Update on Super*B* Tau Physics

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SuperB

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Sharpening the tau physics case at Super*B*

step #1

list measurements where Super*B* can resolve differences between SM and NP predictions

- list processes with precise SM and NP predictions (esp. SM forbidden/ suppressed)
- estimate Super*B* experimental precision

step #2 ($\sim$ since Valencia Workshop)

compare Super*B* physics reach with other competing and/or scheduled facilities
on favorite / popular, non-fine-tuned, experimentally constrained NP models

- estimate Super*B* physics reach on "standard" CMSSM NP scenarios (SPSn)
- identify plausible NP effects not ruled out by experimental constraints
- refine estimate of Super*B* experimental precision on specific processes

results of step #2 efforts documented in Valencia proceedings and here

Tau physics topics best addressed at Super*B*

LFV Decays

- clean and unambiguous physics reach
- Super*B* complementary to MEG
- LHC hardly provides competition
- Super*B* significantly better than SuperKEKB
  - Super*B* statistics and polarization help

CPV in tau decay

- SM prediction precise and clean
- most NP models don't predict it, but can probe some specific models
- Super*B* expected to be best facility
  - Super*B* statistics polarization help

Tau $g{-}2$

- $(g{-}2)_\mu$ exp/th discrepancy exists
- precise SM and CMSSM predictions
- Super*B* best facility
  - Super*B* statistics and polarization help

Tau EDM

- severely constrained from electron EDM
- Super*B* best facility
  - Super*B* statistics and polarization help

Snowmass points and slopes

- benchmark points in the MSSM parameter space (B.C.Allanach *et al.*, hep-ph/0202233)
- mostly suitable for LHC searches
- for LFV one must make assumptions on some additional parameters

SPS	$M_{1/2}$ (GeV)	M_0 (GeV)	A_0 (GeV)	$\tan\beta$	μ
1 a	250	100	-100	10	> 0
1 b	400	200	0	30	> 0
2	300	1450	0	10	> 0
3	400	90	0	10	> 0
4	300	400	0	50	> 0
5	300	150	-1000	5	> 0

LFV searches on tau decays - outline

Theory

- SM predictions are clean: LFV tau decays hugely suppressed
- NP predictions evaluated on Snowmass points
- compared tau LFV searches vs. $\mu \to e\gamma$ LFV searches

Experiment

- Super*B* at 75 ab^{-1} experimental reach re-evaluated
  - extrapolate published results re-optimizized for Super*B* at 75 ab^{-1}
- beam polarization effects investigated with simulations
- physics reach of Super*B* vs. other facilities assessed

LFV searches on tau decays - theory

- NP predictions evaluated on Snowmass points
  - G.Isidori and P.Paradisi for Valencia proceedings
  - E.Arganda, M.Herrero, J.Portoles (arXiv:0803.2039 [hep-ph])
- $\tau \to \mu\gamma$ confirmed as most powerful probe for NP

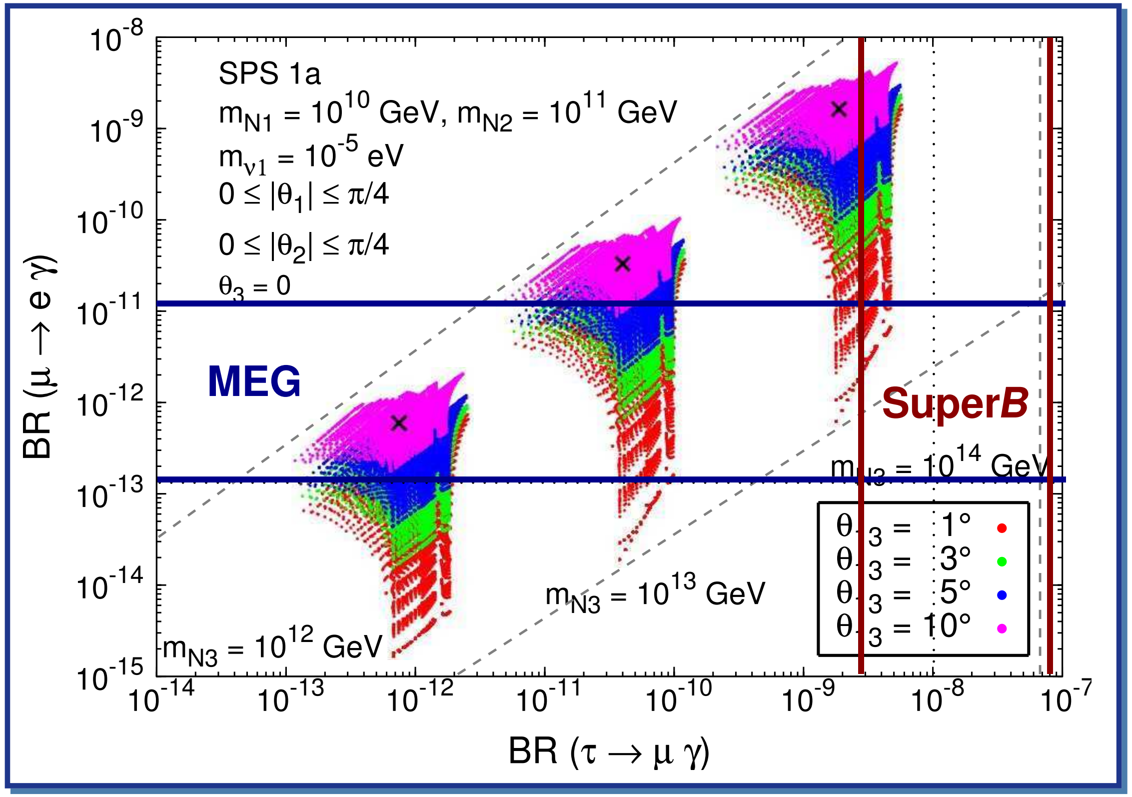
$$\frac{\mathrm{BF}(\tau \to \mu ee)}{\mathrm{BF}(\tau \to \mu\gamma)} \approx 1.0 \times 10^{-2} \qquad \frac{\mathrm{BF}(\tau \to 3\mu)}{\mathrm{BF}(\tau \to \mu\gamma)} \approx 2.2 \times 10^{-3}$$

$$\frac{\mathrm{BF}(\tau \to \mu\rho^0)}{\mathrm{BF}(\tau \to \mu\gamma)} \approx 2.5 \times 10^{-3} \qquad \frac{\mathrm{BF}(\tau \to \mu\eta)}{\mathrm{BF}(\tau \to \mu\gamma)} < 1.0 \times 10^{-3}$$

at all SPS points ("dipole dominance")

- constrained non-universal Higgs model (NUHM) SUSY can have $\mathrm{BF}(\tau \to \mu\eta) \approx \mathrm{BF}(\tau \to \mu\gamma)$ (not too heavy Higgs, large $\tan\beta$)
- more exhotic NP frameworks can have $\mathrm{BF}(\tau \to \mu\mu\mu)$ as large or larger than $\mathrm{BF}(\tau \to \mu\gamma)$ (R-parity viol. SUSY, Little Higgs with T-parity (LHT), Z')

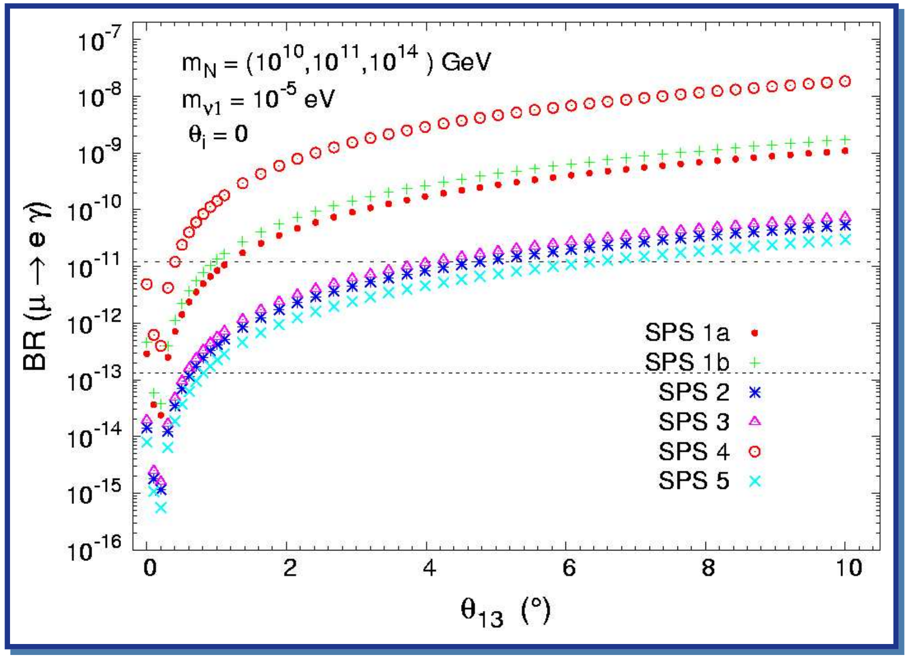
LFV searches on tau decays - comparison with $\mu \to e\gamma$

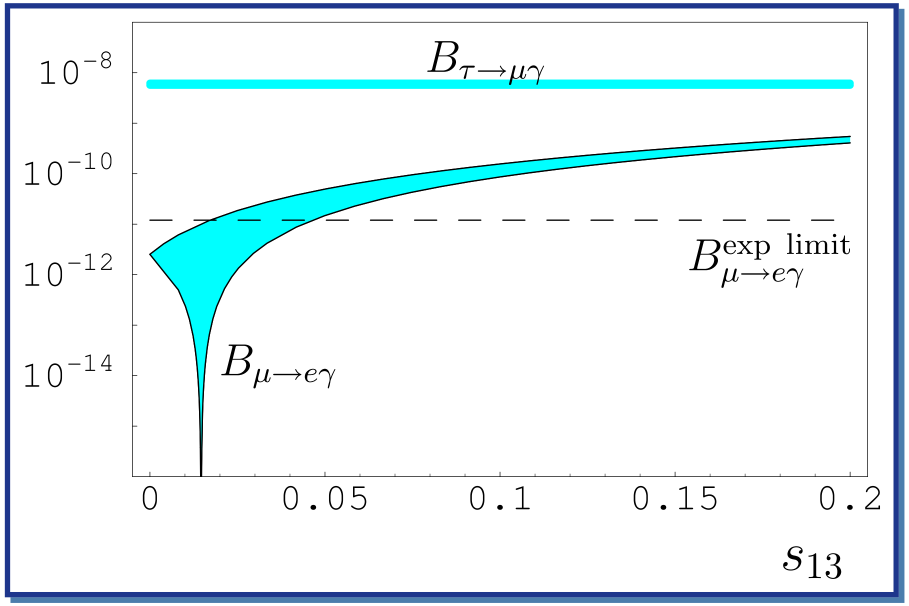


SPS-1a (other points are similar)

- SuperB is complementary to MEG
- $\mu \to e\gamma$ vanishes for small θ_{13}
- $\tau \to \mu\gamma$ independent of θ_{13}
- $\theta_{13} < 9.6^\circ$ (90% CL) (arXiv:0710.5027) [hep-ph])

LFV searches on tau decays - comparison with $\mu \to e\gamma$





within CMSSM,

- ♦ $\mu \to e\gamma$ vanishes for small θ_{13} at all points

within model-independent MFV NP extensions (0801.1826 [hep-ph])

- ♦ $\mu \to e\gamma$ vanishes for small θ_{13}
- ♦ $\tau \to \mu\gamma$ independent of θ_{13}

LFV searches on tau decays - experiment

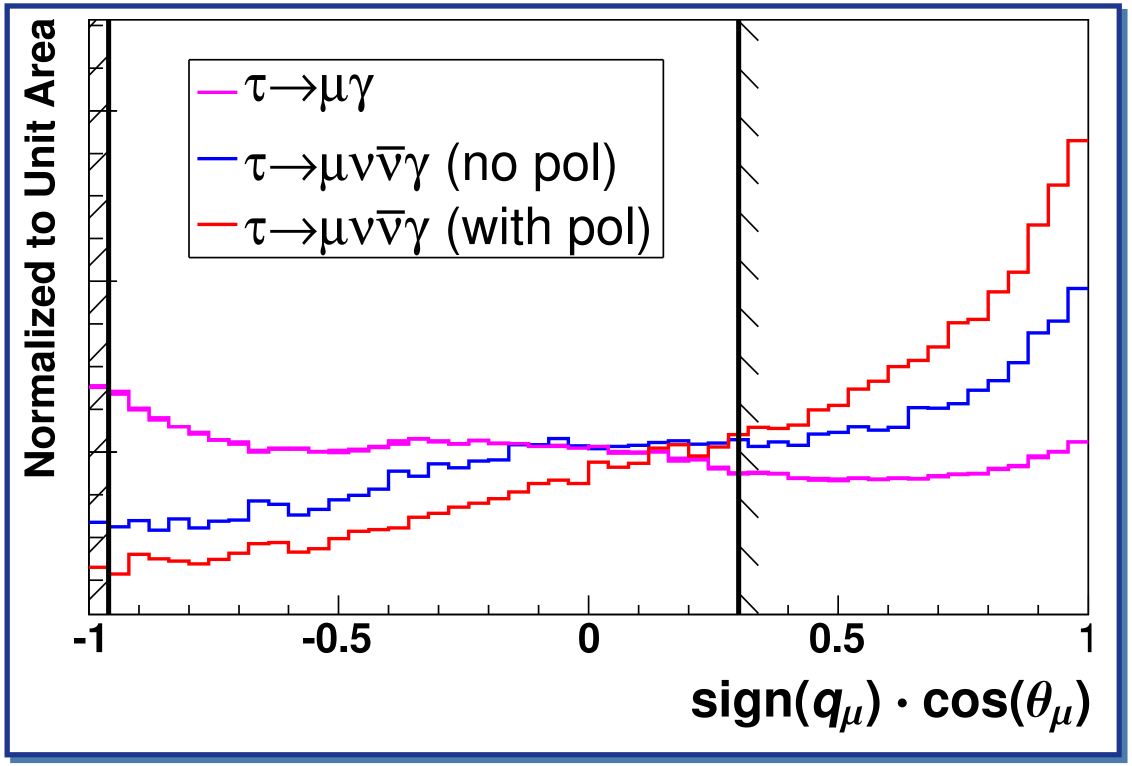
$\tau \to \mu\gamma$

- extrapolate from last BaBar published result (232 fb^{-1}, 1.8·10^{-7} expected 90% UL)
- re-optimize for 75 ab^{-1} integrated luminosity
- include expected increase of geometric acceptance
- assume muon id. efficiency BaBar has reached with its muon detector upgrade
- remove $\tau \to \mu\nu\nu$ mode for the other tau (against $\mu\mu\gamma$(ISR) events)
- 200 ± 50 events from $\tau \to \mu\nu\bar{\nu}(\gamma)$ irreducible background
- expected 2.3×10^{-9} (90% CL) upper limit, 4σ discovery reach 5.6×10^{-9}
- exploiting 80% electron beam polarizazion
  expected 2.1×10^{-9} (90% CL) upper limit, 4σ discovery reach 5.0×10^{-9}

LFV searches on tau decays - electron beam polarization

80% electron beam polarization can serve to:

- determine the specific NP model that produces LFV
  (see hep-ph/9604296, Y.Kuno, Y.Okada, $\mu \to e\gamma$ Search with Polarized Muons)
- improve the signal to background discrimination



LFV searches on tau decays - Super*B* vs. other facilities

	Snowmass points predictions						Super*B*	
	1 a	1 b	2	3	4	5	90% UL	4σ disc.
$\mathrm{BF}(\tau \to \mu\gamma) \times 10^{-9}$	4.2	7.9	0.18	0.26	97	0.019	2	5
$\mathrm{BF}(\tau \to 3\mu) \times 10^{-12}$	9.4	18	0.41	0.59	220	0.043	200	880

Conclusions

- Super*B* can resolve NP on a significant part of the parameter space
- Super*B* is complementary to $\mu \to e\gamma$ searches
- SuperKEKB worse by factor $\sqrt{5}$ for $\mathrm{BF}(\tau \to \mu\gamma)$ and 5 for $\mathrm{BF}(\tau \to \mu\mu\mu)$
- Super*B* LHC not expected to be competitive

NP theoretical predictions for tau $g-2$

- SUSY is a viable explaination for existing th.-exp. discrepancy $\Delta a_\mu = a_\mu^{exp} - a_\mu^{SM} \approx (3 \pm 1) \times 10^{-9}$
- SUSY contribution is larger for tau $\Delta a_\tau / \Delta a_\mu = m_\tau^2 / m_\mu^2 \approx 300$

	Snowmass points predictions						SuperB
	1 a	1 b	2	3	4	5	exp. resolution
$\Delta a_\mu \times 10^{-9}$	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	wait a few slides

Experimental measurement of tau $g-2$ at SuperB

- tau g–2 can be measured from spin-angle differential cross-section $e^+e^- \to \tau^+\tau^-$ (**0707.2496 [hep-ph] (J.Bernabeu et al.)**
- the amplitude for the $f\bar{f}\gamma$ vertex is:

$$\langle f(p_-)\bar{f}(p_+)|\, J^\mu(0)\,|0\rangle = e\,\bar{u}(p_-)\left[\gamma^\mu\ \boldsymbol{F_1} + \frac{1}{2m_f}(i\,\boldsymbol{F_2} + \boldsymbol{F_3}\gamma_5)\sigma^{\mu\nu}q_\nu + \left(q^2\gamma^\mu - q^\mu\ \not{q}\right)\gamma_5\boldsymbol{F_A}\right]v(p_+)$$

$\boldsymbol{F_1(q)} \to$ vector current, $\boldsymbol{F_A(q)} \to$ anapole moment, $\boldsymbol{F_2(q)} \to (g-2)$, $\boldsymbol{F_3(q)} \to$ EDM

$F_2(0) = \mathrm{Re}\,\{F_2(0)\} = a_f = (g-2)_f/2$

$d_f = \frac{e}{2m_f}F_3(0)$

- **Re $\{\boldsymbol{F_2(q)}\}$** can be fitted from shape of polar angle differential cross section

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

- using 100% polarized e^- beam, analyzing tau polarization with tau decay charged prongs angles one can construct asymmetries that are directly proportional to **Re $\{\boldsymbol{F_2(q)}\}$**
- assuming perfect detector for SuperB at 75 ab^{-1}: $\Delta a_\tau = 0.75\cdot 10^{-6}$

Experimental measurement of tau $g-2$ at Super*B*

improved estimate of Δa_τ

- MC study on simulated events with **KK generator** and **Tauola**
  (simulate complete spin correlation density matrix of the initial and final state)
- Super*B* at 75 fb^{-1}, $80\% \pm 1\%$ e^- beam polarization
- estimate real conditions effects
  - 80% geometrical acceptance in polar angle
  - (uneven) track reconstruction efficiency $97.5\% \pm 0.1\%$
- use all tau decay channels (paper only uses $\tau \to \pi\nu, \rho\nu$)
- combine two proposed measurement methods for $\text{Re}\{F_2\}$
- prelim. MC studies for tau EDM show detector systematics $\approx$ 10% of stat. error
  measurements exploiting tau polarization less affected by detector systematics
- $\Delta a_\tau = [1.0 - 2.4] \cdot 10^{-6}$

Tau $g-2$, comparison of Super*B* with other facilities

	Snowmass points predictions						Super*B*
	1 a	1 b	2	3	4	5	exp. resolution
$\Delta a_\mu \times 10^{-9}$	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	1.0 – 2.4

- SuperKEKB, without beam polarization, expected worse by factor ≈ 10, and worse systematics
- LHC not expected to be competitive

NP theoretical expectations for tau EDM

- in natural SUSY frameworks, lepton EDMs scale linearly with the lepton mass

  electron EDM upper limit ($d_e < 1.8{\cdot}10^{-27}$ *e* cm) constrains tau EDM outside of experiment reach
- no exp. sensitivity for most common NP scenarios given the electron limit
- enhancements up to 10^{-22} *e* cm in multi-Higgs models

Experimental measurement of tau EDM

- tau EDM can be measured from spin-angle differential cross-section $e^+e^- \to \tau^+\tau^-$ **(arXiv:0707.1658 [hep-ph])**
- polarized beams improve Super*B* sensitivity
- assuming perfect detector, 100% polarized electron beam: $\Delta\left(\mathrm{Re}\{d_\tau^\gamma\}\right) = 7.2{\cdot}10^{-20}\, e\,\mathrm{cm}$

- estimate real conditions effects
  - 80% geometrical acceptance in polar angle
  - (uneven) track reconstruction efficiency 97.5% ± 0.1%
- Super*B* sensitivity estimated at $\approx 10{\cdot}10^{-20}\, e\,\mathrm{cm}$

- extrapolate result on tau EDM by Belle from $29.5\,\mathrm{fb}^{-1}$ to $75\,\mathrm{ab}^{-1}$
- Super*B* sensitivity estimated at $\approx [17 - 34]{\cdot}10^{-20}\, e\,\mathrm{cm}$ not systematically limited

Super*B* can much reduce tau EDM exp. uncertainty although "natural" SUSY NP effects too small

T/CP-odd observables in tau decay

- clean SM predictions
  - *CP* asymmetry rate of $\tau^\pm \to K^\pm\pi^0\nu$ estimated order of $\sim 10^{-12}$
  - $\tau^\pm \to K_S\pi^\pm\nu$ rate asymmetry 3.3×10^{-3} with 2% relative precision
- most NP cannot generate observable *CP*-violating effects in τ decays
- effects with R-parity viol. SUSY or non-SUSY multi-Higgs up to the current UL from CLEO ($\sim 10^{-3}$)
- CLEO upper limit on charge-dependent angular rate asymmetry for $\tau \to K_S\pi^\pm\nu$ $(13.3\,\text{fb}^{-1})$
- extrapolating to Super*B* at $75\,\text{fb}^{-1}$ ⟶ reduce upper limit by factor ≈ 75 to $\approx 2.4 \cdot 10^{-5}$
  - channel can rely on calibration provided by $\tau \to \pi\pi\pi\nu$ on the K_S sidebands
  - further improvements possible with beam polarization (not yet studied)

T/CP-odd observables in tau decay: comparison with other facilities

- Super*B* more precise than SuperKEKB by factor $\sqrt{5}$, possibly more thanks to beam polarization
- no competition expected from LHC

Conclusions

- Super*B* can effectively probe most plausible NP models with tau LFV searches
  - Super*B* is significantly better than competing facilities
  - there is high complementatiry with $\mu \to e\gamma$ searches
  - beam polarization is useful
- Super*B* can probe whether SUSY is a viable explanation of the muon $g-2$ discrepancy
  - Super*B* is significantly better than competing facilities
  - beam polarization is an advantage
- Super*B* can test some specific NP models by measuring tau EDM and CPV in tau decay
  - Super*B* is significantly better than competing facilities
  - beam polarization is an advantage

Thanks especially to

- Gino Isidori and Paride Paradisi (theory)
- Mike Roney and Swagato Banerjee (LFV experimental reach)