2
  - if MSSM explains today's $\Delta a_\mu \approx 3{\cdot}10^{-9}$ discrepancy $\Longrightarrow$ $\boldsymbol{\Delta a_\tau \approx m_\tau^2/m_\mu^2 \cdot \Delta a_\mu \approx 1{\cdot}10^{-6}}$
  - Super*B* sensitivity is in the range of such prediction
- Tau EDM and CPV
  - Super*B* sensitive to some few NP model CPV effects
  - tau EDM constrained by electron EDM upper limit to a range inaccessible by Super*B*
    anyway, Super*B* can substantially improve the existing limits
- all: **beam polarization improves precision & helps discriminating NP models**

Lepton Flavour Violation in τ decays

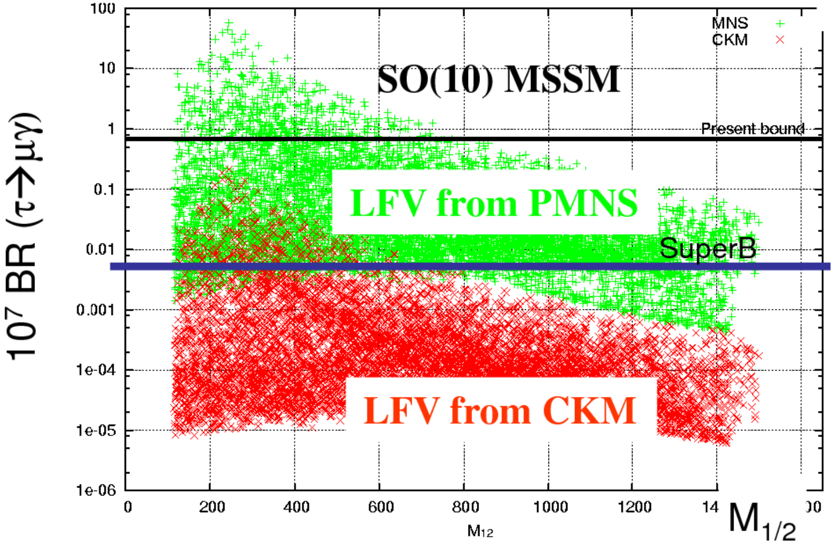
Process	Sensitivity
$\mathcal{B}(\tau \to \mu\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell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



MEG sensitivity μ→eγ ~10⁻¹³
(can be accidentally suppressed)



Measurements and origin of LFV



Discrimination between SUSY and LHT

ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{\mathcal{B}(\tau^-\to e^-e^+e^-)}{\mathcal{B}(\tau\to e\gamma)}$	0.4...2.3	$\sim 1\cdot 10^{-2}$	$\sim 1\cdot 10^{-2}$
$\frac{\mathcal{B}(\tau^-\to \mu^-\mu^+\mu^-)}{\mathcal{B}(\tau\to \mu\gamma)}$	0.4...2.3	$\sim 2\cdot 10^{-3}$	0.06...0.1
$\frac{\mathcal{B}(\tau^-\to e^-\mu^+\mu^-)}{\mathcal{B}(\tau\to e\gamma)}$	0.3...1.6	$\sim 2\cdot 10^{-3}$	0.02...0.04
$\frac{\mathcal{B}(\tau^-\to \mu^-e^+e^-)}{\mathcal{B}(\tau\to \mu\gamma)}$	0.3...1.6	$\sim 1\cdot 10^{-2}$	$\sim 1\cdot 10^{-2}$
$\frac{\mathcal{B}(\tau^-\to e^-e^+e^-)}{\mathcal{B}(\tau^-\to e^-\mu^+\mu^-)}$	1.3...1.7	~ 5	0.3...0.5
$\frac{\mathcal{B}(\tau^-\to \mu^-\mu^+\mu^-)}{\mathcal{B}(\tau^-\to \mu^-e^+e^-)}$	1.2...1.6	~ 0.2	5...10

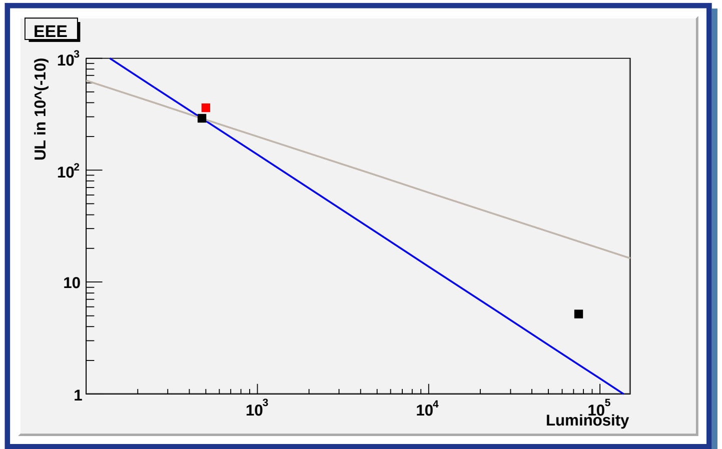
The ratio τ→ lll / τ→ μγ is not suppressed in LHT by α_e as in MSSM

Super*B* sensitivity to Tau LFV

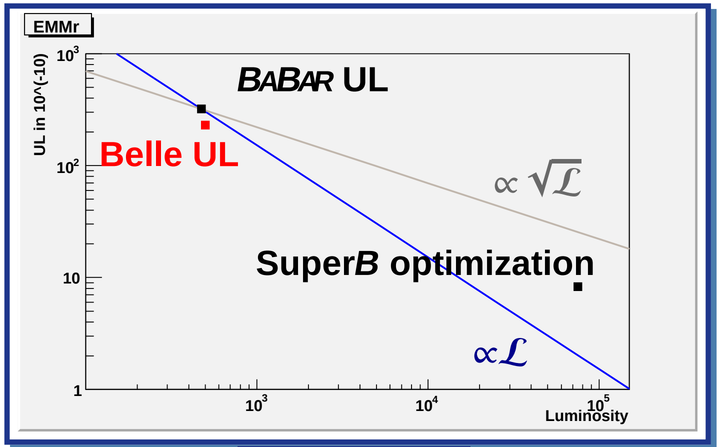
- repeating *BABAR* analysis insures an improvement of $\sqrt{\mathcal{L}_{\text{SuperB}}/\mathcal{L}_{BABAR}} \approx \sqrt{150} \approx 12$
- if n. of expected background events ~1 events, improvement of $\mathcal{L}_{\text{SuperB}}/\mathcal{L}_{BABAR} \approx 150$
- some of previous slide estimates have been refined and updated in the white paper

Process	Expected 90% CL upper limit	3σ evidence reach
$\mathcal{B}(\tau \to \mu\gamma)$	$2.4 \cdot 10^{-9}$	$5.4 \cdot 10^{-9}$
$\mathcal{B}(\tau \to e\gamma)$	$3.0 \cdot 10^{-9}$	$6.8 \cdot 10^{-9}$
$\mathcal{B}(\tau \to \ell\ell\ell)$	$2.3\text{–}8.2 \cdot 10^{-10}$	$1.2\text{–}4.0 \cdot 10^{-9}$

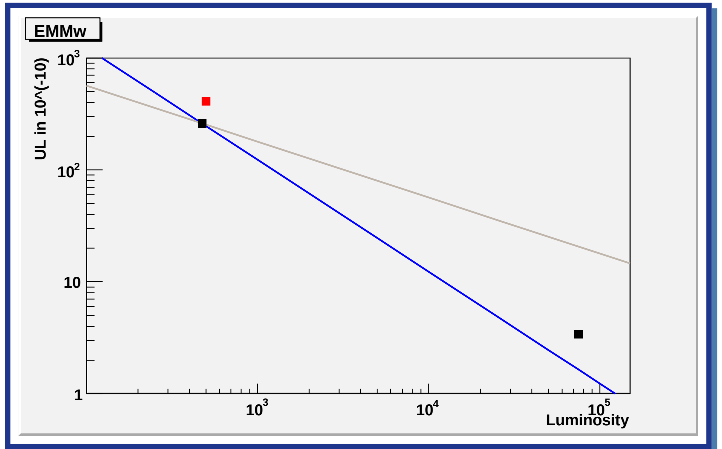
$\tau \to 3\ell$ 90% CM upper limit extrapolations: $\propto \mathcal{L}$ vs. $\propto \sqrt{\mathcal{L}}$ vs. re-optimization



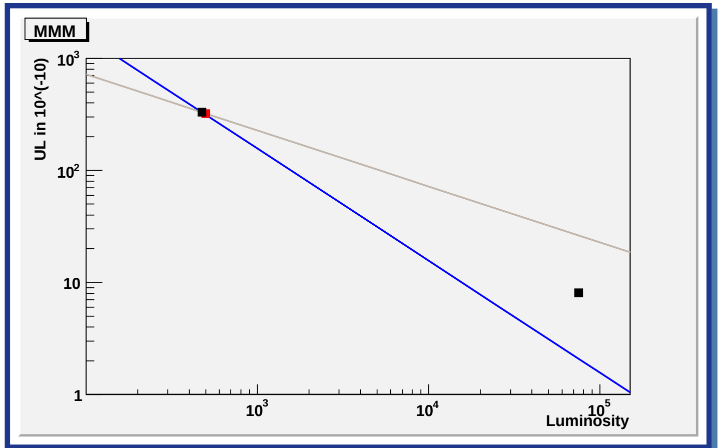
$\tau \to eee$



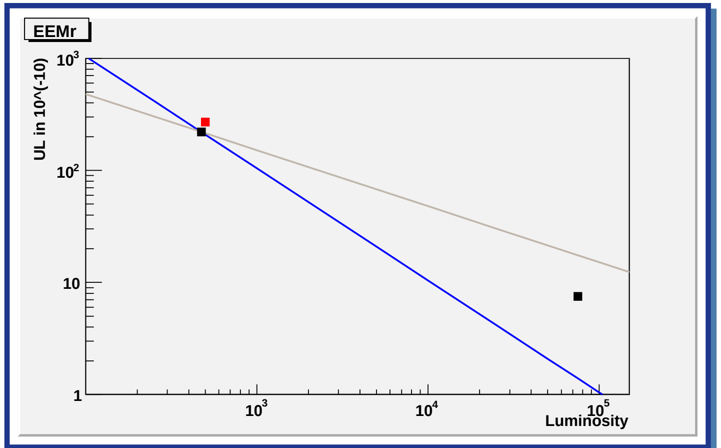
$\tau \to e\mu{+}\mu{-}$



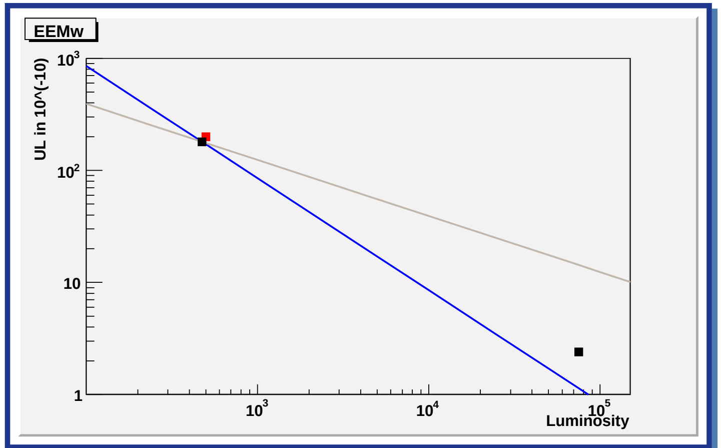
$\tau{-} \to e{+}\mu{-}\mu{-}$



$\tau \to \mu\mu\mu$

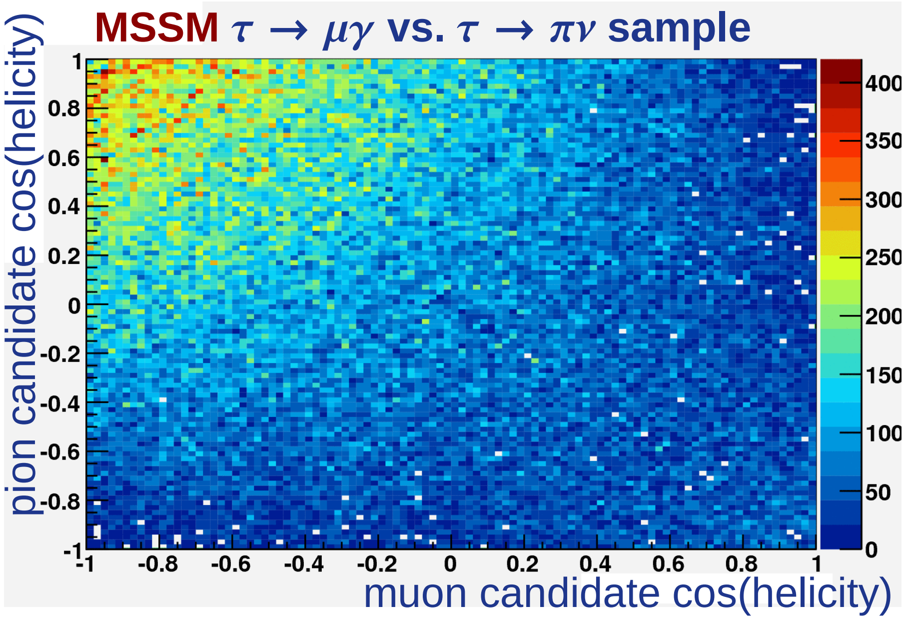


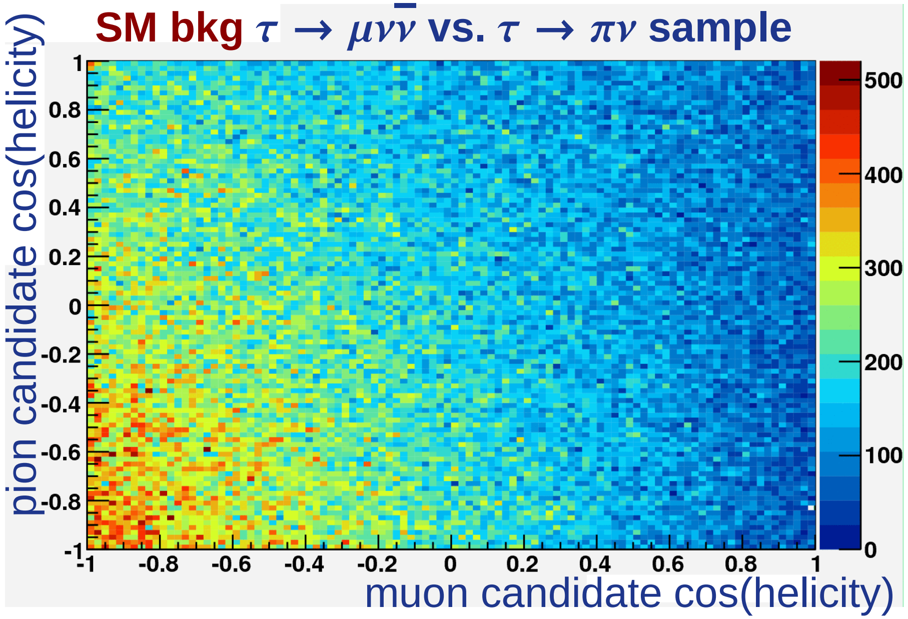
$\tau \to \mu e{+}e{-}$



$\tau{-} \to \mu{+}e{-}e{-}$

Super*B* beam polarization effects on $\tau \to \mu\gamma$ LFV search





- 80% polarized electron beam
- SUSY LFV spin correlations Tauola decay mode added by S.Banerjee
- Super*B* fast simulation

- can improve S/N ratio (assuming LFV NP model)
  - sensitivity improvements being evaluated
- can discriminate between NP models

Tau g–2 at Super*B* with beam polarization

- MSSM would shift muon g–2 by about the presently observed discrepancy $\Delta a_\mu \approx 3{\cdot}10^{-9}$

Δa_μ and Δa_τ for various SPS points

SPS	1 a	1 b	2	3	4	5
$\Delta a_\mu \times 10^{-9}$	3.1	3.2	1.6	1.4	4.8	1.1
$\Delta a_\tau \times 10^{-6}$	0.9	0.9	0.5	0.4	1.4	0.3

(specific parameters can produce Δa_τ as high as $1{\cdot}10^{-5}$)

- J.Bernabeu et al., JHEP098P1108 estimate Super*B* $\sigma(a_\tau) = [0.75 - 1.7]{\cdot}10^{-6}$
  - Super*B* actually measures $\boldsymbol{a_\tau(q^2)}$ from final state distributions of $e^+e^- \rightarrow \tau^+\tau^-$
    - however, Δa_τ from high energy NP contributions is constant for small q^2
  - real part from τ polar angle distribution or transv.&long. polarization
- from tau EDM studies (see next slides) with more realistic assumptions ⟶ Super*B* $\sigma(a_\tau) \sim 2.4{\cdot}10^{-6}$

Tau EDM at Super*B*

- $|d_e| < 1.6{\cdot}10^{-27}$ *e* cm at 90% CL, 10.1103/PhysRevLett.88.071805 / PDG10
- most NP models expect $|d_\tau| \propto (m_\tau/m_e)|d_e|$
- Super*B* 2010 Physic Report reviews NP models expectations and concludes that:
  $|d_e|$ upper limit → $|d_\tau^{NP}| < 10^{-22}$ *e* cm
- Super*B* actually measures **$d_\tau(q^2)$ form factor** from final state distributions of $e^+e^- \to \tau^+\tau^-$
  - however, high energy NP contributions are constant for small q^2
- beam polarization permits measurements based on single tau distributions
- J.Bernabeu et al., arXiv:0707.1658v1 [hep-ph], estimate Super*B* $\sigma(d_\tau) \approx 7.2{\cdot}10^{-20}$ *e* cm
  - 100% electron beam polarization, no uncertainty
  - only $\tau \to \pi\nu$, $\tau \to \rho\nu$, no reconstruction uncertainty
- with more realistic assumptions, Super*B* $\sigma(d_\tau) \approx 10{\cdot}10^{-20}$ *e* cm
  (note that information can be obtained also from the other decay channels)
- extrapolate Belle EDM search, **Phys. Lett. B551, 16 (2003), hep-ex/0210066**
  → Super*B* $\sigma(d_\tau) \approx 17$–$34{\cdot}10^{-20}$ *e* cm (both real and imaginary parts)

Tau *CPV* at Super*B*

- SM predictions in general very small
  ($\tau^{\pm} \to K^{\pm}\pi^{0}\nu$ *CP* asymmetry $\mathcal{O}(10^{-12})$, D. Delepine et al., PRD 72, 033009 (2005), hep-ph/0503090)
- small SM *CP* asymmetry in $\tau^{\pm} \to K_S\pi^{\pm}\nu$ from *CPV* in $K^0\overline{K}^0$
  $3.3{\cdot}10^{-3} \pm 2\%$ relative, I.I.Bigi & A. I. Sanda, PLB 625, 47 (2005), hep-ph/0506037
- most NP models do not induce measurable tau CPV
- R-parity violating SUSY ⟶ CPV related asymmetries up to 10%, saturating existing limits
  - sizable asymmetries in $\tau \to K\pi\nu_\tau$, $\tau \to K\eta^{(\prime)}\nu_\tau$, and $\tau \to K\pi\pi\nu_\tau$
- CLEO, PRL 88, 111803 (2002), hep-ex/0111095, 13.3 fb^{-1}, $\tau \to K_S\pi\nu$

  ⟶ optimal asymmetry observable $\langle\xi\rangle$ **= (–2.0 ± 1.8)·10^{-3}**
  - data calibration with $\tau \to \pi\pi\pi\nu$
- extrapolating at Super*B*, $\sigma_{\langle\xi\rangle} \approx 2.4{\cdot}10^{-5}$
- beam polarization can provide extra equivalent luminosity (to be studied)

Sensitivity of Super$B$ golden modes to specific NP models

Observable/mode	H^+ high $\tan\beta$	MFV NP low $\tan\beta$	non-MFV 2-3 sector	NP in Z peng.	RH currents	LHT	SUSY AC	SUSY RVV2	SUSY AKM	SUSY δLL	SUSY FBMSSM	SUSY GUT-CMM
$\tau \to \mu\gamma$							★★★	★★★	★	★★★	★★★	★★★
$\tau \to \ell\ell\ell$						★★★						?
$B \to \tau\nu, \mu\nu$	★★★(CKM)											
$B \to K^{(*)+}\nu\bar{\nu}$			★	★★★			★	★	★	★	★	?
S in $B \to K_S^0\pi^0\gamma$			★★		★★★							
S in other penguins			★★★(CKM)		★★★		★★★	★★	★	★★★	★★★	?
$A_{CP}(B \to X_s\gamma)$			★★★		★★		★	★	★	★★★	★★★	?
$BR(B \to X_s\gamma)$		★	★★		★							★★
$BR(B \to X_s\ell\ell)$			★★	★	★							?
$B \to K^{(*)}\ell\ell$ (FBA)							★	★	★	★★★	★★★	?
a_{sl}^s			★★★			★★★						★★★
Charm mixing							★★★	★	★	★	★	
CPV in Charm	★★									★★★		

This is the end

Observable/mode	Current now	LHC*b* (2017) 5 fb^{-1}	Super*B* (2021) 75 ab^{-1}	Belle2 (2021) 50 ab^{-1}	LHC*b* upgrade (10 years of running) 50 fb^{-1}	theory now
τ Decays						
$\tau \to \mu\gamma$ ($\times 10^{-9}$)	< 44		< 2.4	< 5.0		
$\tau \to e\gamma$ ($\times 10^{-9}$)	< 33		< 3.0	< 3.7 (est.)		
$\tau \to \ell\ell\ell$ ($\times 10^{-10}$)	$< 150 - 270$	< 244	$< 2.3 - 8.2$	< 10	< 24	
$B_{u,d}$ Decays						
BR($B \to \tau\nu$) ($\times 10^{-4}$)	1.64 ± 0.34		0.05	0.04		1.1 ± 0.2
BR($B \to \mu\nu$) ($\times 10^{-6}$)	< 1.0		0.02	0.03		0.47 ± 0.08
BR($B \to K^{*+}\nu\overline{\nu}$) ($\times 10^{-6}$)	< 80		1.1	2.0		6.8 ± 1.1
BR($B \to K^{+}\nu\overline{\nu}$) ($\times 10^{-6}$)	< 160		0.7	1.6		3.6 ± 0.5
BR($B \to X_s\gamma$) ($\times 10^{-4}$)	3.55 ± 0.26		0.11	0.13	0.23	3.15 ± 0.23
$A_{CP}(B \to X_{(s+d)}\gamma)$	0.060 ± 0.060		0.02	0.02		$\sim 10^{-9}$
$B \to K^*\mu^+\mu^-$ (events)	250	5000	10-15k	7-10k	65,000	-
BR($B \to K^*\mu^+\mu^-$) ($\times 10^{-6}$)	1.15 ± 0.16		0.06	0.07		1.19 ± 0.39
$B \to K^*e^+e^-$ (events)	165	400	10-15k	7-10k	5,000	-
BR($B \to K^*e^+e^-$) ($\times 10^{-6}$)	1.09 ± 0.17		0.05	0.07		1.19 ± 0.39
$A_{FB}(B \to K^*\ell^+\ell^-)$	0.27 ± 0.14		0.040	0.03		-0.089 ± 0.020
$B \to X_s\ell^+\ell^-$ (events)	280		8,600	7,000		-
BR($B \to X_s\ell^+\ell^-$) ($\times 10^{-6}$)	3.66 ± 0.77		0.08	0.10		1.59 ± 0.11
S in $B \to K^0_S\pi^0\gamma$	-0.15 ± 0.20		0.03	0.03		-0.1 to 0.1
S in $B \to \eta' K^0$	0.59 ± 0.07		0.01	0.02		± 0.015
S in $B \to \phi K^0$	0.56 ± 0.17	0.15	0.02	0.03	0.03	± 0.02
B^0_s Decays						
BR($B^0_s \to \gamma\gamma$) ($\times 10^{-6}$)	< 8.7		0.3	$0.2 - 0.3$		0.4 - 1.0
A^s_{SL} ($\times 10^{-3}$)	-7.87 ± 1.96		4.			0.02 ± 0.01
***D* Decays**						
x	$(0.63 \pm 0.20\%$	0.06%	0.02%	0.04%	0.02%	$\sim 10^{-2}$
y	$(0.75 \pm 0.12)\%$	0.03%	0.01%	0.03%	0.01%	$\sim 10^{-2}$ (see above).
y_{CP}	$(1.11 \pm 0.22)\%$	0.05%	0.03%	0.05%	0.01%	$\sim 10^{-2}$ (see above).
$\lvert q/p \rvert$	$(0.91 \pm 0.17)\%$	10%	2.7%	3.0%	3%	$\sim 10^{-3}$ (see above).
$\arg\{q/p\}$ (°)	-10.2 ± 9.2	5.6	1.4	1.4	2.0	$\sim 10^{-3}$ (see above).
Other processes Decays						
$\sin^2\theta_W$ at $\sqrt{s} = 10.58\,\mathrm{GeV}/c^2$			0.0002			clean