



Hot Topics in BaBar



- *Search for light Higgs-like particle:*
 - $\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \mu^+ \mu^-$
- *Searches for Lepton Flavor Violation decays:*
 - $\Upsilon(3S) \rightarrow e^\pm \tau^\mp, \mu^\pm \tau^\mp$
 - $\tau \rightarrow 3l (l = e, \mu)$

João Firmino da Costa (LAL Orsay)
on behalf of the BaBar Collaboration

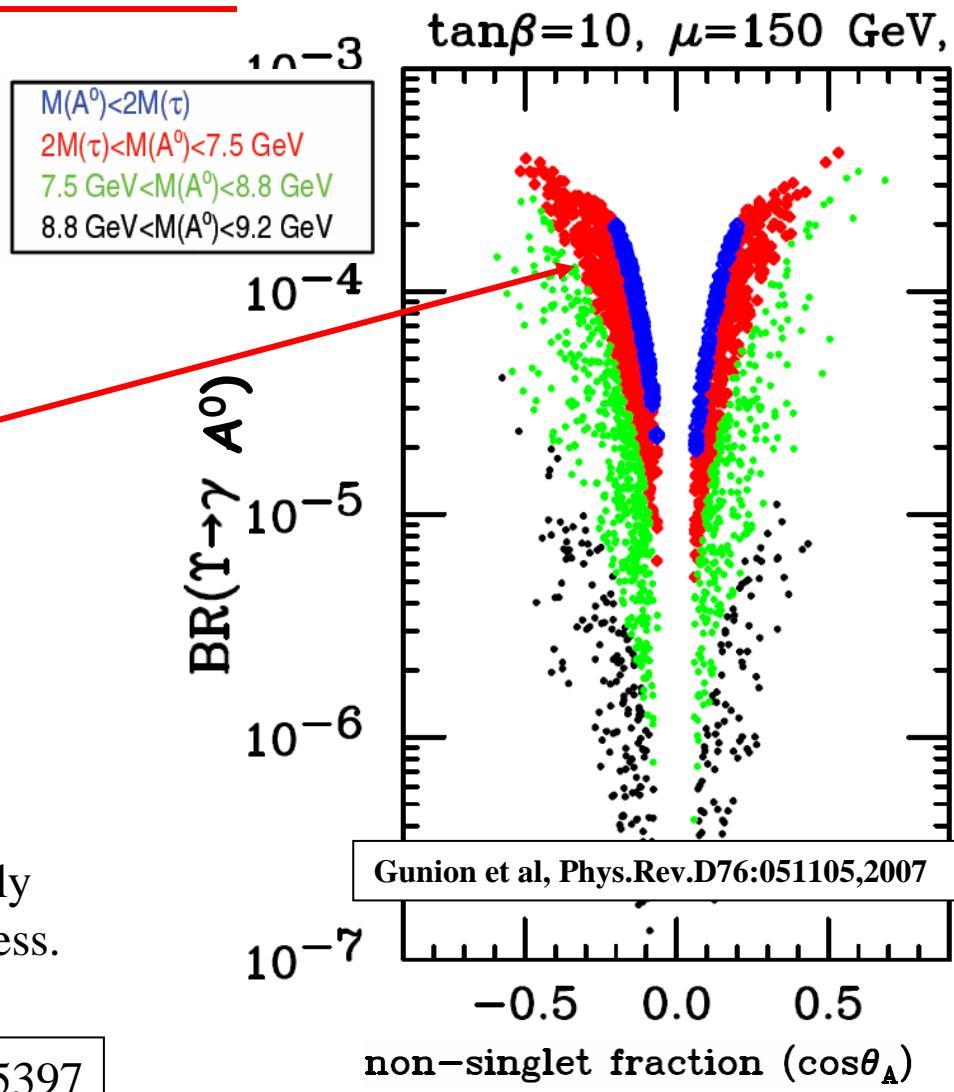


Why $\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \mu^+ \mu^-$

NMSSM

- NMSSM introduces a singlet Higgs field which mixes with standard Higgs creating a A^0 , CP-odd & possibly light.
- NMSSM parameter space allows

$BR(\Upsilon(3S) \rightarrow \gamma A^0)$ up to 10^{-4}



Axions

- Axion-like pseudoscalar bosons decaying mainly to leptons, that could explain PAMELA e^+ excess.

$BR(\Upsilon(3S) \rightarrow \gamma A^0) \simeq 10^{-5} - 10^{-6}$

hep-ph:0810.5397



Why $\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \mu^+ \mu^-$

HyperCP

- 3 events with $m_{\mu\mu} = 214.3 \text{ MeV}/c^2$, interpreted as coming from a light scalar in decays $\Sigma \rightarrow p \mu^+ \mu^-$

PRL 94, 021801 (2005)
hep-ex/0501014

η_b

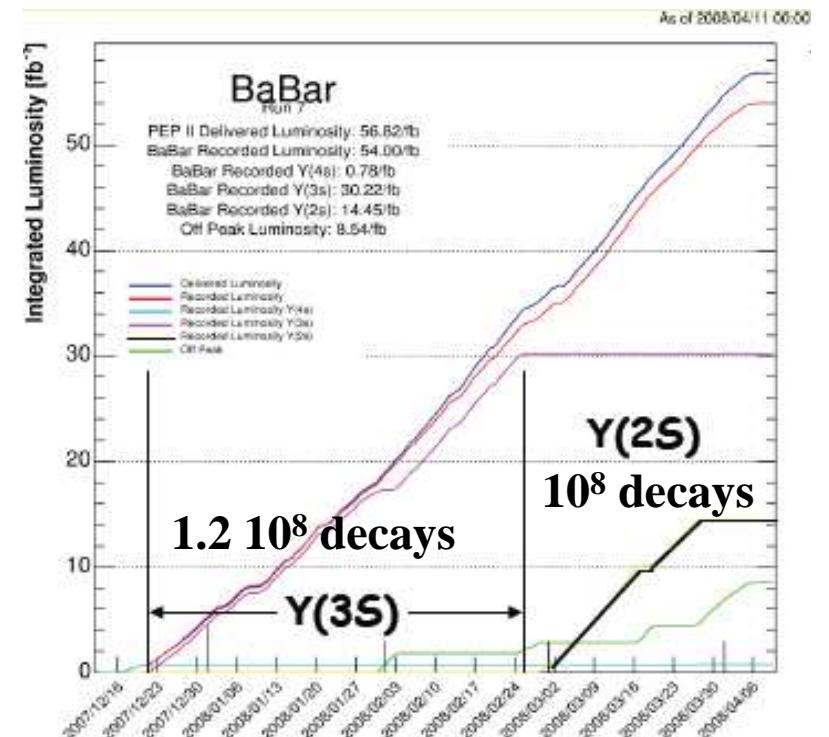
- $\eta_b \rightarrow \mu^+ \mu^-$ expected negligible if η_b is a conventional $b\bar{b}$ state.

• CLEO has set limits on $\Upsilon(1S) \rightarrow \gamma A^0(\mu^+ \mu^-) \sim 4 \cdot 10^{-6}$ for $m(A^0) < 2m(\tau)$

PRL 101, 151802 (2008)

$\Gamma_{\Upsilon(4S)} / \Gamma_{\Upsilon(3S)} \sim 10^3$ (greater sensitivity to rare decays)

- Expected sensitivity for $\Upsilon(3S) \rightarrow \gamma A^0(\mu^+ \mu^-) \sim 10^{-6}$





Signal & Bkg PDFs

- Signal m_R PDF from simulated signal events generated at many different mass points

- PDF shape parameters interpolated between mass points

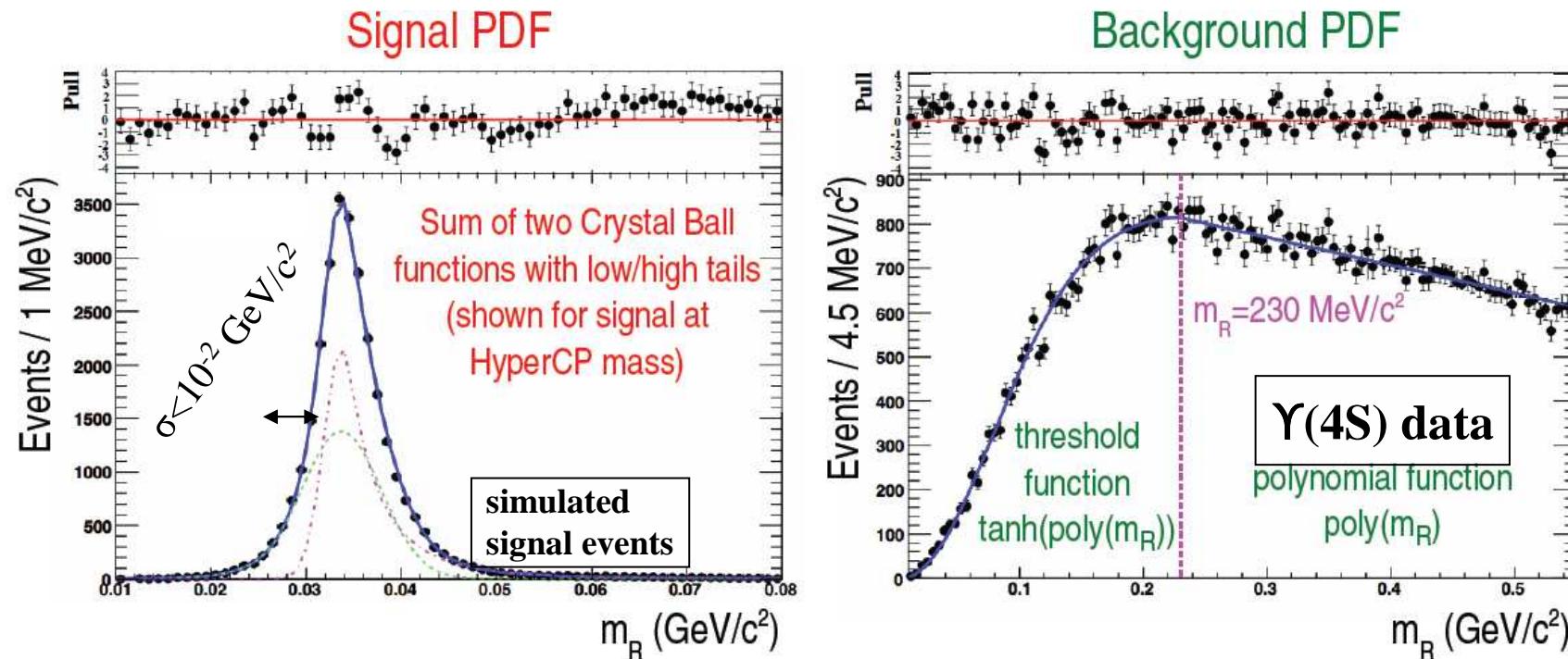
- Simulation results calibrated using charmonium backgrounds

$$m_R = \sqrt{m_{\mu\mu}^2 - 4m_\mu^2}$$

m_R =mass reduced

- Background m_R PDF determined from fit to $\Upsilon(4S)$ data

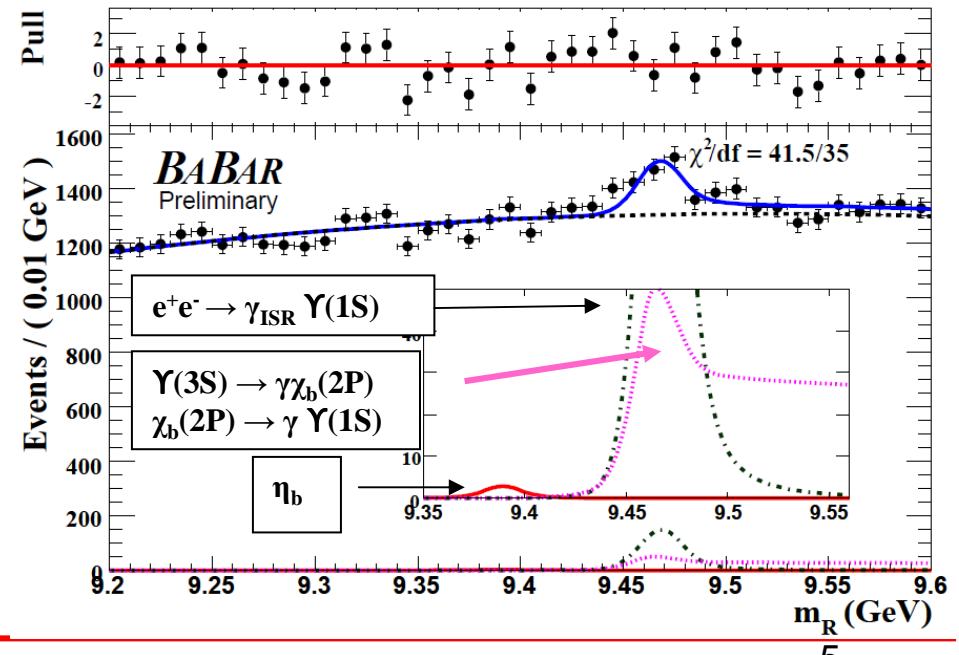
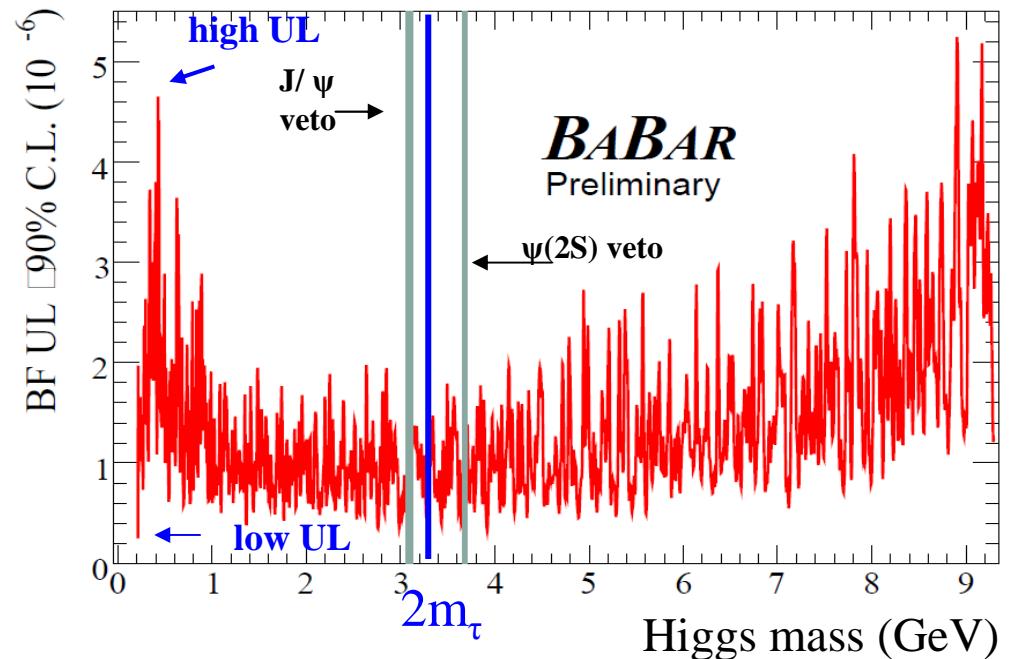
- Bkg dominated by $e^+e^- \rightarrow \mu^+\mu^-$ either from continuum or ISR $J/\psi, \psi(2S), \Upsilon(1S)$





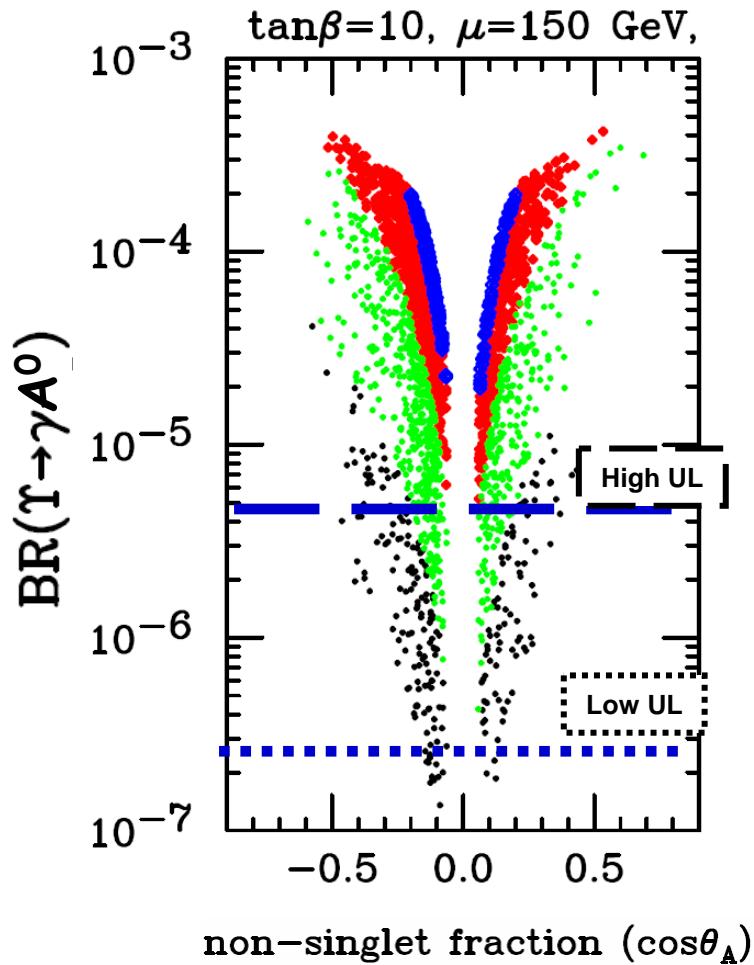
Results:

- No significant signal found
- Upper limits (90% CL) range:
 $(0.25\text{--}5.2) \times 10^{-6}$
 $(0.25\text{--}4.7) \times 10^{-6}, \quad m < 2m(\tau)$
- HyperCP mass region ($m_{\mu\mu} = 0.214 \text{ GeV}/c^2$):
 $\text{BF} = (0.12^{+0.43}_{-0.41} \pm 0.17) \times 10^{-6}$
 $\text{BF} < 0.8 \times 10^{-6} \text{ (90% CL)}$
- η_b mass region :
 $\text{BF}(\Upsilon(3S) \rightarrow \gamma\eta_b) \times \text{BF}(\eta_b \rightarrow \mu^+\mu^-) =$
 $(0.2 \pm 3.0 \pm 0.9) \times 10^{-6}$
 $\text{BF}(\eta_b \rightarrow \mu^+\mu^-) < 0.8\% \text{ (90% CL)}$





Experimental Limits:



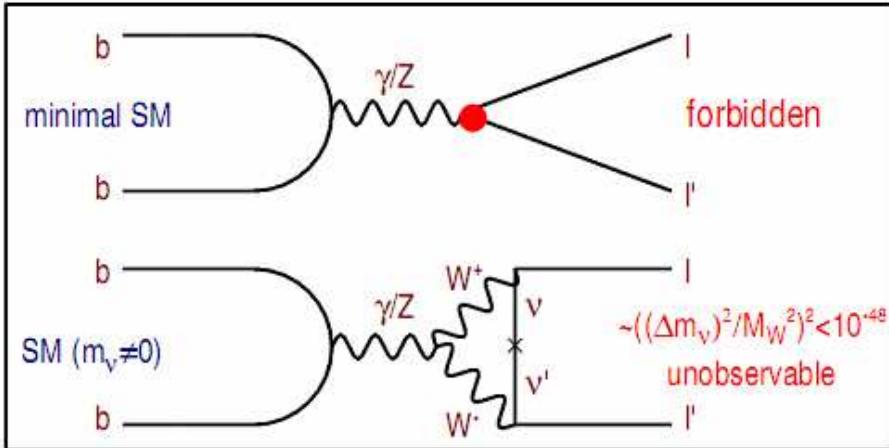
$M(A^0) < 2M(\tau)$
 $2M(\tau) < M(A^0) < 7.5 \text{ GeV}$
 $7.5 \text{ GeV} < M(A^0) < 8.8 \text{ GeV}$
 $8.8 \text{ GeV} < M(A^0) < 9.2 \text{ GeV}$

- For $M(A^0) < 2M(\tau)$ much of the parameter space is excluded.
- If $2M(\tau) < M(A^0) < \Upsilon(3S)$, more relevant to observe tau and hadronic decay modes (ongoing)

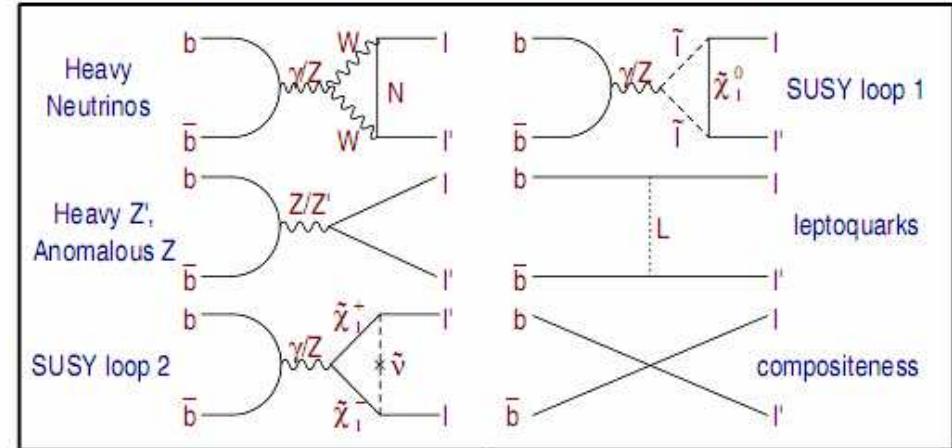


Why $\Upsilon(3S) \rightarrow e^\pm \tau^\mp, \mu^\pm \tau^\mp$

SM Diagrams

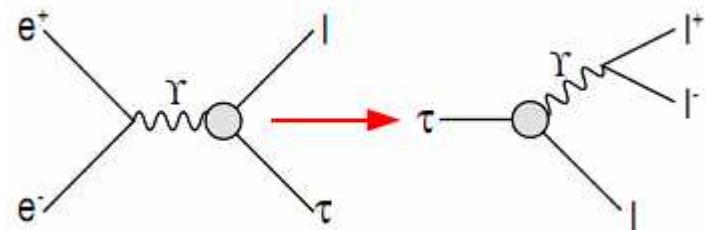


beyond SM Diagrams



- Charged Flavor Lepton Violation(CFLV) in Υ sector relatively untouched despite many beyond Standard Model mechanisms for CLFV in Υ decays
- New physics in Higgs sector couples preferentially to heavy flavors
- Current limit is $\sim 2 \times 10^{-5}$ for the $(\Upsilon \rightarrow \mu \tau)$ channel
- $\Upsilon \rightarrow l \tau$ can be related to $\tau \rightarrow 3l$ by re-ordering input-output lines

hep-ph/0004153



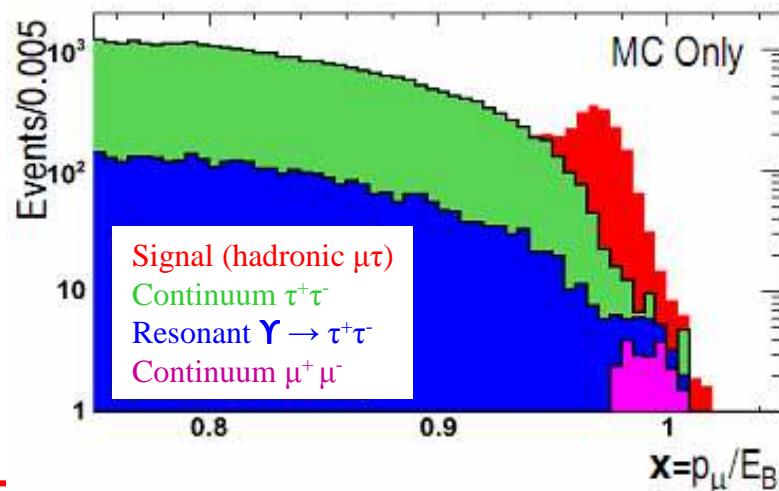


STRATEGY

- 4 channels:

Process	τ Decay	Channel
$\Upsilon(3S) \rightarrow e\tau$	$\tau \rightarrow \mu\nu\nu$	leptonic $e\tau$
$\Upsilon(3S) \rightarrow e\tau$	$\tau \rightarrow \pi^+\pi^0\nu/\pi^+\pi^0\pi^0\nu$	hadronic $e\tau$
$\Upsilon(3S) \rightarrow \mu\tau$	$\tau \rightarrow e\nu\nu$	leptonic $\mu\tau$
$\Upsilon(3S) \rightarrow \mu\tau$	$\tau \rightarrow \pi^+\pi^0\nu/\pi^+\pi^0\pi^0\nu$	hadronic $\mu\tau$

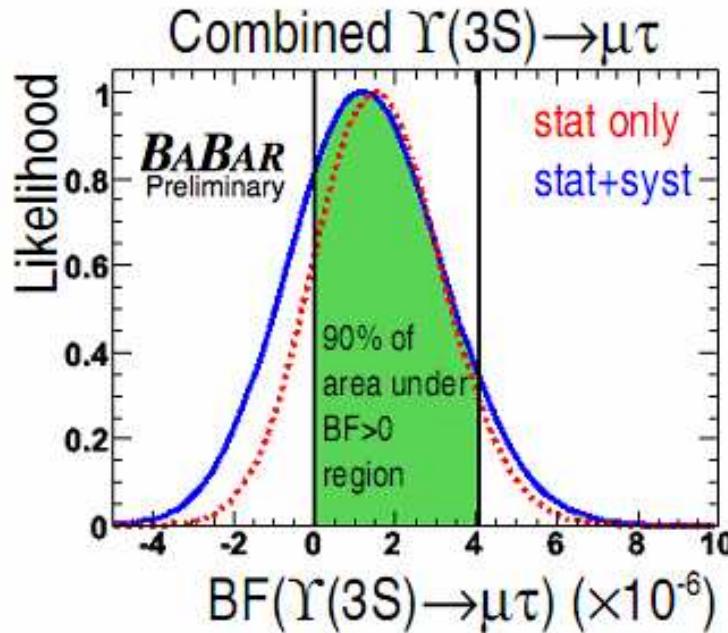
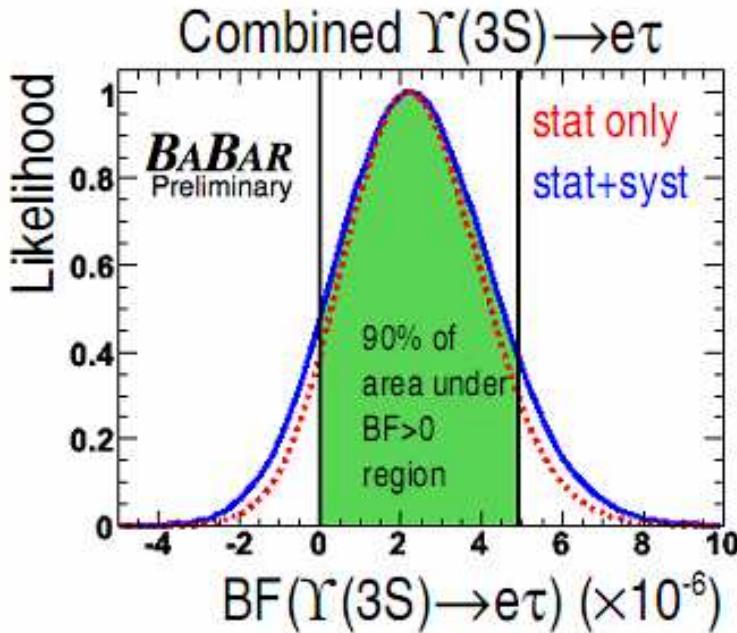
Primary discriminant variable x :
 $x = p_e/E_B$ for $\Upsilon(3S) \rightarrow e\tau$ channels
 $x = p_\mu/E_B$ for $\Upsilon(3S) \rightarrow \mu\tau$ channels



- **Signal $\Upsilon(3S) \rightarrow e\tau/\mu\tau$ Production**
- x distribution peaked at 0.97
- **Main irreducible background from τ -pair events**
- x distribution follows smooth Michel spectrum truncating at $x \sim 0.97$
- **Peaking backgrounds:**
 - $e\tau$ channels: Bhabha events
 - $\mu\tau$ channels: μ -pair events
 - x distribution has smooth threshold component truncating at $x \sim 1$ + Gaussian peaked at $x \sim 1$
- **Strategy:** unbinned extended maximum likelihood fit to x distribution



RESULTS



$BF(\Upsilon(3S) \rightarrow e\tau) < 5.0 \times 10^{-6}$
(first upper limit)

$BF(\Upsilon(3S) \rightarrow \mu\tau) < 4.1 \times 10^{-6}$
(>4 times lower than previous upper limit)



Improved search for $\tau \rightarrow 3l(l = e, \mu)$

- Finding Charged Lepton Flavor Violation.
- Some models predict BR up to present B-factories sensitivity

Framework	Model	BR
BSM	SM + right heavy Majorana ν	$< 10^{-10}$
	SM + left-right neutral isosinglets	$\sim 10^{-9}$
SUSY	MSSM + right heavy Majorana ν	$\sim 10^{-9}$
	left-right SUSY	$\sim 10^{-10}$
	SUSY + neutral Higgs	$10^{-10} - 10^{-7}$
	SUSY + Higgs triplet	$\sim 10^{-7}$
	MSSM + universal soft SUSY breaking	$\sim 10^{-9}$
Other	MSSM + non-universal soft SUSY breaking	$\sim 10^{-6}$
	Technicolor	$\sim 10^{-8}$

- This measurement is complementary to $\tau \rightarrow l\gamma$ since depending on the NP model for LFV the ratio $BR(\tau \rightarrow 3l) / BR(\tau \rightarrow l\gamma)$ can vary from $O(10^{-3})$ to $O(10)$.



MOTIVATION

Existing measurement before the improved limits
we report here

Channel	BaBar	Belle
$e^+e^-e^+$	4.3×10^{-8}	3.6×10^{-8}
$e^+e^-\mu^+$	8.0×10^{-8}	2.7×10^{-8}
$e^+e^+\mu^-$	5.8×10^{-8}	2.0×10^{-8}
$e^+\mu^-\mu^+$	5.6×10^{-8}	4.1×10^{-8}
$e^-\mu^+\mu^+$	3.7×10^{-8}	2.3×10^{-8}
$\mu^+\mu^-\mu^+$	5.3×10^{-8}	3.2×10^{-8}

376 fb^{-1} 535 fb^{-1}

Innovations for this analysis:

- Total BaBar $\Upsilon(4S)$ ($472 \text{ fb}^{-1} \rightarrow 4.3 \times 10^8 \tau$ pairs)
- Much improved particle identification and tracking, e.g:

Single μ eff. 66% \rightarrow 77%

Single el. eff. 89% \rightarrow 91%

Six channels studied:

$$\tau^- \rightarrow e^- e^+ e^-$$

$$\tau^- \rightarrow \mu^- e^+ e^-$$

$$\tau^- \rightarrow e^- \mu^+ e^-$$

$$\tau^- \rightarrow \mu^- \mu^+ e^-$$

$$\tau^- \rightarrow \mu^- e^+ \mu^-$$

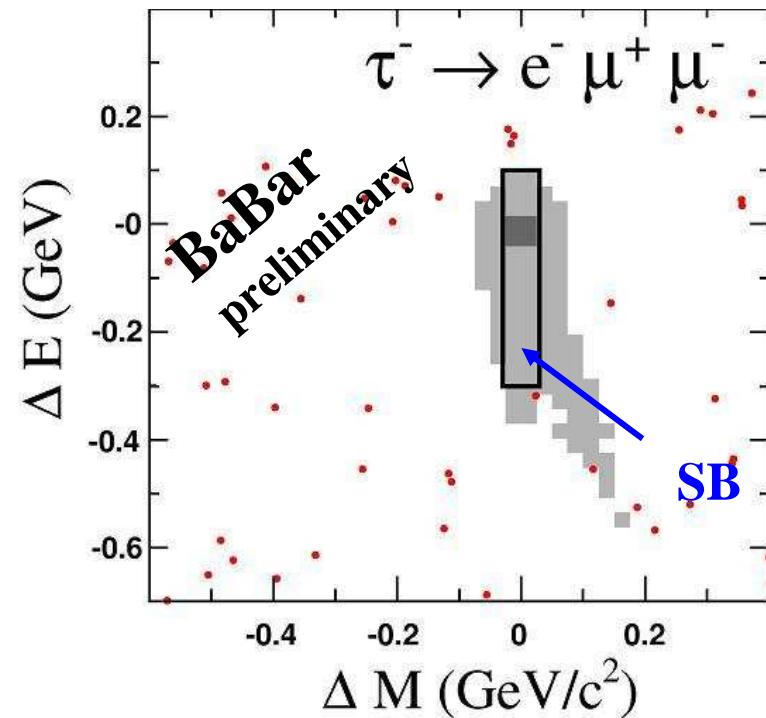
$$\tau^- \rightarrow \mu^- \mu^+ \mu^-$$



STRATEGY

- Signature is a set of 3 charged tracks (μ, e) (no neutrinos) with inv. mass & E equal to τ
- Tag τ decays in 1-prong mode
- Selection criteria is optimized separately for each channel
- Blinded signal region (SB)
 - Estimate background using sideband data
 - Unblind and estimate signal yield

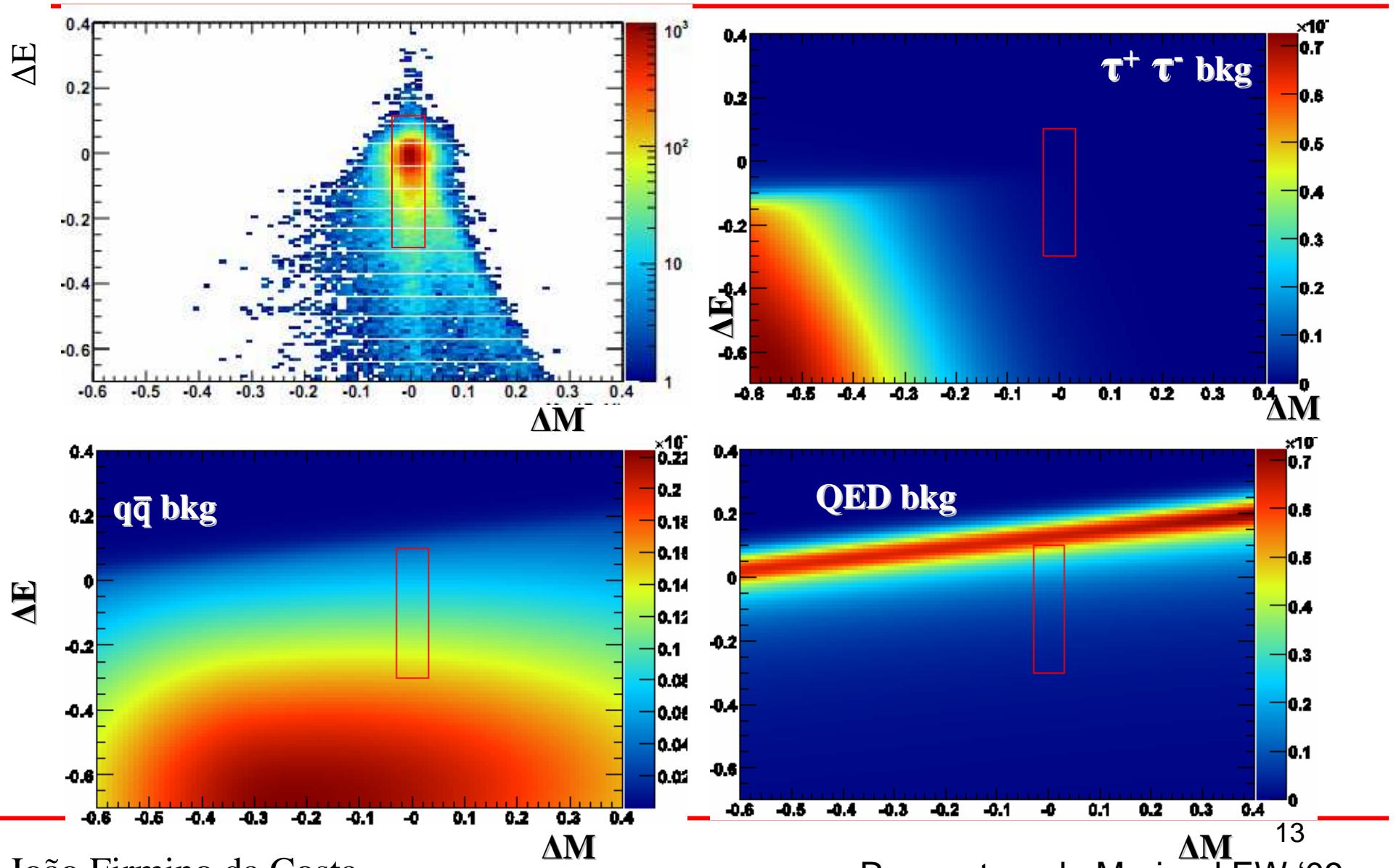
$$\Delta M = M_{INV}^{*}(\ell\ell\ell) - M_{PDG}(\tau)$$
$$\Delta E = E^{cms}(\ell\ell\ell) - \sqrt{s}/2$$





SIGNAL & BKG simulations

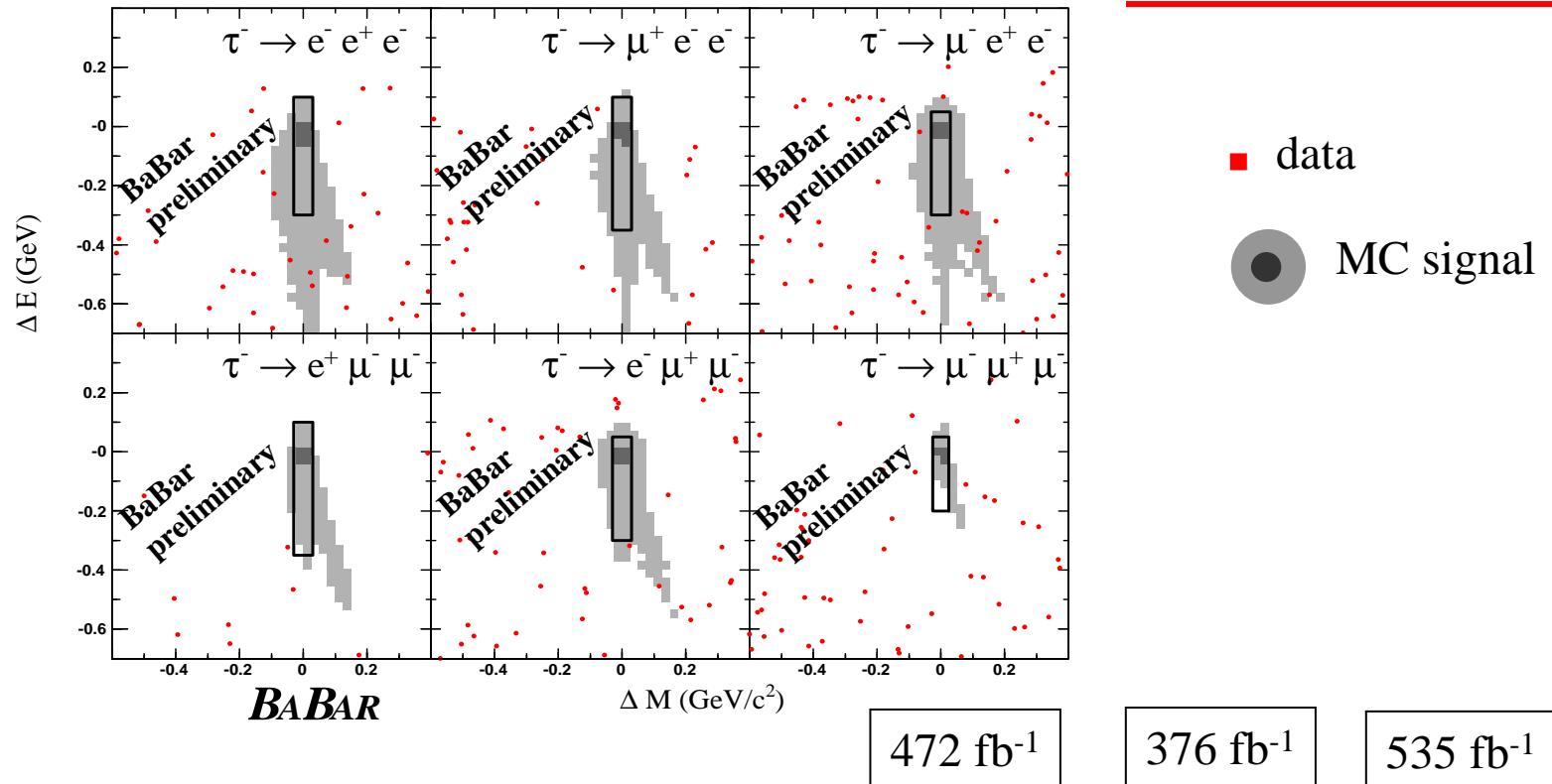
(Example : $e^+e^-\mu^+$)





RESULTS

(preliminary)



Channel	Efficiency (%)	N_{bgd}	Expected UL	N_{obs}	UL	NEW!	PREVIOUS	BABAR	Belle
$e^+e^-e^+$	8.6 ± 0.2	0.12 ± 0.02	3.4×10^{-8}	0	2.9×10^{-8}			4.3×10^{-8}	3.6×10^{-8}
$e^+e^-\mu^+$	8.8 ± 0.5	0.64 ± 0.19	3.7×10^{-8}	0	2.2×10^{-8}			8.0×10^{-8}	2.7×10^{-8}
$e^+e^+\mu^-$	12.6 ± 0.7	0.34 ± 0.12	2.2×10^{-8}	0	1.8×10^{-8}			5.8×10^{-8}	2.0×10^{-8}
$e^+\mu^-\mu^+$	6.4 ± 0.4	0.54 ± 0.14	4.6×10^{-8}	0	3.2×10^{-8}			5.6×10^{-8}	4.1×10^{-8}
$e^-\mu^+\mu^+$	10.2 ± 0.6	0.03 ± 0.02	2.8×10^{-8}	0	2.6×10^{-8}			3.7×10^{-8}	2.3×10^{-8}
$\mu^+\mu^-\mu^+$	6.6 ± 0.6	0.44 ± 0.17	4.0×10^{-8}	0	3.3×10^{-8}			5.3×10^{-8}	3.2×10^{-8}



CONCLUSIONS

$$\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \mu^+ \mu^-$$

No significant $\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \mu\mu$ signal observed

Conference note at arXiv:0902.2176 [hep-ex]

Upper limits (90% CL) range from $(0.25-5.2) \times 10^{-6}$

No significant signal at HyperCP mass (di-muon threshold)

$\text{BF}(\Upsilon(3S) \rightarrow \gamma A^0 \text{ (} m_{\mu\mu} = 214 \text{ MeV/c}^2 \text{)}) < 0.8 \times 10^{-6}$ (90% CL)

No evidence of $\eta_b \rightarrow \mu^+ \mu^-$ decays

$\text{BR}(\eta_b \rightarrow \mu^+ \mu^-) < 0.8\%$ (90% CL)

$$\Upsilon(3S) \rightarrow e^\pm \tau^\mp, \mu^\pm \tau^\mp$$

No charged LFV observed

$\text{BR}(\Upsilon(3S) \rightarrow e^\pm \tau^\mp) < 5 \times 10^{-6}$ (90% CL)

$\text{BR}(\Upsilon(3S) \rightarrow e^\pm \tau^\mp) < 4.1 \times 10^{-6}$ (90% CL)

arXiv:0812.1021[hep-ex]

$$\tau \rightarrow 3l(l = e, \mu)$$

Results are not background limited, great opportunities for SuperB factories

No charged LFV observed in the 6 analysed channels

$\text{BR}(\tau \rightarrow 3l) < (1.8 - 3.3) \times 10^{-6}$ (90% CL) depending on the channel (preliminary results)

Significant improvement from previous BaBar analysis



BACK-UP SLIDES

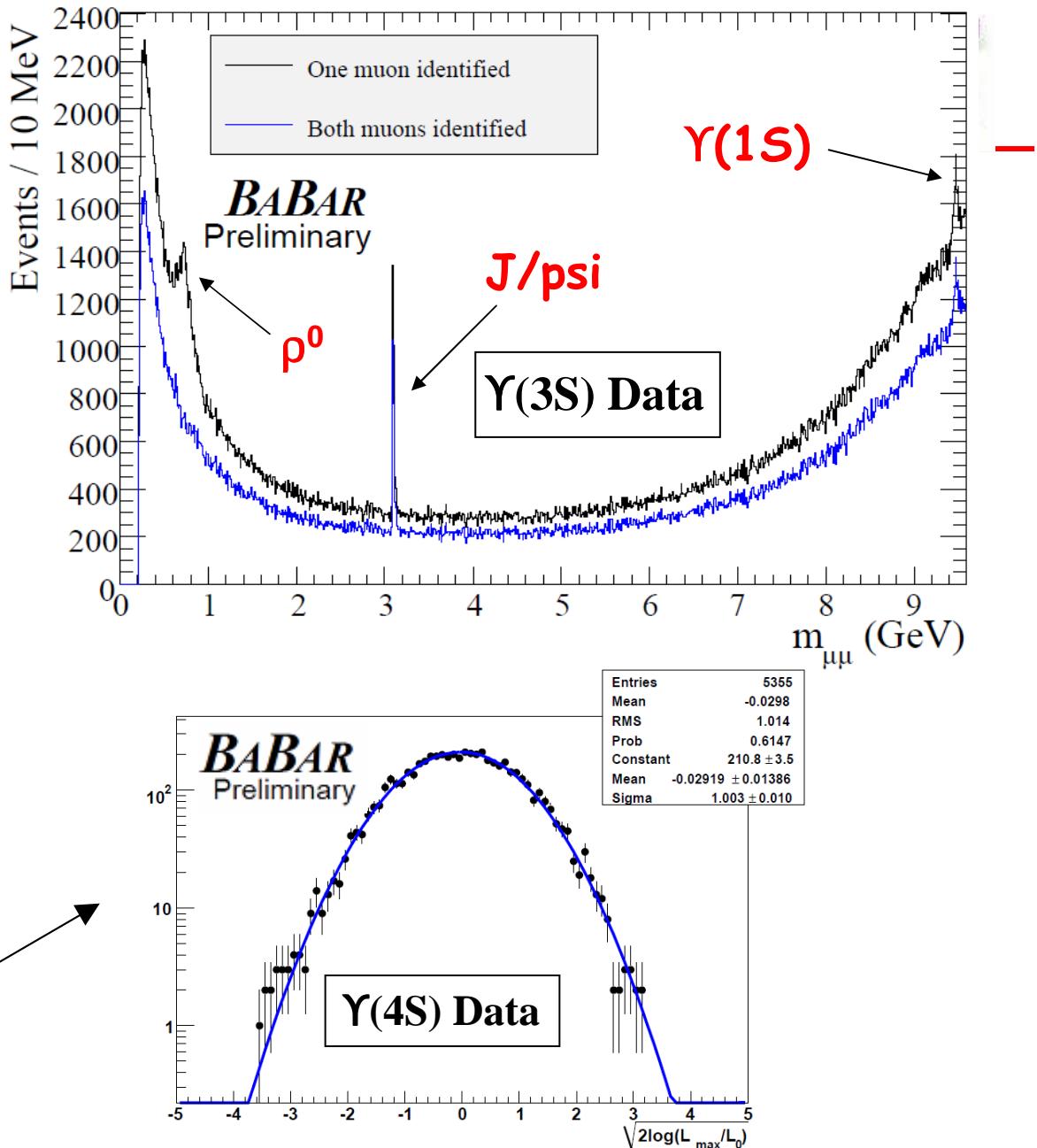


BACK-UP SLIDES $\Upsilon(3S) \rightarrow \dots$



Mass Scan

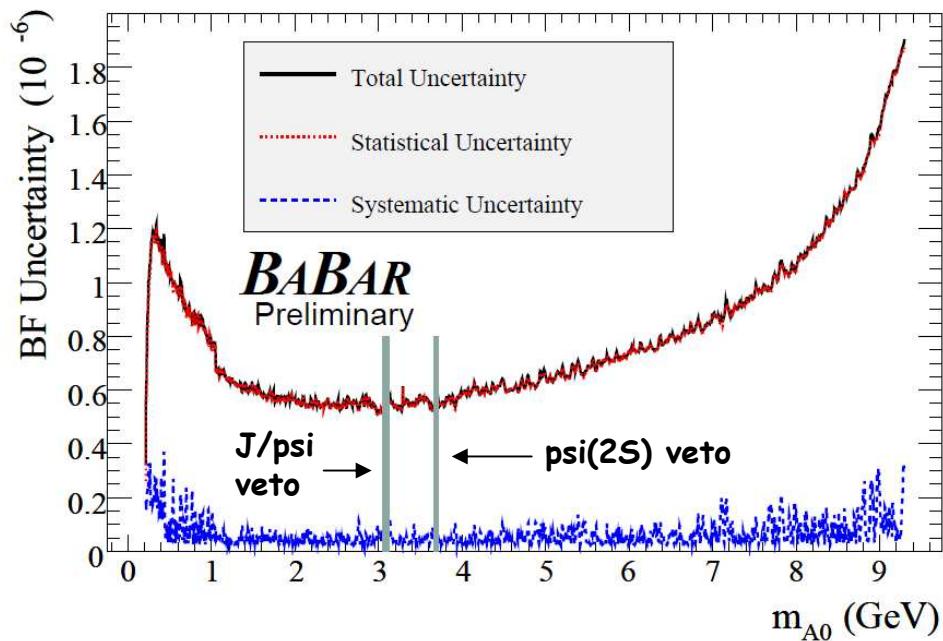
- $M(A^0)$ mass scan over ~ 2000 points
 - $2M(m) < M(A^0) < 9.3$ GeV
- Signal yield from ML fit in ~ 300 MeV m_R bins
- To suppress ρ^0 background, require two identified muons for $M(A^0) < 1.05$ GeV
 - Muon mis-id as pion $\sim 5\%$
- Signal significances from mass fits on 78.5 fb^{-1} $\Upsilon(4S)$ data control sample are Gaussian distributed with no significant outliers



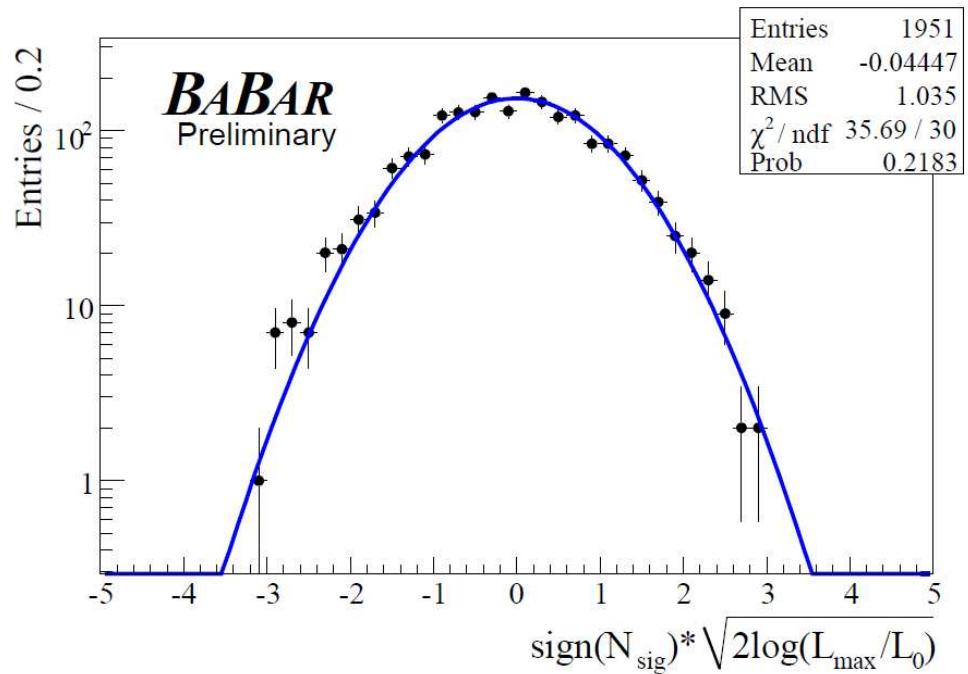


Systematics & Significance

- PDF systematics
 - ± 1 sigma PDF parameter variations
 - Signal width correction
 - calibrated from J/psi data/MC
 - Peaking background mean, width, tail
- Fit bias $s_{BF} \sim 0.02 \times 10^{-6}$
- Efficiency corrections $\sim 2\text{-}10\%$
- $\Upsilon(3S)$ counting $\sim 1\%$



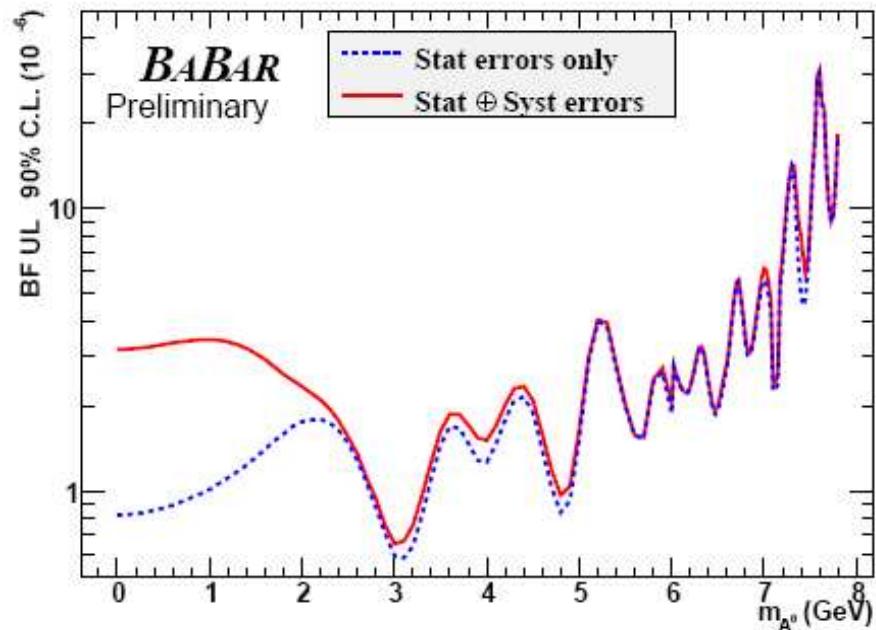
- Signal significance distribution (stat+sys) in $\Upsilon(3S)$ data shows no significant outliers
 - No excess signal events observed at HyperCP mass ~ 214 MeV
 - Most significant upward fluctuations ($\sim 3\sigma$) at 4.94 GeV and 0.426 GeV
 - $\sim 80\%$ probability to see one $>3\sigma$ result for number of points here





$\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow invisible$

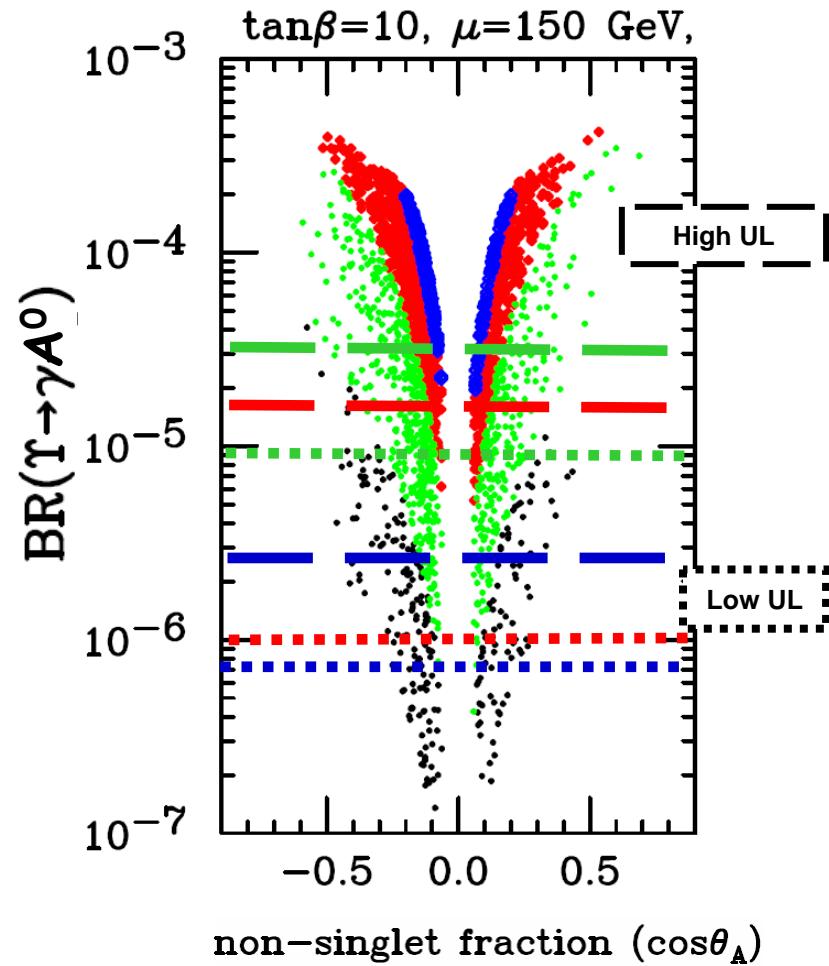
- Dominant A^0 decay mode may be invisible, e.g. to neutralino LSP pair
- Fit for missing mass in events with a high-energy photon with energy consistent with $0 < M(A^0) < 7.8$ GeV
- No significant signal seen anywhere, limits similar to di-muon results





$\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow invisible$

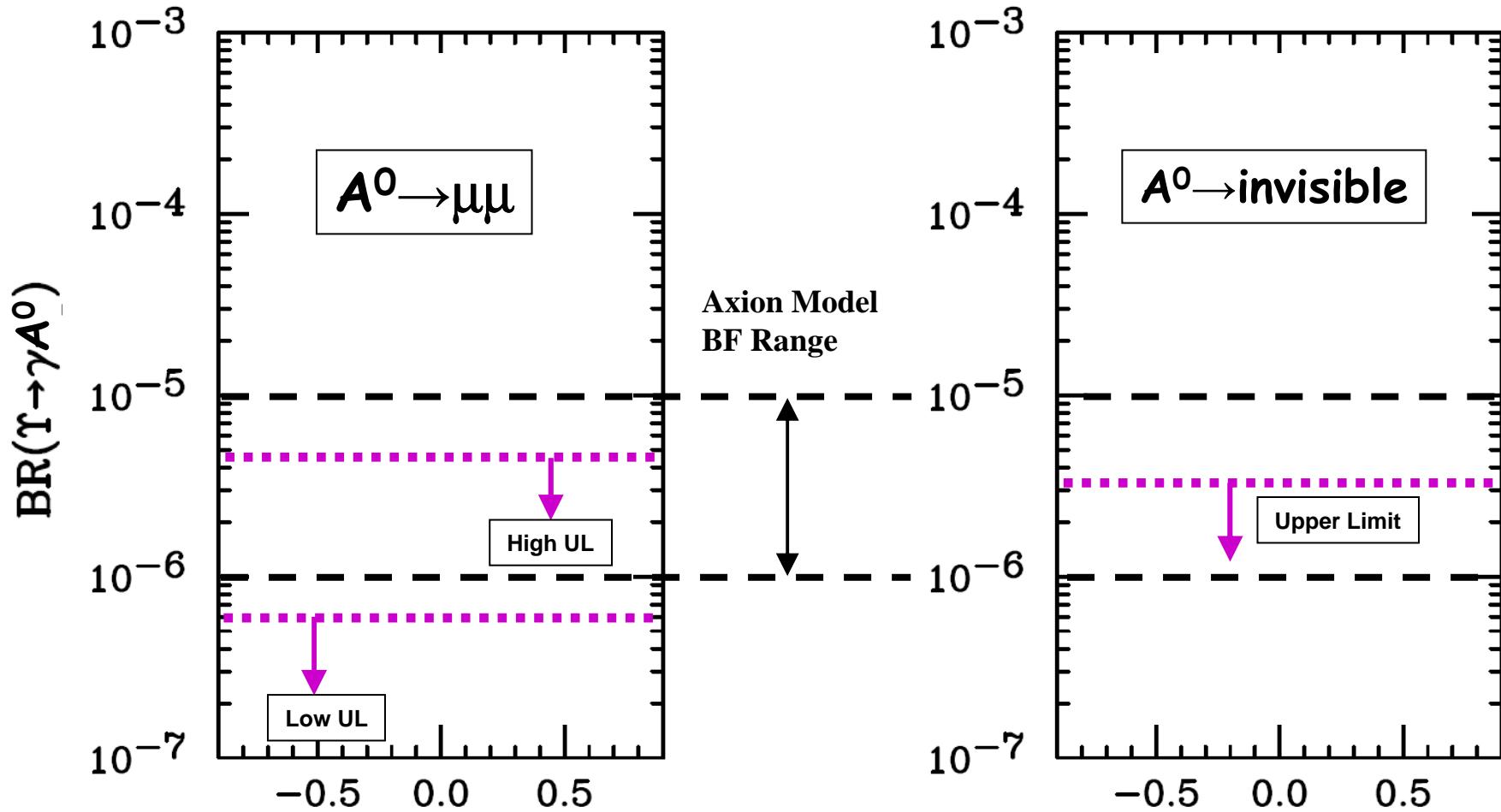
$M(A^0) < 2M(\tau)$
 $2M(\tau) < M(A^0) < 7.5 \text{ GeV}$
 $7.5 \text{ GeV} < M(A^0) < 8.8 \text{ GeV}$
 $8.8 \text{ GeV} < M(A^0) < 9.2 \text{ GeV}$





Experimental Limits:

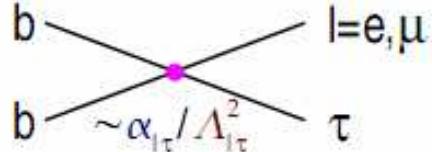
$0.36 < M(A^0) < 0.8 \text{ GeV}$ (Axion Model Mass Range)



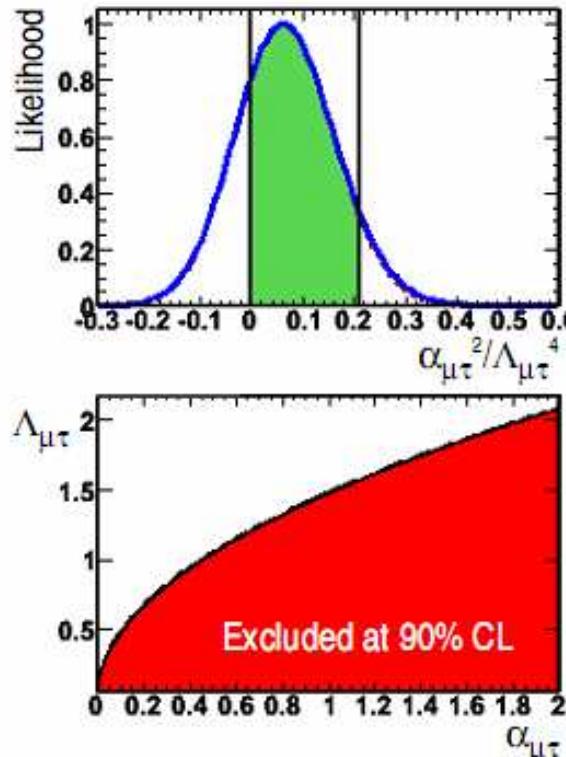
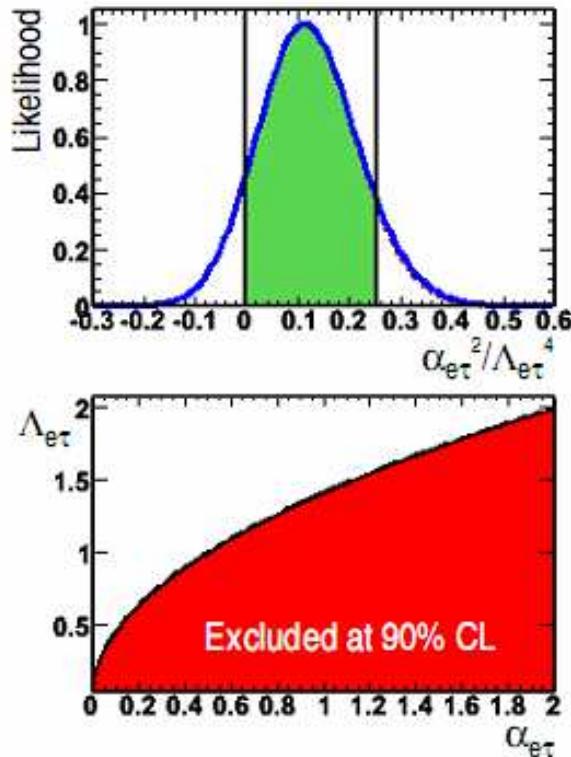


$Y(3S) \rightarrow l\tau$

CLFV Υ decays \rightarrow 4-fermion interaction with NP coupling constant and mass scale:



$$\frac{\alpha_{l\tau}^2}{\Lambda_{l\tau}^4} = \frac{BF(\Upsilon(3S) \rightarrow l\tau)}{BF(\Upsilon(3S) \rightarrow ll)} \frac{2q_b^2 \alpha^2}{(M_{\Upsilon(3S)})^4} (l = e, \mu)^*$$



q_b = b quark charge
 α = fine structure constant
assumes vector coupling
Silagadze Phys. Scripta 64.128
Black et al. PRD 66.053002

Assume strong coupling

$$\alpha_{e\tau} = \alpha_{\mu\tau} = 1:$$

$$\boxed{\Lambda_{e\tau} > 1.4 \text{ TeV}}$$
$$\boxed{\Lambda_{\mu\tau} > 1.5 \text{ TeV}}$$



BACK-UP SLIDES TAU -> 31



- Different models predict very different ratios between branching ratios of $\tau \rightarrow l\gamma$ and $\tau \rightarrow 3l$.
- This however will only be an acute test with increased sensitivity from experiments (SuperB?)

ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{\mathcal{B}(\tau^- \rightarrow e^- e^+ e^-)}{\mathcal{B}(\tau \rightarrow e\gamma)}$	0.4...2.3	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$
$\frac{\mathcal{B}(\tau^- \rightarrow \mu^- \mu^+ \mu^-)}{\mathcal{B}(\tau \rightarrow \mu\gamma)}$	0.4...2.3	$\sim 2 \cdot 10^{-3}$	0.06...0.1
$\frac{\mathcal{B}(\tau^- \rightarrow e^- \mu^+ \mu^-)}{\mathcal{B}(\tau \rightarrow e\gamma)}$	0.3...1.6	$\sim 2 \cdot 10^{-3}$	0.02...0.04
$\frac{\mathcal{B}(\tau^- \rightarrow \mu^- e^+ e^-)}{\mathcal{B}(\tau \rightarrow \mu\gamma)}$	0.3...1.6	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$
$\frac{\mathcal{B}(\tau^- \rightarrow e^- e^+ e^-)}{\mathcal{B}(\tau^- \rightarrow e^- \mu^+ \mu^-)}$	1.3...1.7	~ 5	0.3...0.5
$\frac{\mathcal{B}(\tau^- \rightarrow \mu^- \mu^+ \mu^-)}{\mathcal{B}(\tau^- \rightarrow \mu^- e^+ e^-)}$	1.2...1.6	~ 0.2	5...10

Blanke et al., [hep-ph/0702136](#)

SuperB CDR, [arXiv:0709.0451](#)



BACKGROUNDS & SYST.

Breakdown of expected backgrounds in signal box and GS

	$e^+e^-e^+$		$e^+e^-\mu^+$		$e^+e^+\mu^-$		$\mu^+\mu^-e^+$		$\mu^+\mu^+e^-$		$\mu^+\mu^-\mu^+$	
	GS	SB	GS	SB	GS	SB	GS	SB	GS	SB	GS	SB
<i>uds</i>	29.6	0.09	38.2	0.18	11.3	0.24	12.9	0.15	1.7	0.02	45.7	0.43
QED	5.2	0.03	15.1	0.46	29.6	0.04	28.4	0.32	0	0	0	0
$\tau\tau$	0	0	13.3	0.002	10.7	0.06	5.2	0.07	5.9	0.01	14.1	0.01
TOTAL	34.8	0.12	66.6	0.64	51.6	0.34	46.5	0.54	7.6	0.03	59.8	0.44

	$e^+e^-e^+$	$e^+e^-\mu^+$	$e^+e^+\mu^-$	$\mu^+\mu^-e^+$	$\mu^+\mu^+e^-$	$\mu^+\mu^-\mu^+$
Uncertainties on Signal Selection Efficiency						
Mc Statistics	0.63	0.44	0.55	0.83	0.59	0.48
Tau BF	0.7	0.7	0.7	0.7	0.7	0.7
PID (3-prong)	1.8	4.3	4.2	5.7	6.1	7.8
PID (1-prong)	0.9	3.2	3.2	0.9	0.9	3.2
Tracking efficiency	0.6	0.6	0.6	0.6	0.6	0.6
Total Uncertainty	2.3	5.4	5.5	5.9	6.3	8.5
Uncertainties on Background Estimation						
GS fluctuations	16.9	13.2	18.5	14.7	33.3	14.1
Fit to MC	10.2	26.4	16.7	12.6	42.8	31.3
Fit to Data	7.6	6.4	24.9	16.3	43.2	14.8
Total Uncertainty	21.1	30.2	35.2	25.3	69.3	38.6



STRATEGY II

- Goal is to put the lowest UL on Br ($\tau \rightarrow lll$)

$$B_{UL} = f(N^{obs}, N_{bgd}, \epsilon_{sig}, N_{\tau^+ \tau^-})$$

obtained using Cousins and Highland method with Barlow implementation

- Selection was optimized to obtain the best expected Upper Limit.

$$B_{UL}^{ex} = \sum_{n=0}^{\infty} P(n, N_{bgd}) B_{UL}(n, N_{bgd}, \epsilon_{sig})$$

- Each cut value (including SB dimensions) was chosen by varying their values with all the other variables fixed, and using the value giving the best expected UL