Super*B* potential to discover lepton flavour violation with the decay τ→μμμ

Cédric Weiland, ENS Lyon

Outline

- **Lepton Flavour Violation**
  - Predictions for the decay $\tau \rightarrow lll$
  - Latest results
- **Simulate large amount of data with FastSim**
  - How and how much
  - New tools
- **Find a new upper limit for $\tau \rightarrow \mu\mu\mu$**
  - The cuts and their optimisation
  - The results

Some theoretical predictions

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LFV
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Q & A

Model dependant predictions

		$\tau \to \mu\gamma$	$\tau \to lll$
SM + ν mixing	Lee, Shrock, PRD 16 (1977) 1444 Cheng, Li, PRD 45 (1980) 1908	Undetectable	
SUSY Higgs	Dedes, Ellis, Raidal, PLB 549 (2002) 159 Brignole, Rossi, PLB 566 (2003) 517	10^{-10}	10^{-7}
SM + heavy Maj ν_R	Cvetic, Dib, Kim, Kim , PRD66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	Yue, Zhang, Liu, PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	Masiero, Vempati, Vives, NPB 649 (2003) 189 Fukuyama, Kikuchi, Okada, PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA + Seesaw	Ellis, Gomez, Leontaris, Lola, Nanopoulos, EPJ C14 (2002) 319 Ellis, Hisano, Raidal, Shimizu, PRD 66 (2002) 115013	10^{-7}	10^{-9}

Theoretical branching ratios in some New Physics models

Latest results for τ→lll

➢ Results from the EPS in July

Mode	ε (%)	N_{BG}^{EXP}	N_{obs}	UL ($\times 10^{-8}$)	BaBar's
$e^-e^+e^-$	6.0 → 7.9	0.21+-0.15 → 0.48+-0.21	0→0	**2.7→1.8**	2.9
$\mu^-\mu^+\mu^-$	7.6 → 8.9	0.13+-0.06 → 0.42+-0.17	0→0	**2.1→1.6**	3.3
$e^-\mu^+\mu^-$	6.1 → 6.8	0.10+-0.04 → 0.52+-0.21	0→0	**2.7→2.0**	3.2
$\mu^-e^+e^-$	9.3 → 12.1	0.04+-0.04 → 0.41+-0.20	0→0	**1.8→1.2**	2.2
$\mu^-e^+\mu^-$	10.1 → 11.8	0.02+-0.02 → 0.09+-0.09	0→1	**1.7→2.5**	2.6
$e^-\mu^+e^-$	11.5 → 13.1	0.01+-0.01 → 0.01+-0.01	0→0	**1.5→1.3**	1.8

Belle results

Channel	Efficiency (%)	N_{bgd}	Exp. UL	N_{obs}	UL
$e^+e^-e^+$	8.6 ± 0.2	0.12 ± 0.02	3.4×10^{-8}	0	2.9×10^{-8}
$e^+e^-\mu^+$	8.8 ± 0.5	0.64 ± 0.19	3.7×10^{-8}	0	2.2×10^{-8}
$e^+e^+\mu^-$	12.6 ± 0.7	0.34 ± 0.12	2.2×10^{-8}	0	1.8×10^{-8}
$e^+\mu^-\mu^+$	6.4 ± 0.4	0.54 ± 0.14	4.6×10^{-8}	0	3.2×10^{-8}
$e^-\mu^+\mu^+$	10.2 ± 0.6	0.03 ± 0.02	2.8×10^{-8}	0	2.6×10^{-8}
$\mu^+\mu^-\mu^+$	6.6 ± 0.6	0.44 ± 0.17	4.0×10^{-8}	0	3.3×10^{-8}

BaBar results

Using the FastSim

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Q & A

- **Study conducted using V0.0.9**
- **Hypothesis:** $Br(\tau \rightarrow \mu\mu\mu) \approx 10^{-9}$
- **All the events in the 5-year data sample**
  - 25TB of data
  - 11000 years of simulation on 1 computer

Background Type	MC Class	$\sigma(nb)$	Events in a $75ab^{-1}$ data sample
signal	$e^+e^- \rightarrow \tau^+\tau^-, \tau^+ \rightarrow \mu^+\mu^-\mu^+$	0.94×10^{-9}	70
$B^0\bar{B}^0$	$e^+e^- \rightarrow B^0\bar{B}^0$	0.525	39.4×10^9
B^+B^-	$e^+e^- \rightarrow B^+B^-$	0.525	39.4×10^9
$c\bar{c}$	$e^+e^- \rightarrow c\bar{c}$	1.30	97.5×10^9
uds	$e^+e^- \rightarrow u\bar{u}/d\bar{d}/s\bar{s}$	2.09	157×10^9
Bhabha	$e^+e^- \rightarrow e^+e^-$	40	3.0×10^{12}
$\mu^+\mu^-$	$e^+e^- \rightarrow \mu^+\mu^-$	1.16	87.0×10^9
$\tau^+\tau^-$	$e^+e^- \rightarrow \tau^+\tau^-$	0.94	70.5×10^9

Number of events for every channel considered in this study

Solutions and new tools

- **A. Bevan wrote a filter for the FastSim**
  - Divided the average event size by 241 in this case
  - Sped up the simulation
- **Simulate less events**
  - Virtually increase the size of the data sample by not applying the PID but using its mis-ID rate
  - Mimic the PID using data from the MCTruth block

Background Type	mis-ID rate	Events in the simulated sample
$B^0\bar{B}^0$	5.12×10^{-3}	923.1×10^6
B^+B^-	4.07×10^{-3}	914.3×10^6
$c\bar{c}$	6.21×10^{-4}	88×10^6
uds	1.21×10^{-4}	99×10^6
Bhabha	1.27×10^{-9}	2.0975×10^9
$\mu^+\mu^-$	1.37×10^{-4}	2×10^9
$\tau^+\tau^-$	2.86×10^{-5}	99.2×10^6

Defining the cuts

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- **Reject particles that are errors in the reconstruction**
  - Loose cuts on the momentum, the polar angle
- **Use the event geometry**
  - 3-x topology: maximum number of muons, neutral candidates and reconstructed taus
- **Use kinematic variables**
  - Invariant mass and momentum of the reconstructed taus
  - Momentum of the muons

Selection requirements for the filter

Cuts Type	Value
Polar angle	$13^o \leq \theta \leq 165^o$
Momentum (for charged particles only)	$0.1 \leq \lvert\vec{p_c}\rvert \leq 5GeV$
Number of tracks	$3 \leq nTRK \leq 7$
Number of neutral particles	$ngamma \leq 6$
Mass of the reconstructed particles	$1.70 \leq tauMass \leq 1.85GeV$

Loose cuts

Cuts Type	Value
Polar angle (for charged particles)	$-0.96 \leq \cos\theta_c \leq 0.966$
Momentum (for charged particles only)	$0.15 \leq \lvert\vec{p_c}\rvert \leq 4.9GeV$
Polar angle (for neutral particles)	$-0.96 \leq \cos\theta_n \leq 0.966$

Optimizing the cuts

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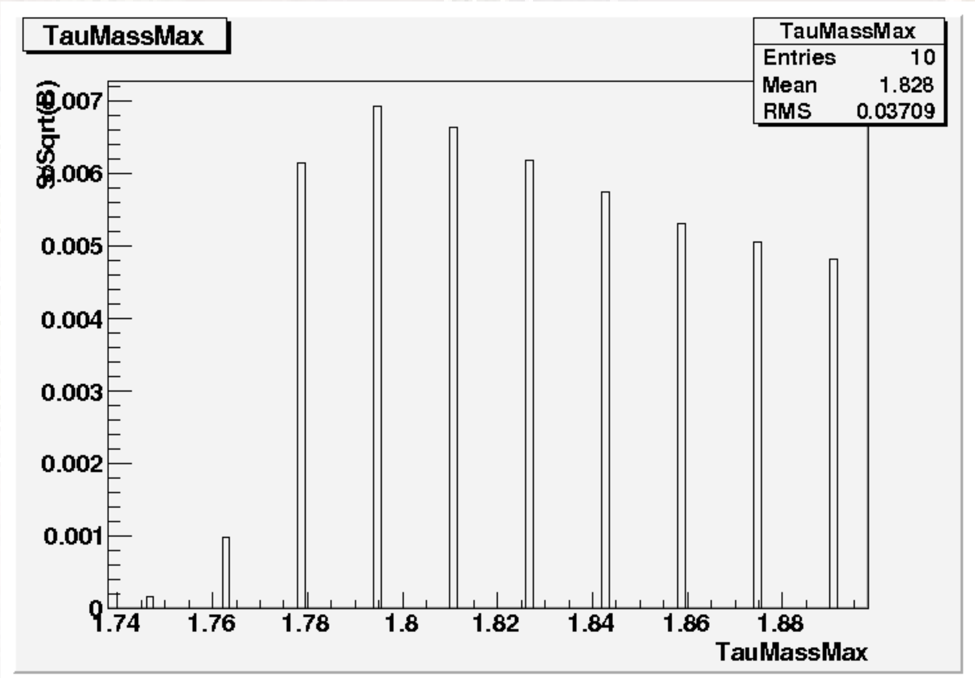
Q & A

- **Maximize S/√B for different values of the cuts**



S/√B as a function of the tau mass

- **Do it properly**
  - No over-training
  - Use a training sample

- **Results of the optimization**

Cuts	n_{TRK}	n_γ	n_μ	E_μ^{CM}	$\lvert\vec{p}_\mu^{\,CM}\rvert$	n_{rec}	m_{rec}	$\lvert\vec{p}_{rec}^{\,CM}\rvert$
No optimization	$[3,6]$	$[0,6]$	$[3,4]$	$[0.15,4.9]$	$[0.15,4.9]$	$[1,4]$	$[1.70,1.85]$	$[4.5,5.2]$
1^{st} optimization	$[4,6]$	$[0,5]$	3	~~[0.15, 5]~~	$[0.15,4.6]$	~~1~~	$[1.76,1.79]$	$[4.5,5.2]$
2^{nd} optimization	4	$[0,5]$	3	~~[1., 4.9]~~	$[1.,4.9]$	~~1~~	$[1.77,1.8084]$	$[4.92,4.976]$

Results

- **Compute the upper-limit**
  - Get the efficiencies for every channel
  - Calculate the expected number of events
  - Use the Cousins-Highland method

Sample	Size	n_{TRK}	n_γ	n_μ	$\lvert\vec{p}_\mu^{\,CM}\rvert$	m_{rec}	$\lvert\vec{p}_{rec}^{\,CM}\rvert$	total/ϵ
Signal	1×10^6	0.569	0.896	0.512	0.228	0.726	0.338	0.0145 ± 0.0001
$B^0\bar{B}^0$	923.1×10^6	1.68×10^{-4}	0.563	0.254	6.4×10^{-3}	0.232	0.0	$(0+1) \times 10^{-9}$
B^+B^-	914.3×10^6	7.9×10^{-5}	0.492	0.306	5.4×10^{-3}	0.254	0.0	$(0+1) \times 10^{-9}$
$c\bar{c}$	88×10^6	1.0×10^{-3}	0.534	0.229	0.017	0.188	0.0	$(0+1) \times 10^{-8}$
uds	99×10^6	3.1×10^{-3}	0.619	0.251	0.038	0.259	0.030	$(1.4 \pm 0.4) \times 10^{-7}$
Bhabha	2.0975×10^9	6.2×10^{-6}	0.911	0.246	0.173	0.182	0.014	$(4.8 \pm 4.8) \times 10^{-10}$
$\mu^+\mu^-$	2.0×10^9	2.1×10^{-5}	0.984	0.776	0.136	0.307	0.037	$(2.5 \pm 0.4) \times 10^{-8}$
$\tau^+\tau^-$	99.2×10^6	8.2×10^{-3}	0.779	0.281	2.1×10^{-3}	0.208	0.13	$(1.0 \pm 1.0) \times 10^{-8}$

Partial efficiencies for every channel

- **Final result: upper-limit at the 90% confidence level:** 1.2×10^{-9}

Conclusion

- **Lepton Flavour Violation is one of the best way to find New Physics and to constrain it**
- **Super*B* will divide by more than 10 the current upper-limits on $\tau\rightarrow\mu\mu\mu$**
- **One of the largest data sample generated with the FastSim so far**
- **Numerous improvements can be done**
  - Variables with a better separation
  - Multivariate analysis methods

Questions & Answers

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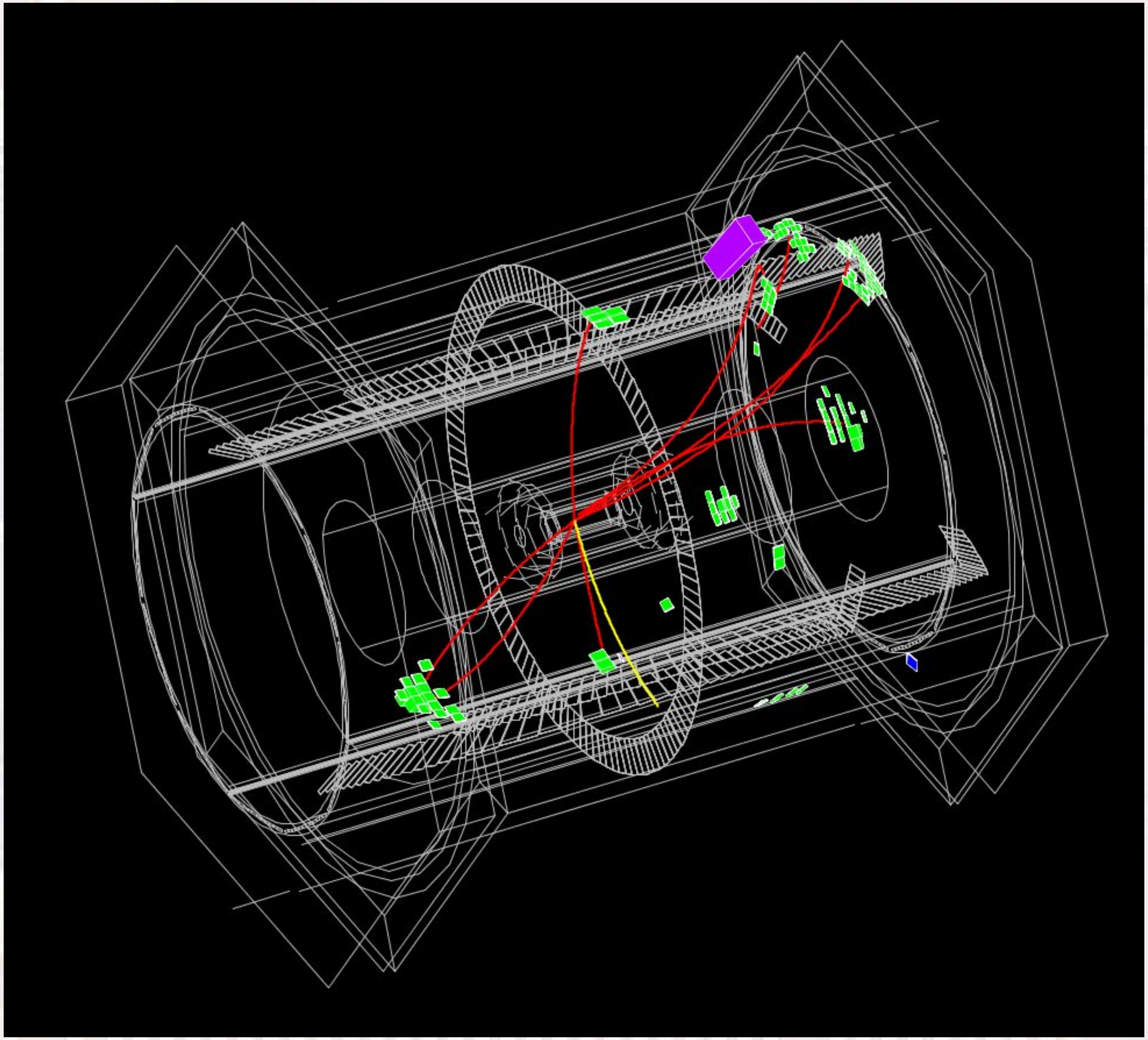

Event recorded at *BaBar*

- **Simulate data samples**
  - Signal
  - Backgrounds
- **Define cuts and optimise them**
- **Get the efficiencies**
- **Compute the upper limit for the branching ratio**