Tau physics at SuperB

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(on behalf of the Super*B* collaboration)

11th International Workshop on Tau Lepton Physics
Manchester, UK, 13-17 September 2010

MANCHESTER
1824
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Super*B* project

- project of high luminosity asymmetric B-factory at $\Upsilon(4s)$ peak
- **~100 times more luminosity** than *BABAR* and Belle with **similar beam currents** (nanobeams)
  - aimed at collecting $75\,\mathrm{ab}^{-1}$ of data
- 80% polarized electron beam
- ability to also operate ad the charm threshold
- detector is moderately improved *BABAR* detector
  - smaller beam spot and improved vertex detector resolution
    - same or better B decay length resolution with smaller beam energy asymmetry w.r.t. *BABAR*
  - more hermetic
- proposed site in Rome (Frascati or Tor Vergata)
- passed all formal reviews, awaiting a decision on funding

Tau Physics in increasingly focused on New Physics searches

- **LEP experiments and past**: more focused on precision measurements
  - tau universality
  - $\alpha_s(m_\tau)$ from R_τ = BF($\tau \to X_h \nu$)/BF($\tau \to e\nu\overline{\nu}$)
  - g–2 hadronic contribution
- **B-factories** ⟶ more focused on NP searches - Cabibbo suppressed decays
  - **LFV searches**, 2nd class current searches
  - rare decays, high-multiplicity decays, Cabibbo suppressed decays (V_{us})
  - limited progress on many precision measurements
    also because of remarkable precision of several results by M.Davier ALEPH group. . .
- **Super Flavour factories** (in proposal / preparation phase): even more focused on NP searches
  - **LFV searches**
  - **tau *g*–2**, tau EDM, tau CPV
  - with less priority, 2nd class current searches, mainly a test of QCD predictions
  - high intensity experimental sensitivity to NP can exceed the LHC accessible energy range
  - recent preprint 2010 Super*B* Physics Report, arXiv:1008.1541v1 [hep-ex]

Best tau-related new physics probes at Super*B*

- preference to **mainstream models** with **experiment-constrained expectations**
  - MSSM-seesaw, NUHM SUSY, LHT
- best channels identified comparing NP expectations with Super*B* sensitivity
- Lepton Flavor violation in tau decays
  - MSSM-seesaw “naturally” expects some BRs in the sensitivity range of Super*B*
  - Super*B* is complementary with LHC and MEG
  - 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*

Tau Lepton Flavour Violation, NP models expectations

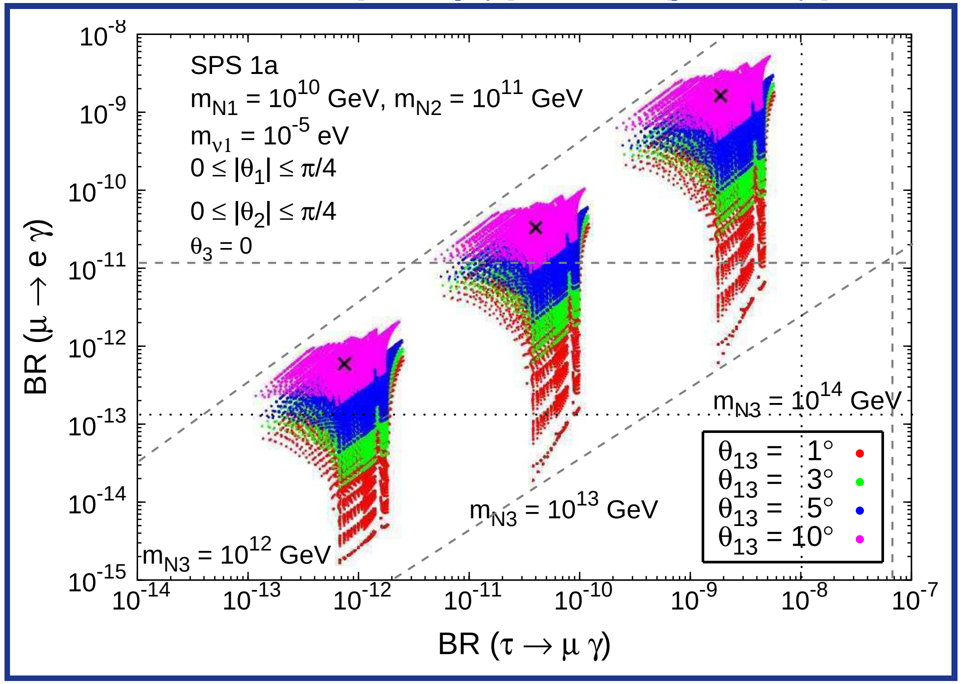
- constrained **MSSM-seesaw** and **NUHM SUSY** expectations from
  - S. Antusch, E. Arganda, M.J. Herrero, A.M. Texeira, JHEP11(2006)090, arXiv:hep-ph/0607263v2
    E. Arganda, M.J. Herrero, J. Portoles, JHEP06(2008)079, arXiv:0803.2039v3 [hep-ph]
    + several other refs. in 2010 Super*B* physics report
  - G.Isidori and P.Paradisi in the 2010 Super*B* physics report itself

Snowmass Points and Slopes reference points

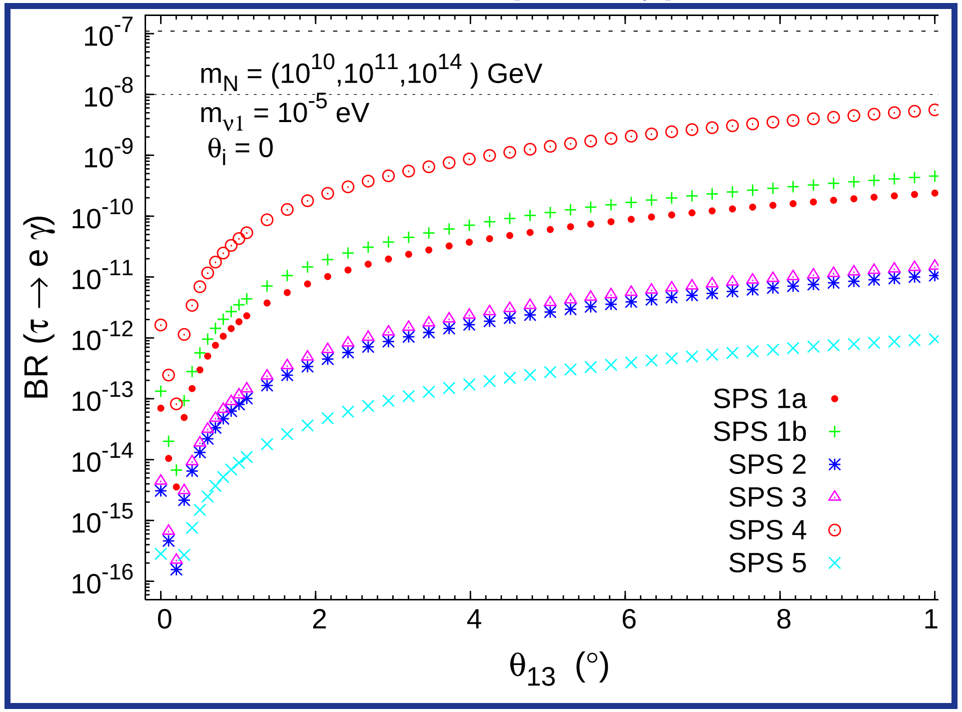
SPS	$M_{1/2}$ (GeV)	M_0 (GeV)	A_0 (GeV)	$\tan\beta$	μ
1 a	250	100	-100	10	> 0
1 b	400	200	0	30	> 0
2	300	1450	0	10	> 0
3	400	90	0	10	> 0
4	300	400	0	50	> 0
5	300	150	-1000	5	> 0

Tau LFV, CMSSM expectations

CMSSM BF($\tau \to \mu\gamma$) vs. BF($\mu \to e\gamma$)



CMSSM BF($\tau \to e\gamma$)

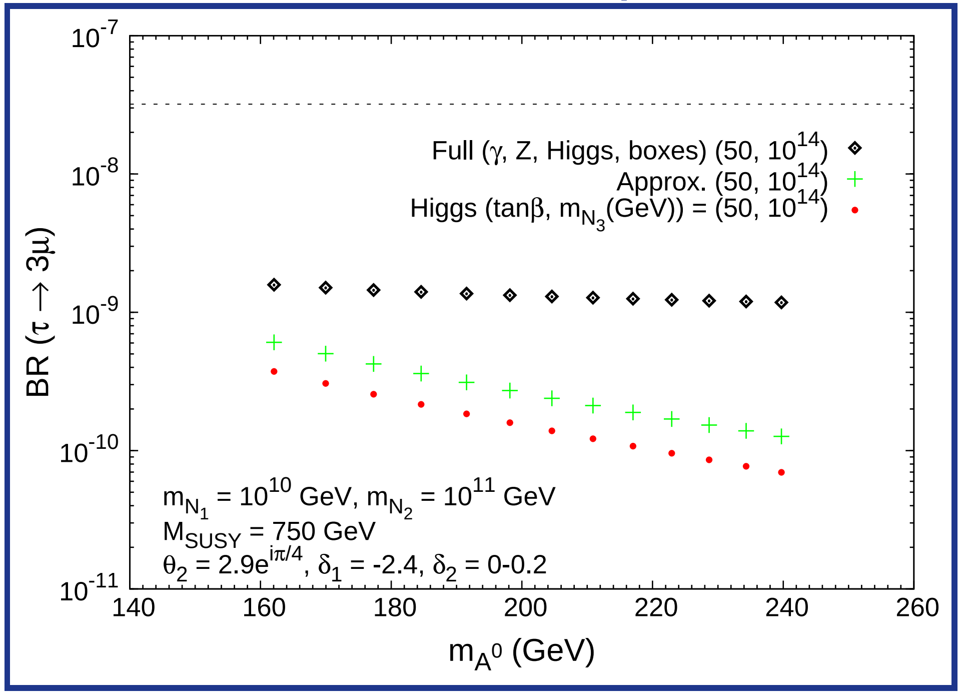


N_i = right-handed neutrinos
ν_i = left-handed neutrinos
θ_i = N complex mixing angles
θ_{13} refers to PNMS mixing matrix
other info on JHEP11(2006)090

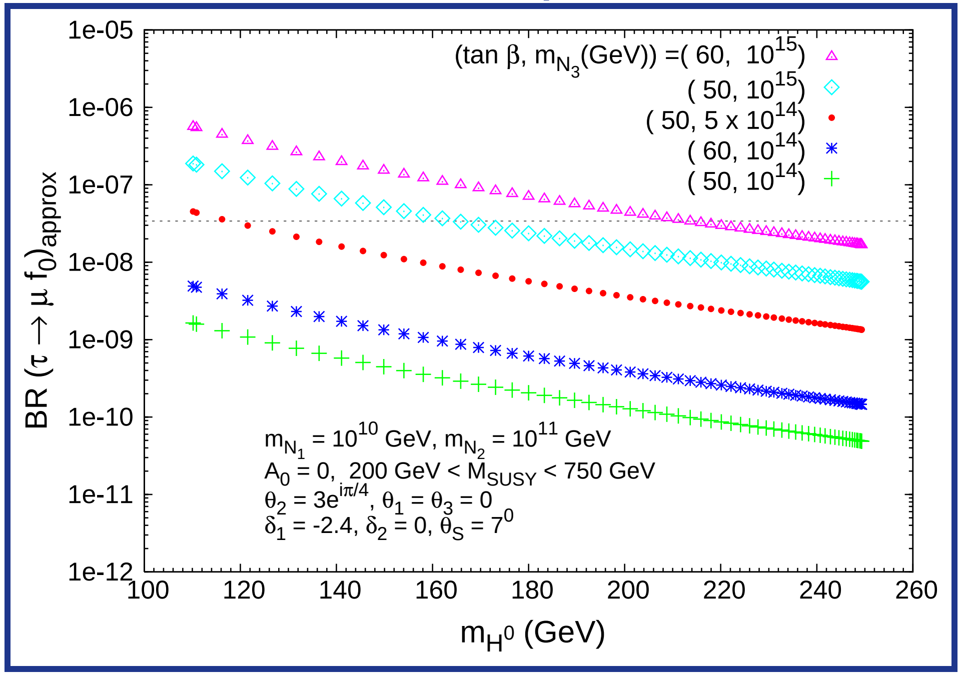
- tau LFV decays up to present limits for some SPS points
- $\tau \to \mu\gamma$ complementary to θ_{13}-sensitive $\mu \to e\gamma$

Tau LFV, NUHM SUSY expectations

NUHM BF($\tau \to 3\mu$)



NUHM BF($\tau \to \mu f_0(980)$)



δ_1, δ_2 parametrize non-universal Higgs masses
other info in JHEP06(2008)079 for left plot
other info in arXiv:0812.2692v1 [hep-ph] for right plot

- with NUHM Super*B* may be more sensitive to $\tau \to \mu f_0(980)$, $\tau \to \mu\eta$ than to $\tau \to \mu\gamma$

Tau LFV, CMSSM expectations summary

CMSSM expectations for some SPS reference points

SPS	1 a	1 b	2	3	4	5
BF($\tau \to \mu\gamma$) $\times 10^{-9}$	4.2	7.9	0.18	0.26	97	0.019
BF($\tau \to 3\mu$) $\times 10^{-12}$	9.4	18	0.41	0.59	220	0.043

(maximum values using m_{N_i} and m_{ν_1} in JHEP11(2006)090)

Tau LFV, Little Higgs expectations

- **Little Higgs with T parity (LHT)**, e.g. Eur.Phys.J.C57:13-182,2008, arXiv:0801.1826 [hep-ph]
- can have BF($\tau \to 3\mu$) > BF($\tau \to \mu\gamma$) up to the present experimental limits
- typically expect $\tau \to 3\ell$ comparable to $\tau \to \ell gamma$

Super*B* sensitivity to Tau LFV

- repeating *BABAR* analysis insures an improvement of $\boxed{\sqrt{\mathcal{L}_{\textbf{Super}B}/\mathcal{L}_{BABAR}} \approx \sqrt{150} \approx 12}$
- if n. of expected background events $\sim$1 events, improvement of $\boxed{\mathcal{L}_{\textbf{Super}B}/\mathcal{L}_{BABAR} \approx 150}$
- sensitivity increases with detector resolution, hermeticity
- sensitivity decreases with beam backgrounds (only moderate worsening is expected)
- recent *BABAR* papers results extrapolated to Super*B*
  - $\boldsymbol{\tau \to \mu, e\gamma}$ **LFV**, Phys.Rev.Lett.104:021802,2010, arXiv:0908.2381v2 [hep-ex]
  - $\boldsymbol{\tau \to 3\ell}$ **LFV**, PhysRevD.81.111101(2010), arXiv:1002.4550v1 [hep-ex]

Super*B* sensitivity to $\tau \to \mu\gamma$, $\tau \to e\gamma$ LFV

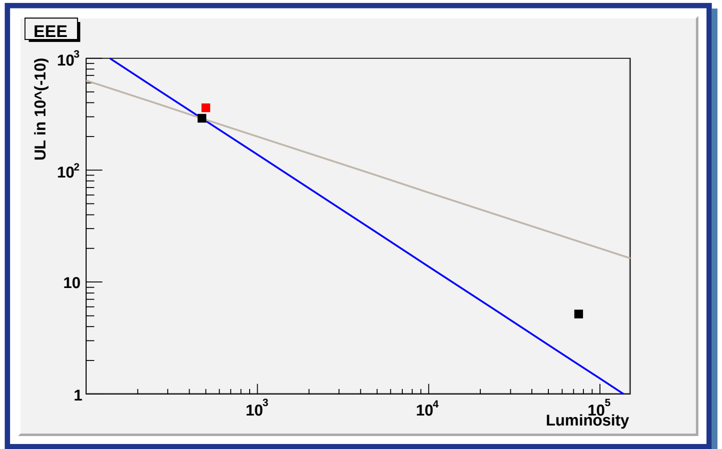
- start from *BABAR* 2010, Phys.Rev.Lett.104:021802,2010, arXiv:0908.2381v2 [hep-ex]
- use *BABAR* efficiency, scale expected background with ratio of luminosity
  - i.e. analysis not re-optimized for Super*B*
- assume 35% reduction of signal region from smaller beam-spot, better vertex detector (better resolution is planned to compensate smaller boost)
- assume 20% efficiency increase for photons from better hermeticity, DIRC redesign
- approximate frequentistic upper limits, only Poissonian BKG uncertainty
- at least 5 observed events for evidence

process	efficiency	expected background	expected 90% CL upper limit	3σ evidence reach
BF($\tau \to \mu\gamma$)	7.3%	335	$2.4 \cdot 10^{-9}$	$5.4 \cdot 10^{-9}$
BF($\tau \to e\gamma$)	3.9%	149	$3.0 \cdot 10^{-9}$	$6.8 \cdot 10^{-9}$

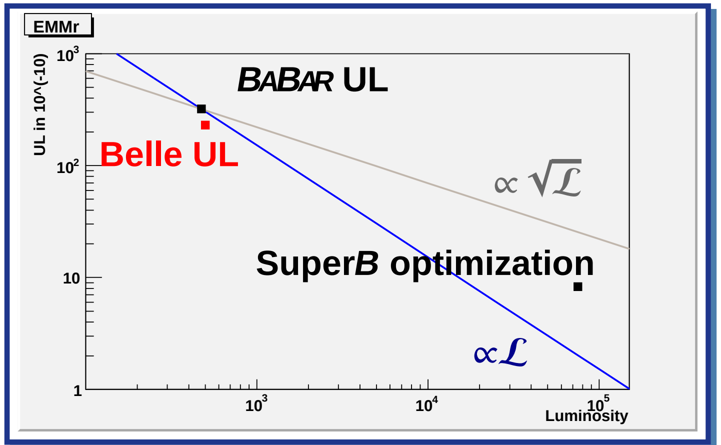
Super*B* sensitivity to $\tau \rightarrow 3\ell$ LFV

- start from *BABAR* 2010, PhysRevD.81.111101(2010), arXiv:1002.4550v1 [hep-ex]
- selection requirements re-optimized for best upper limit at Super*B*
  - fair simulation of background through lepton mis-id
  - only very approximate simulation of BKG from true leptons or Bhabha/dimuon events
- no detector improvement has been assumed
- approximate frequentistic upper limits, only Poissonian BKG uncertainty
- at least 5 observed events for evidence
- Super*B* sensitivity improvement $\sim$150

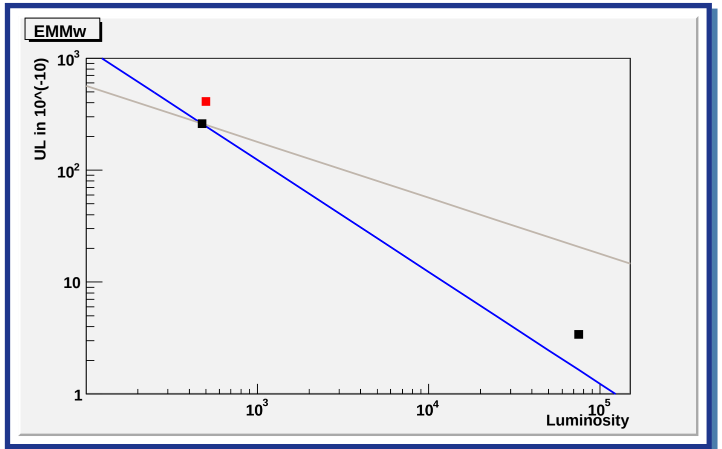
$\tau \to 3\ell$ 90% CM upper limit extrapolations: $\boxed{\propto \mathcal{L}}$ vs. $\boxed{\propto \sqrt{\mathcal{L}}}$ vs. re-optimization



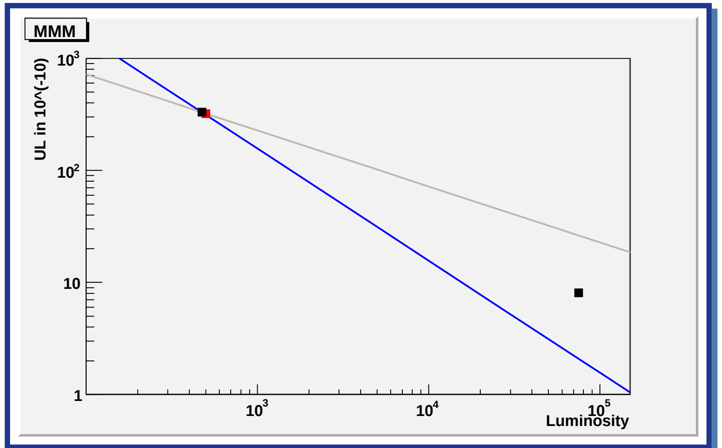
$\tau \to eee$



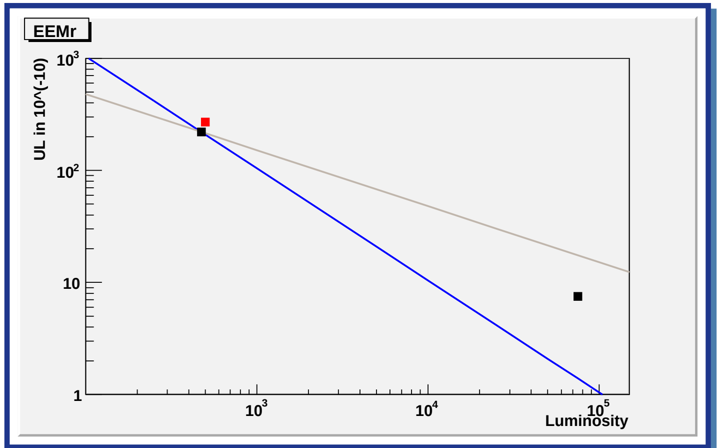
$\tau \to e\mu{+}\mu{-}$



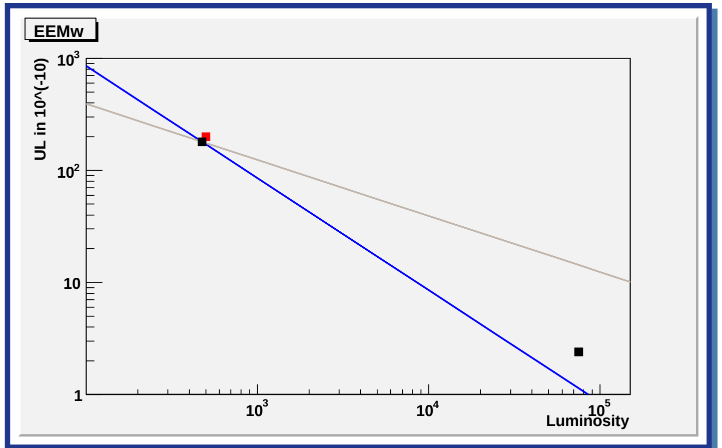
$\tau{-} \to e{+}\mu{-}\mu{-}$



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



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

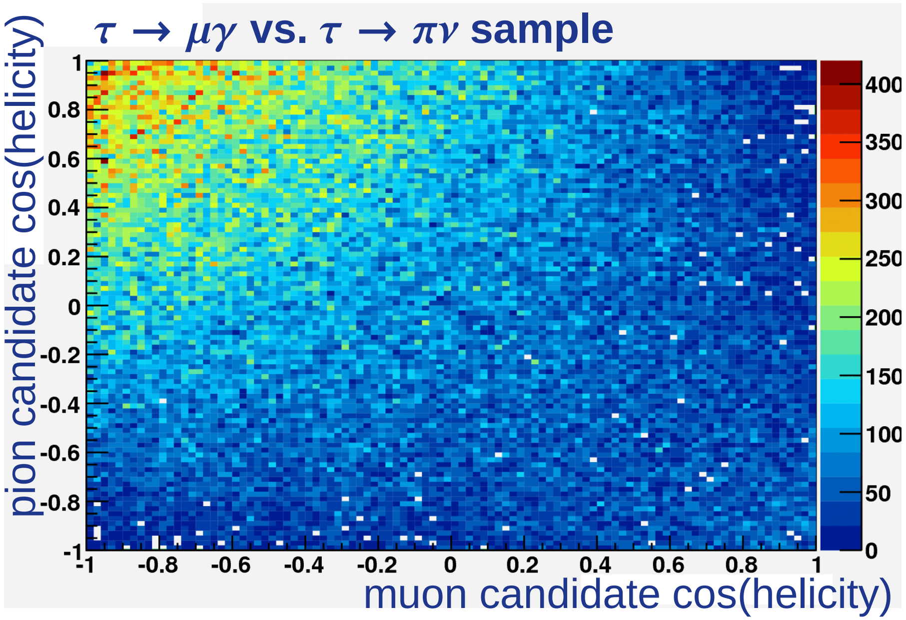


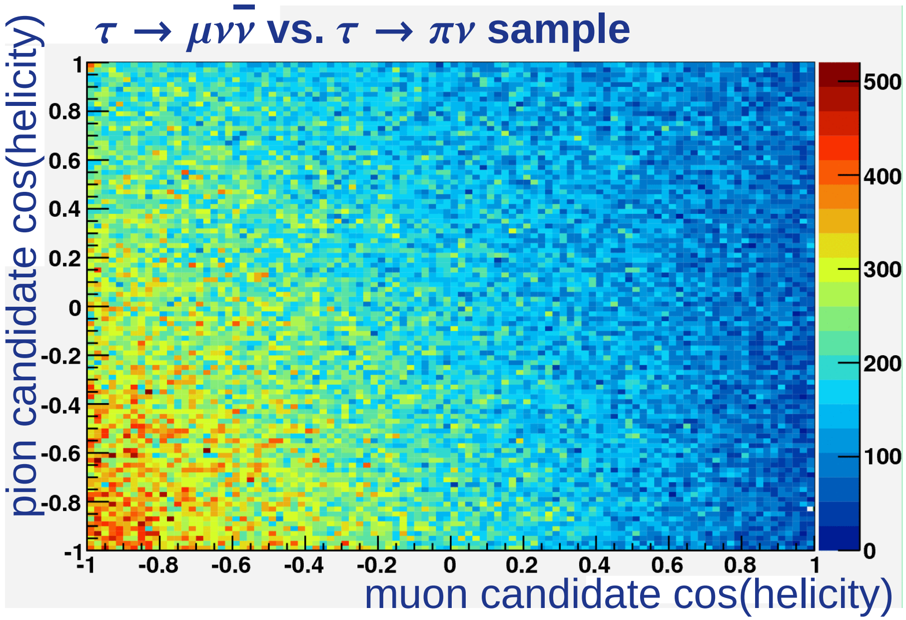
$\tau{-} \to \mu{+}e{-}e{-}$

Summary of Super*B* LFV reach

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

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



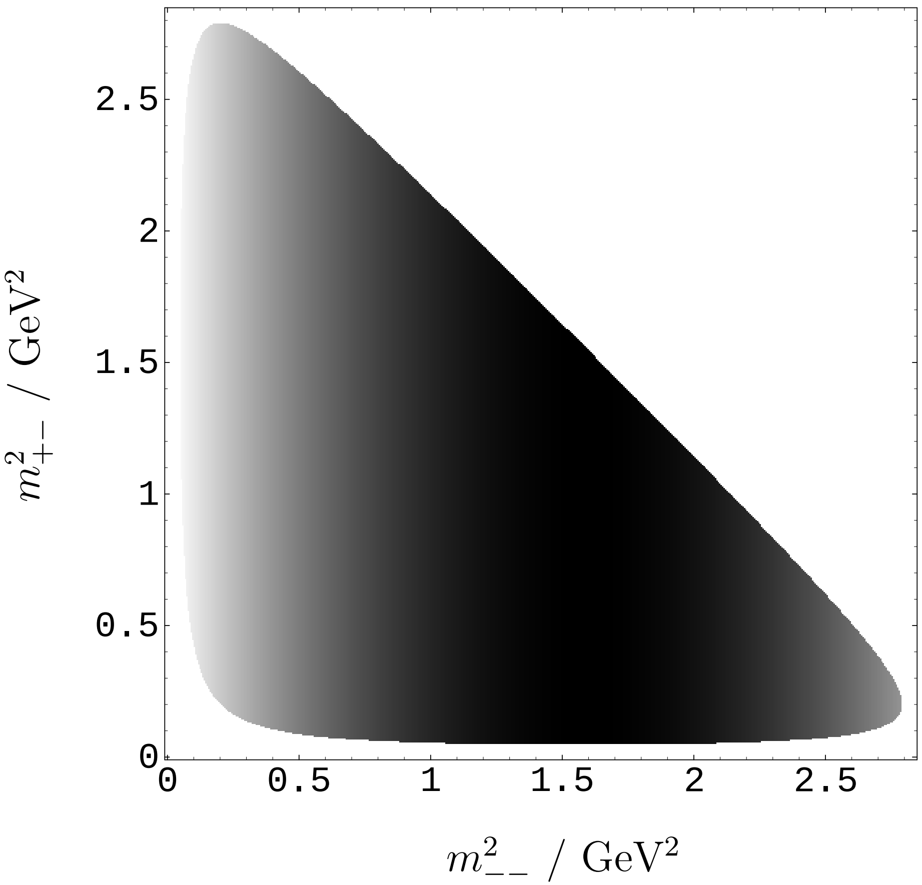


- 80% polarized electron beam
- SUSY LFV spin correlations Tauola decay mode added by S.Banerjee
- Super*B* fast simulation

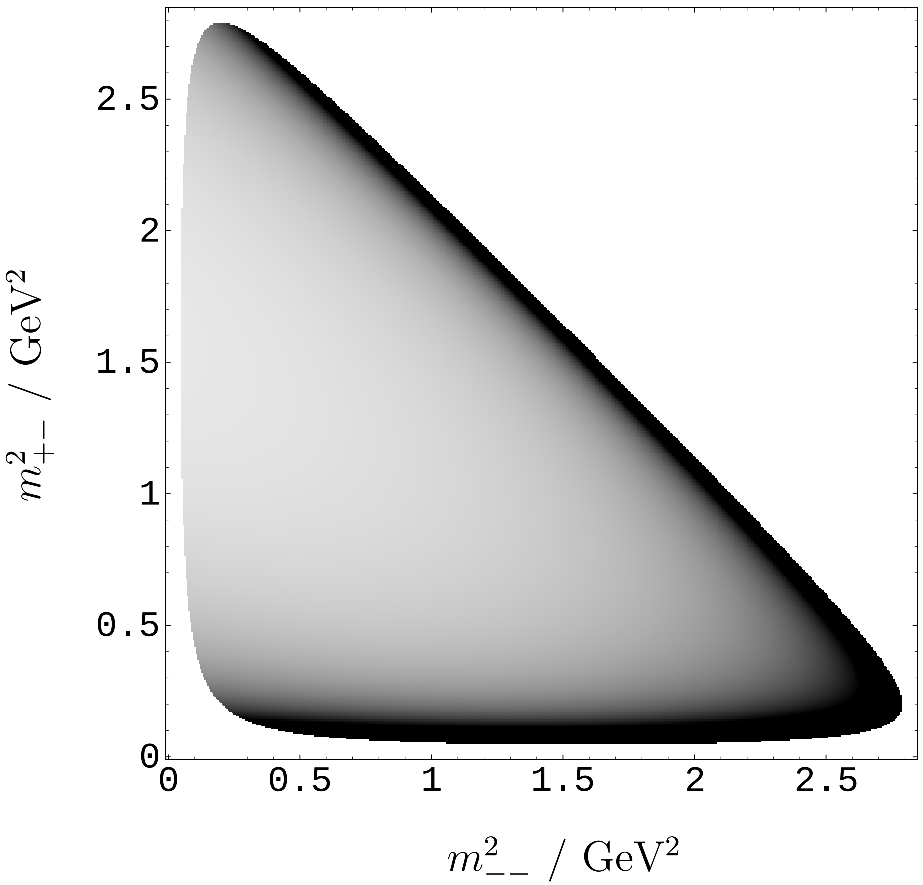
- can improve S/N ratio (assuming LFV NP model)
  - sensitivity improvements being evaluated
- can discriminate between NP models

Super*B* beam polarization effects on $\tau \to 3\ell$ LFV search

4-lepton interaction, all left handed



4-lepton interaction, radiative transition



- plots from S.Turczyk, arXiv:0812.3830 [hep-ph]
- can disentangle different 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 $e^+e^- \to \tau^+\tau^-$
    - 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 → $\boxed{\text{Super}B\ \sigma(a_\tau) \sim 2.4{\cdot}10^{-6}}$

Tau EDM at Super*B*, NP expectations

- $|d_e| < 1.6 \cdot 10^{-27}$ e cm at 90% CL, 10.1103/PhysRevLett.88.071805 / PDG10
- most 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 $\longrightarrow$ $|d_\tau^{NP}| < 10^{-22}$ 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

Super*B* sensitivity to tau EDM, with beam polarization

- beam polarization permits measurements based on single tau distributions
- J.Bernabeu et al., arXiv:0707.1658v1 [hep-ph], estimate $\boxed{\text{Super}B\ \sigma(d_\tau) \approx 7.2{\cdot}10^{-20}\ e\,\text{cm}}$
  - 100% electron beam polarization, no uncertainty
  - only $\tau \to \pi\nu$, $\tau \to \rho\nu$, no reconstruction uncertainty
- with some additional realistic assuptions
  - electron beam with a linear polarization of 80% ± 1%.
  - 80% geometric acceptance
  - track reconstruction efficiency 97.5% ± 0.1%

→ $\boxed{\text{Super}B\ \sigma(d_\tau) \approx 10{\cdot}10^{-20} e\,\text{cm}}$, (integrated angular asymmetry $\approx 3{\cdot}10^{-5}$)

- note that information can be obtained also from the other decay channels

Super*B* sensitivity to tau EDM from previous published results

- Belle EDM search, **Phys. Lett. B551, 16 (2003), hep-ex/0210066**
  - $29.5\,\mathrm{fb}^{-1}$ data sample
  - experimental resolution on real & imaginary d_τ is $\mathbf{0.9\text{–}1.7{\cdot}10^{-17}}$ ***e*** **cm**
- at Super*B* with $75\,\mathrm{ab}^{-1}$: $\boxed{\text{Super}B\ \sigma(d_\tau) \approx 17\text{–}34{\cdot}10^{-20} e\,\mathrm{cm}}$ (both real and imaginary parts)
  - assume also systematics scale with $1/\sqrt{\mathcal{L}}$, not unrealistic for asymmetry measurement

Tau *CPV* at Super*B*, expectations

- 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 $\longrightarrow$ 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 $\tau \to K\pi\pi\nu_\tau$

Super*B* sensitivity to tau *CPV*

- 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)$\cdot 10^{-3}$
  - ► data calibration with $\tau \to \pi\pi\pi\nu$
- extrapolating at Super*B*, $\boxed{\sigma_{\langle\xi\rangle} \approx 2.4 \cdot 10^{-5}}$
  - ► assume also systematics scale with $1/\sqrt{\mathcal{L}}$
  - ► will update the extrapolation using **Belle analysis presented at Tau10**
- beam polarization can provide extra equivalent luminosity (to be studied)

Summary

- Super*B* physics studies focused on NP searches
- **tau LFV**
  - Super*B* is sensitive to mainstream NP models effects
  - complementary to MEG and LHC
- **tau *g*–2**: Super*B* sensitivity close to SUSY expectations to explain present muon discrepancy
- **tau EDM**: Super*B* sensitivity insufficient, strong constraint from electron EDM upper limit
- **tau CPV**: a few NP models predict measurable asymmetries
- **beam polarization**
  - can provide additional information on NP interaction structure
  - increases statistical power of NP searches
- recent preprint **2010 Super*B* Physics Report**, arXiv:1008.1541v1 [hep-ex]