Tau Physics status report

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4th SuperB Collaboration Meeting
La Biodola (Isola d’Elba)
May 31 – June 4, 2012
**Tau physics at SuperB**

**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**
- $(g–2)_\mu$: ~3σ 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

SuperB physics documents

SuperB 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 $\text{BABAR}$ 3 leptons analysis [mainly B.Oberhof (Pisa)]
♦ study of events with $\tau \rightarrow \mu \gamma$ against $\tau \rightarrow \pi \nu$ with beam polarization [mainly A.Cervelli (Pisa)]
♦ independent work on $\tau \rightarrow 3\ell$ by C.Weiland, S.Coquereau [w. A.Bevan (QMUL)]
(related) on-going and planned work

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

- $\tau \rightarrow 3\ell$ $\textit{BABAR}$ analysis by A.Cervelli
- analysis re-optimized for best UL at SuperB@75 ab$^{-1}$ (under hypothesis of no signal) (B.Oberhof)
$\tau \rightarrow 3\ell$ UL extrapolations: $\propto L$ vs. $\propto \sqrt{L}$ vs. re-optimization

$\tau \rightarrow eee$

$\tau \rightarrow \ell\mu\ell\mu$

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

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

♦ to be compared with 2$\cdot$10$^{-10}$ in the Valencia report first estimate
SUSY is a viable explanation for existing th.-exp. discrepancy

\[ \Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} \approx (3 \pm 1) \times 10^{-9} \]

SUSY contribution is larger for tau

\[ \frac{\Delta a_\tau}{\Delta a_\mu} = \frac{m_\tau^2}{m_\mu^2} \approx 300 \]

### Snowmass points predictions

<table>
<thead>
<tr>
<th>SuperB</th>
<th>1a</th>
<th>1b</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>exp. resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta a_\mu \times 10^{-9}$</td>
<td>3.1</td>
<td>3.2</td>
<td>1.6</td>
<td>1.4</td>
<td>4.8</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>$\Delta a_\tau \times 10^{-6}$</td>
<td>0.9</td>
<td>0.9</td>
<td>0.5</td>
<td>0.4</td>
<td>1.4</td>
<td>0.3</td>
<td>2.4–1.0</td>
</tr>
</tbody>
</table>
**Experimental measurement of tau $g - 2$ at SuperB**

- $g - 2$ can be measured from spin-angle differential cross-section $e^+ e^- \rightarrow \tau^+ \tau^-$

  (0707.2496 [hep-ph] (J.Bernabeu et al.)

- The amplitude for the $f \bar{f} \gamma$ vertex is:

  $$\langle f(p_-) \bar{f}(p_+) | J^\mu(0) | 0 \rangle = e \bar{u}(p_-) \left[ \gamma^\mu F_1 + \frac{1}{2m_f} (i F_2 + F_3 \gamma_5) \sigma^{\mu\nu} q_\nu + \left( q^2 \gamma^\mu - q^\mu q \right) \gamma_5 F_A \right] v(p_+)$$

$F_1(q) \rightarrow$ vector current, $F_A(q) \rightarrow$ anapole moment, $F_2(q) \rightarrow (g-2)$, $F_3(q) \rightarrow$ EDM

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

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

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

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

- 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 SuperB at 75 ab$^{-1}$: $\Delta a_\tau = 0.75 \cdot 10^{-6}$
Experimental measurement of tau $g-2$ at SuperB

- Improved estimate of $\Delta a_{\tau}$
  - MC study on simulated events with **KK generator** and **Tauola**
    (simulate complete spin correlation density matrix of the initial and final state)
  - SuperB 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 $\tau \rightarrow \pi\nu, \rho\nu$)
  - 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

\[ d_e < 1.8 \cdot 10^{-27} \text{ e cm} \]

♦ electron EDM upper limit (\( d_e < 1.8 \cdot 10^{-27} \text{ e cm} \)) constrains tau EDM outside of experiment reach

♦ no exp. sensitivity for most common NP scenarios given the electron limit

♦ enhancements up to \( 10^{-22} \text{ e cm} \) in multi-Higgs models
Experimental measurement of tau EDM

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

- Estimate real conditions effects
  - 80% geometrical acceptance in polar angle
  - (uneven) track reconstruction efficiency 97.5% ± 0.1%
- SuperB sensitivity estimated at \( \approx 10 \cdot 10^{-20} \) e cm

- Extrapolate result on tau EDM by Belle from 29.5 fb\(^{-1}\) to 75 ab\(^{-1}\)
- SuperB sensitivity estimated at \( \approx [17 - 34] \cdot 10^{-20} \) e cm
  - Not systematically limited

**SuperB can much reduce tau EDM exp. uncertainty**

Although “natural” SUSY NP effects too small
**Theory expectations**

- **clean SM predictions**
  - CP asymmetry rate of $\tau^\pm \rightarrow K^\pm \pi^0 \nu$ estimated order of $\sim 10^{-12}$
  - $\tau^\pm \rightarrow K_S \pi^\pm \nu$ rate asymmetry $3.3 \times 10^{-3}$ with 2% relative precision

- most NP cannot generate observable CP-violating effects in $\tau$ decays

- effects with R-parity viol. SUSY or non-SUSY multi-Higgs up to the current UL from CLEO ($\sim 10^{-3}$)

**SuperB sensitivity**

- experimental upper limit on charge-dependent angular rate asymmetry for $\tau \rightarrow K_S \pi^\pm \nu$

- **extrapolating to SuperB at 75 fb$^{-1}$:** exp. sensitivity improves by a factor $\approx 75$
  - resolution on optimal observable from $1.8 \cdot 10^{-3}$ to $\sim 2.4 \cdot 10^{-5}$
    - channel can rely on calibration provided by $\tau \rightarrow \pi \pi \pi \nu$ on the $K_S$ sidebands
    - further improvements may be possible with beam polarization (not yet studied)
Update on $\tau \rightarrow \mu \gamma$ sensitivity

- extrapolate from final $BABAR$ result expected upper limit
  - $BABAR$ bkg estimates, $2\sigma$ box cut & count
  - assume improved SuperB 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

<table>
<thead>
<tr>
<th>Valencia limits</th>
<th>SuperB limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau \rightarrow \mu \gamma$</td>
<td>$\tau \rightarrow \mu \gamma$</td>
</tr>
<tr>
<td>efficiency</td>
<td>efficiency</td>
</tr>
<tr>
<td>$= 7.40%$</td>
<td>$= 7.32%$</td>
</tr>
<tr>
<td>expected background</td>
<td>expected background</td>
</tr>
<tr>
<td>$= 200$</td>
<td>$= 335$</td>
</tr>
<tr>
<td>upper limit 90% CL</td>
<td>upper limit 90% CL</td>
</tr>
<tr>
<td>$= 1.84e-09$</td>
<td>$= 2.39e-09$</td>
</tr>
<tr>
<td>3sigma evidence</td>
<td>3sigma evidence</td>
</tr>
<tr>
<td>$= 4.16e-09$</td>
<td>$= 5.44e-09$</td>
</tr>
</tbody>
</table>
**τ → µγ vs. τ → πν helicity angles with polarized beams**

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

**Correlation between τ and µ angle for polarized (bkg)**

**Correlation between τ and µ angle for polarized (sig)**

**Correlation between τ and π angle for polarized (bkg) MC**

**Correlation between τ and π angle for polarized (sig) MC**
Update on $\tau \rightarrow \mu \gamma$ sensitivity with beam polarization

- using A.Cervelli May 2011 (Elba) presentation on $\tau \rightarrow \mu \gamma$ vs. $\tau \rightarrow \pi(\rho)\nu$ simulated with FastSim
- using most natural SUSY LFV $\tau \rightarrow \mu \gamma$ 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)

<table>
<thead>
<tr>
<th>SuperB, hadronic tags, 2D Fastsim helicity cuts</th>
<th>SuperB limits with 1D helicity cut on MC truth</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau \rightarrow \mu\gamma$</td>
<td>$\tau \rightarrow \mu\gamma$</td>
</tr>
<tr>
<td>efficiency = 1.60%</td>
<td>efficiency = 5.12%</td>
</tr>
<tr>
<td>expected background = 27</td>
<td>expected background = 167</td>
</tr>
<tr>
<td>upper limit 90% CL = 3.35e-09</td>
<td>upper limit 90% CL = 2.44e-09</td>
</tr>
<tr>
<td>3sigma evidence = 7.09e-09</td>
<td>3sigma evidence = 5.50e-09</td>
</tr>
</tbody>
</table>