Tau Physics status report

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4th SuperB Collaboration Meeting

La Biodola (Isola d'Elba)

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Tau physics at Super*B*

LFV Decays

- clean and unambiguous New Physics probe
- complementary to muon LFV (MEG,. . .)
- no real competition but Belle II
  - advantage of beam polarization

Tau $g{-}2$

- $(g{-}2)_\mu$: $\sim 3\sigma$ exp vs. th discrepancy
- precise SM and CMSSM predictions
- no real competition but Belle II
  - advantage of beam polarization

CPV in tau decay

- precise and clean SM prediction
- most NP models below our sensitivity
  - → can probe some specific models
  - → set new much improved limits
- beam polarization may help

Tau EDM

- severely constrained from electron EDM
- no real competition but Belle II
  - advantage of beam polarization

plenty of precision physics also possible

Outline of work done

Super*B* physics documents

- arXiv:1109.5028v2 [hep-ex] The impact of SuperB on flavour physics
- arXiv:1008.1541v1 [hep-ex] SuperB white paper: Physics
- arXiv:1007.4241v1 [physics.ins-det] SuperB white paper: Detector
- arXiv:0810.1312 [hep-ex], Valencia Jan 2008 Workshop Proceedings

Super*B* tau physics specific activities

- extrapolations from published analyses results
- exp. limitations on J.Bernabeu et al. tau EDM and *g*–2 sensitivity estimates with polarized beams
- re-optimization of *BABAR* 3 leptons analysis [mainly B.Oberhof (Pisa)]
- study of events with $\tau \to \mu\gamma$ against $\tau \to \pi\nu$ with beam polarization [mainly A.Cervelli (Pisa)]
- independent work on $\tau \to 3\ell$ by C.Weiland, S.Coquereau [w. A.Bevan (QMUL)]

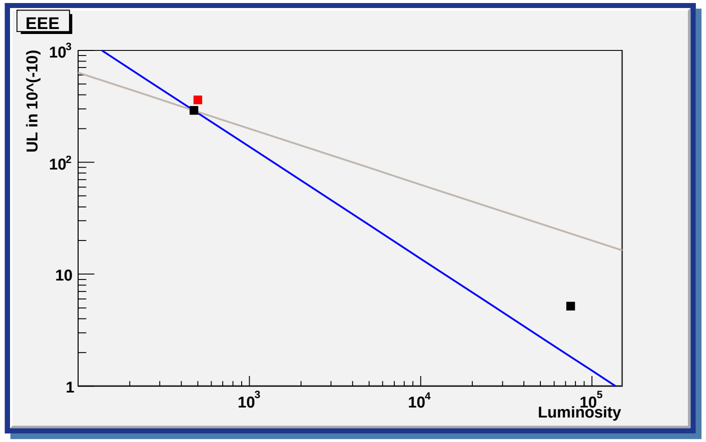
(related) on-going and planned work

- since ~2011 tau $g{-}2$ measurement with BABAR [B.Oberhof (Pisa) PHD thesis]
- since ~2011 tau EDM measurement with BABAR [S.Martellotti (Pisa) PHD thesis]
- about to start: beam polarization effects in $\tau \to 3\ell$ [M.Chrzaszcz (Cracow) and A.L.]
- about to start: CPV in tau decay, F.Wilson (RAL)

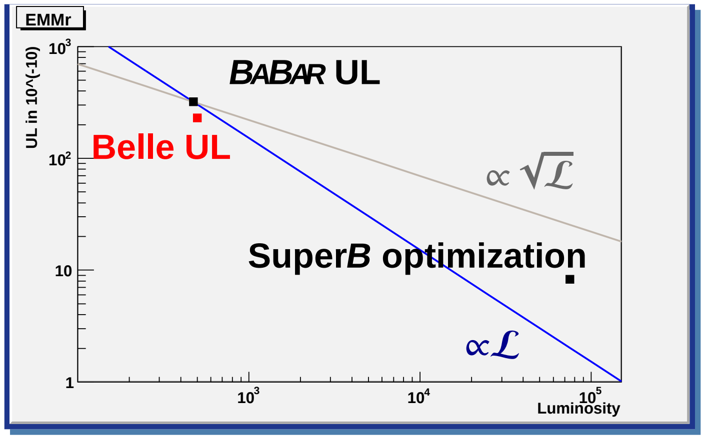
Super*B* $\tau \to 3\ell$ sensitivity re-optimizzing *BABAR* analysis

- $\tau \to 3\ell$ *BABAR* analysis by A.Cervelli
- analysis **re-optimized for best UL at Super*B*@75 ab^{-1}** (under hypothesis of no signal) (B.Oberhof)

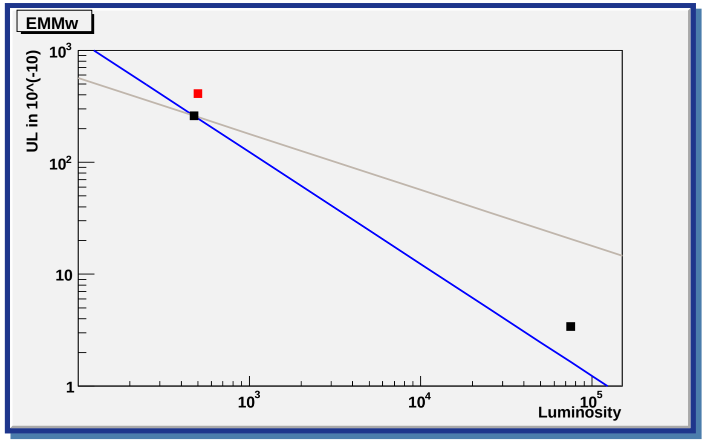
$\tau \to 3\ell$ UL extrapolations: $\propto \mathcal{L}$ vs. $\propto \sqrt{\mathcal{L}}$ vs. re-optimization



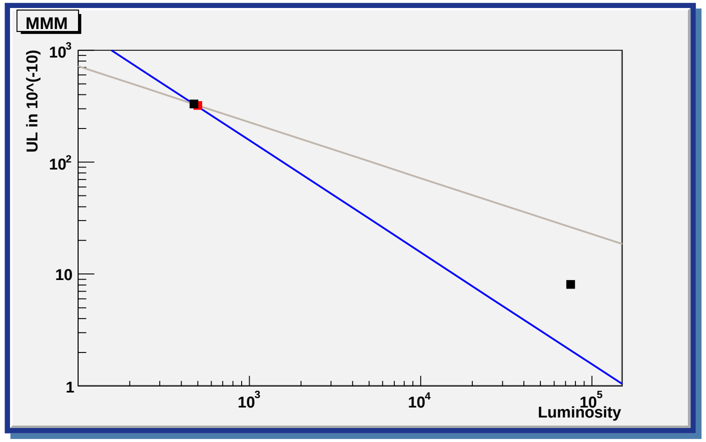
$\tau \to eee$



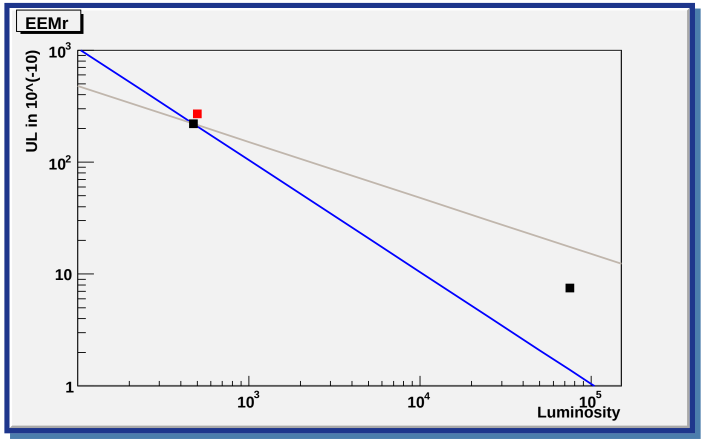
$\tau \to e\mu+\mu-$



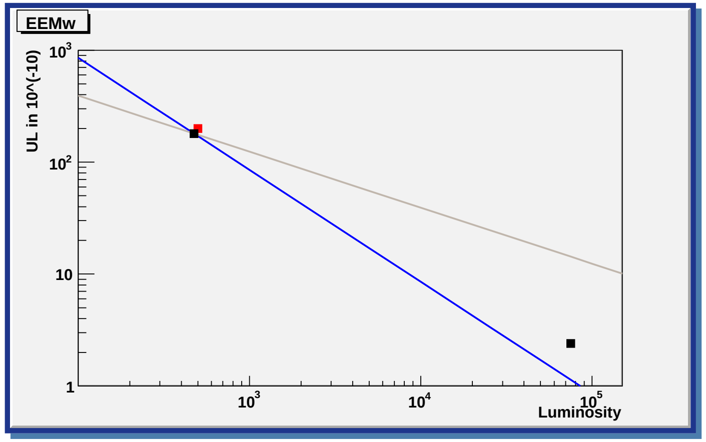
$\tau- \to e+\mu-\mu-$



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



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



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

Expected 90% CL upper limits for $\tau \to 3\ell$ at Super$B$@75 ab^{-1} (preliminary)

Channel	Efficiency (%)	exp.bkg	90% CL UL (10^{-10})
$e^+e^-e^+$	5.2 ± 0.5	1.7 ± 0.6	5.1
$e^+e^-\mu^+$	2.3 ± 0.2	0.16 ± 0.05	7.5
$e^+e^+\mu^-$	8.6 ± 0.9	0.3 ± 0.1	2.4
$\mu^+\mu^-e^+$	4.2 ± 0.4	3.8 ± 1.3	8.3
$\mu^+\mu^+e^-$	6.5 ± 0.6	0.8 ± 0.3	3.4
$\mu^+\mu^-\mu^+$	4.1 ± 0.4	3.3 ± 1.0	8.1

- to be compared with $2{\cdot}10^{-10}$ in the Valencia report first estimate

SuperB sensitivity on 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	2.4–1.0

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

- 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

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

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

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

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

- using 100% polarized e^- beam, analyzing tau polarization with tau decay charged prongs angles one can construct asymmetries that are directly proportional to **Re $F_2(q)$**
- assuming perfect detector for Super$B$ 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% ± 1% e^- beam polarization
- estimate real conditions effects
  - 80% geometrical acceptance in polar angle
  - (uneven) track reconstruction efficiency 97.5% ± 0.1%
- use all tau decay channels (paper only uses $\tau \to \pi\nu, \rho\nu$)
- combine two proposed measurement methods for Re F_2
- prelim. MC studies for tau EDM show detector systematics ≈ 10% of stat. error measurements exploiting tau polarization less affected by detector systematics
- $\Delta a_\tau = [1.0 - 2.4] \cdot 10^{-6}$ (uncertainty depends on how well we can exploit all tau decay modes)

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

Theory expectations

- 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 ($\sim 10^{-3}$)

Super*B* sensitivity

- experimental upper limit on charge-dependent angular rate asymmetry for $\tau \to K_S \pi^\pm \nu$
  [CLEO Collaboration, Phys. Rev. Lett. 88, 111803 (2002), hep-ex/0111095, (13.3 fb^{-1}]
- extrapolating to Super*B* at 75 fb^{-1} ⟶ exp. sensitivity improves by a factor ≈ 75
  resolution on optimal observable from $1.8 \cdot 10^{-3}$ to $\sim 2.4 \cdot 10^{-5}$
  - channel can rely on calibration provided by $\tau \to \pi\pi\pi\nu$ on the K_S sidebands
  - further improvements may be possible with beam polarization (not yet studied)

Update on $\tau \to \mu\gamma$ sensitivity

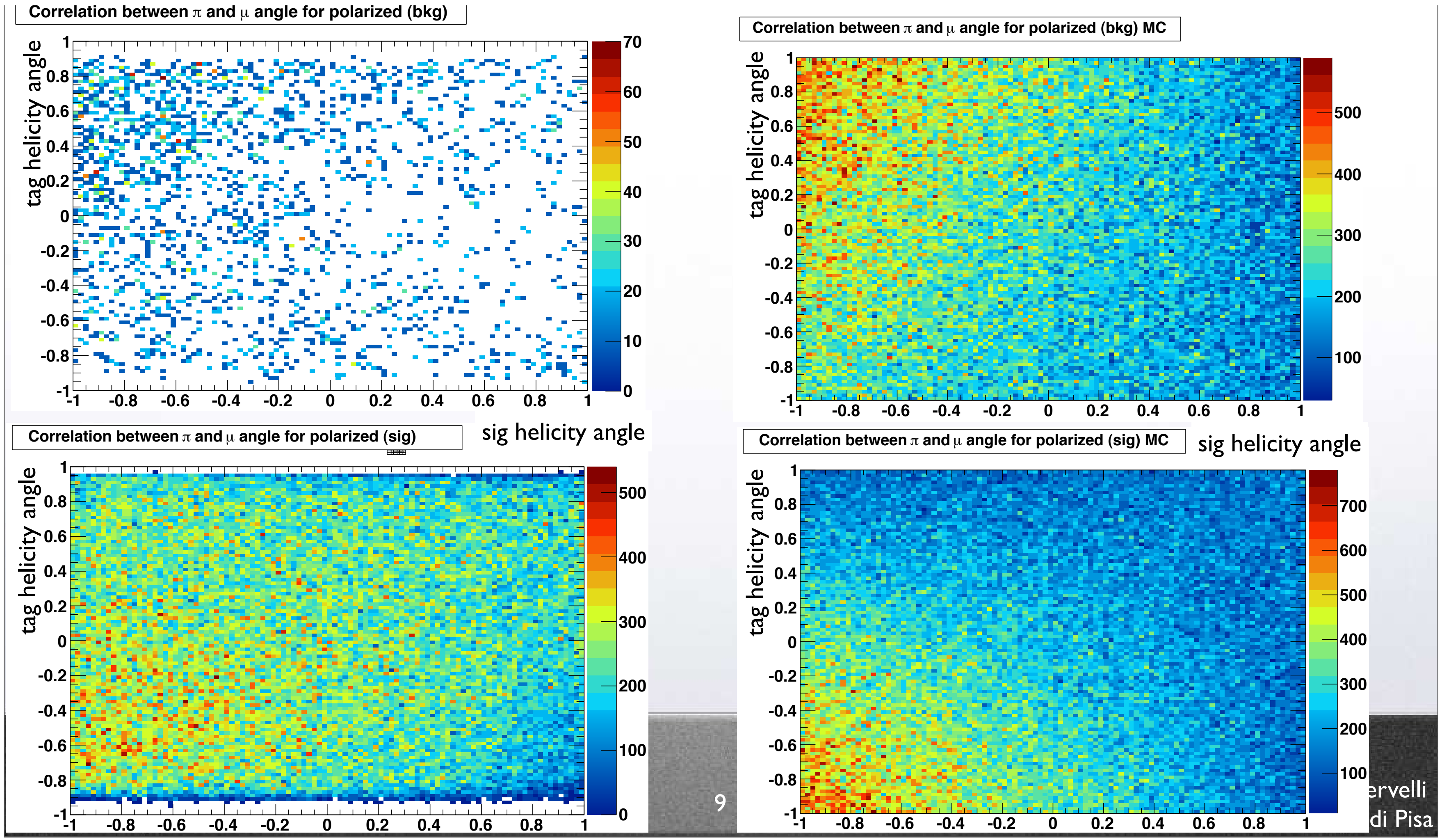
- extrapolate from final *BABAR* result **expected upper limit**
  - *BABAR* bkg estimates, 2σ box cut & count
  - assume improved Super*B* tracking reduces $\Delta m - \Delta E$ box to 65% of *BABAR* size
  - assume photon efficiency improves by 20%
    (no significant gain possible on loose muon PID used in this analysis)

sensitivity without using beam polarization

```
Valencia limits                          SuperB limits
  tau -> mu gamma                          tau -> mu gamma
    efficiency          = 7.40%              efficiency          = 7.32%
    expected background = 200                expected background = 335
    upper limit 90% CL  = 1.84e-09           upper limit 90% CL  = 2.39e-09
    3sigma evidence     = 4.16e-09           3sigma evidence     = 5.44e-09
```

$\tau \to \mu\gamma$ vs. $\tau \to \pi\nu$ helicity angles with polarized beams

A. Cervelli, Elba, May 2011, FastSim selected candidates left, MC truth right



Tuesday, May 31, 2011

Update on $\tau \to \mu\gamma$ sensitivity with beam polarization

- using A.Cervelli May 2011 (Elba) presentation on $\tau \to \mu\gamma$ vs. $\tau \to \pi(\rho)\nu$ simulated with FastSim
- **using most natural SUSY LFV $\tau \to \mu\gamma$ production mode**
- assuming cuts have same effect on all tau hadronic decays in tag side
- assuming we use only hadronic decays on tag side
  (actually, with some degradation leptonic decays can be used as well)

```
SuperB, hadronic tags, 2D Fastsim helicity cuts
  tau -> mu gamma
    efficiency          = 1.60%
    expected background = 27
    upper limit 90% CL  = 3.35e-09
    3sigma evidence     = 7.09e-09
```

```
SuperB limits with 1D helicity cut on MC truth
  tau -> mu gamma
    efficiency          = 5.12%
    expected background = 167
    upper limit 90% CL  = 2.44e-09
    3sigma evidence     = 5.50e-09
```