Direct Searches for New Physics at e^+e^- B-Factories

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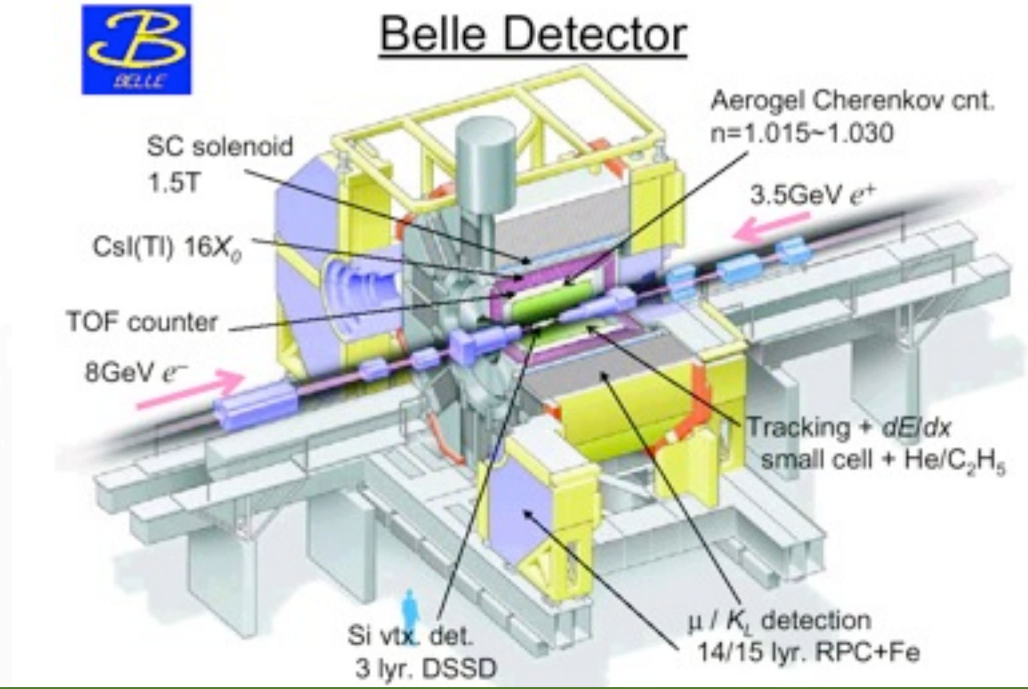
Outline

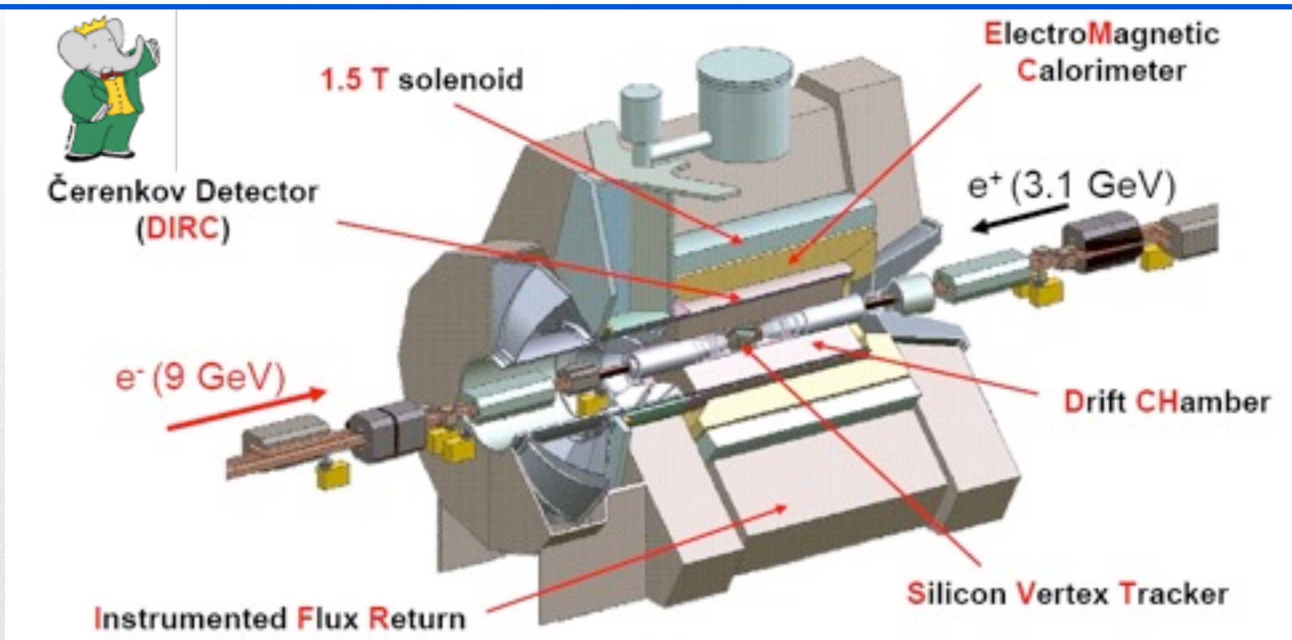
- New Physics searches in B decays
- Search for LFV in τ decays
- Search for LFV in Υ decays
- Search for Higgs-Like Particle in Υ decays

Babar & Belle

Belle @ KEK

- E_{e+} = 3.5 GeV E_{e-} = 8.0 GeV
- $\Upsilon(4S)$ boost: $\beta\gamma = 0.425$
- Data sample:
  - $\Upsilon(4S)$ 711 fb^{-1} off-peak 87 fb^{-1}
  - $\Upsilon(5S)$ 121 fb^{-1}





BaBar @ PeP-II

- E_{e+} = 3.1 GeV E_{e-} = 9.0 GeV
- $\Upsilon(4S)$ boost: $\beta\gamma = 0.425$
- Data sample:
  - $\Upsilon(4S)$ 432 fb^{-1} off-peak 54 fb^{-1}
  - $\Upsilon(3S)$ 30 fb^{-1} $\Upsilon(2S)$ 14 fb^{-1}

New Physics Searches in B decays

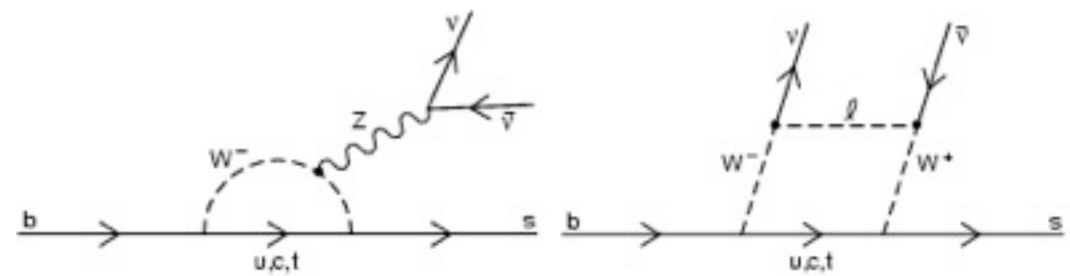
$$B \to K^{(\star)}\nu$$

Theoretical Overview

SM predicts B →K$^{(*)}$νν decays

$$\mathcal{B}(B \to K^{\star}\nu\nu) = (6.8^{+1.0}_{-1.1}) \times 10^{-6}$$

$$\mathcal{B}(B \to K\nu\nu) = (4.7 \pm 0.7) \times 10^{-6}$$

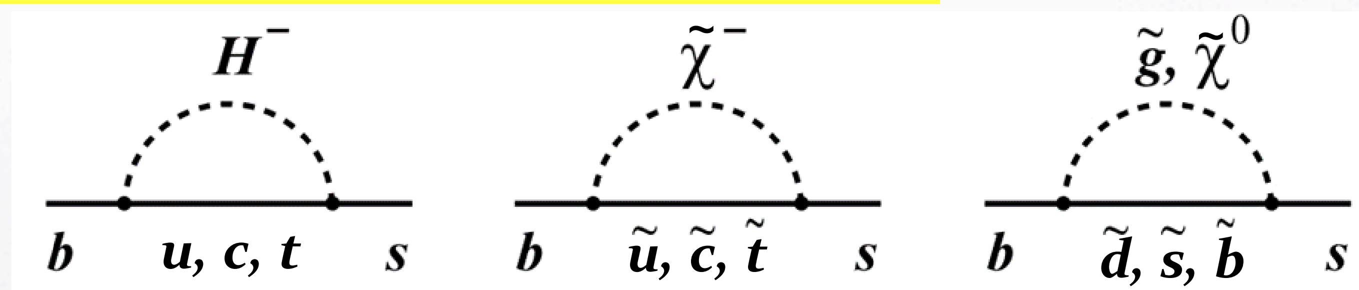


G.Altmannshofer et al., arXiv:0902.0160 [hep-ph]

New Physics Produces Visible Effects

New Particles in Loops

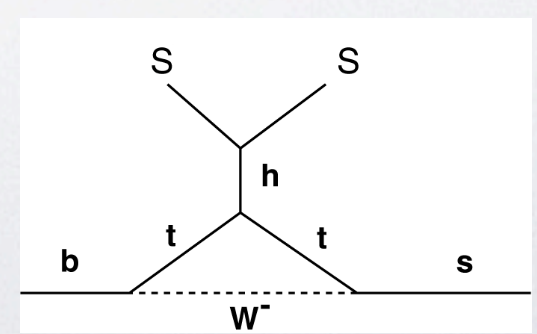
Higgs, chargino and squark , gluino or neutralino and squark in loops produces x5 enhancement in BR



G.Buchalla et al. Phys. Rev. D 63, 014015,2000

Dark Matter

Low mass singlet scalar WIMP (S) may be produced in B decays
Particles with masses <2GeV may increase BR by a factor 10



Bird, PRL 93, 201803 (2004)

Results from Belle

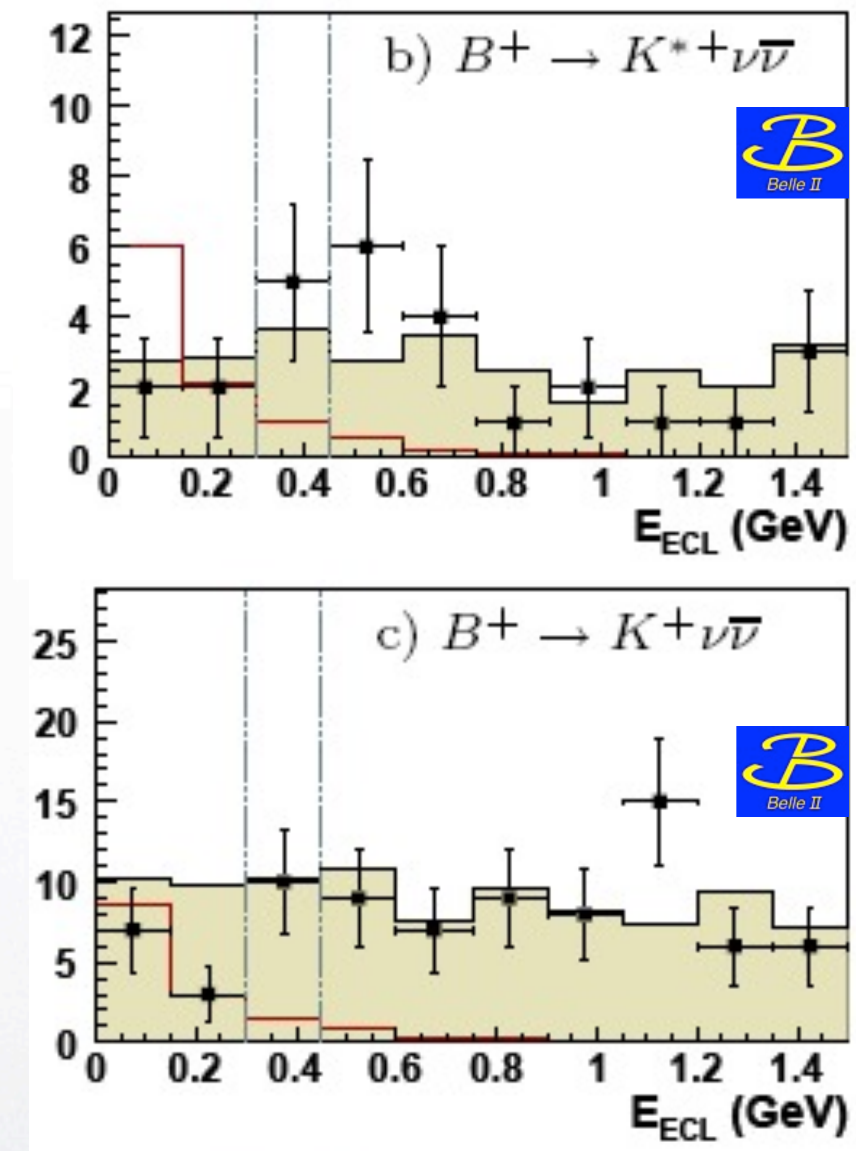
$B \to K^{(\star)}\nu\nu$

492 fb^{-1}

Phys.Rev.Lett 99:221802,2007

- Tag side: inclusive reconstruction of B in hadronic channel ($B_{tag} \to D^{(*)}$ nK mπ).
- Rest of the event used to identify $B_{sig} \to K^{(*)}\nu\nu$:
  - PID applied on K or K* daughters
  - Cut on number of tracks and π^0
  - Cut on E_{extra}
- Background rejection:
  - Main contribution from b→c transition → cut on p_K
  - Particles along the beam pipe →cut on missing momentum polar angle
  - Small contribution from qq

Mode	N_{obs}	N_{side}	N_b	$\epsilon(\times 10^{-5})$	U.L.
$K^{*0}\nu\overline{\nu}$	7	16	4.2 ± 1.4	5.1 ± 0.3	$< 3.4 \times 10^{-4}$
$K^{*+}\nu\overline{\nu}$	4	18	5.6 ± 1.8	5.8 ± 0.7	$< 1.4 \times 10^{-4}$
$\to K^0_S\pi^+$	1	7	2.3 ± 1.2	2.8 ± 0.3	
$\to K^+\pi^0$	3	11	3.3 ± 1.4	3.0 ± 0.4	
$K^+\nu\overline{\nu}$	10	60	20.0 ± 4.0	26.7 ± 2.9	$< 1.4 \times 10^{-5}$
$K^0\nu\overline{\nu}$	2	8	2.0 ± 0.9	5.0 ± 0.3	$< 1.6 \times 10^{-4}$



$E_{ECL} = E_{tot} - E_{rec}$ in ECL

Total energy in ECL

candidate recon energy

Results from Babar

$B \to K^{\star} \nu\nu$

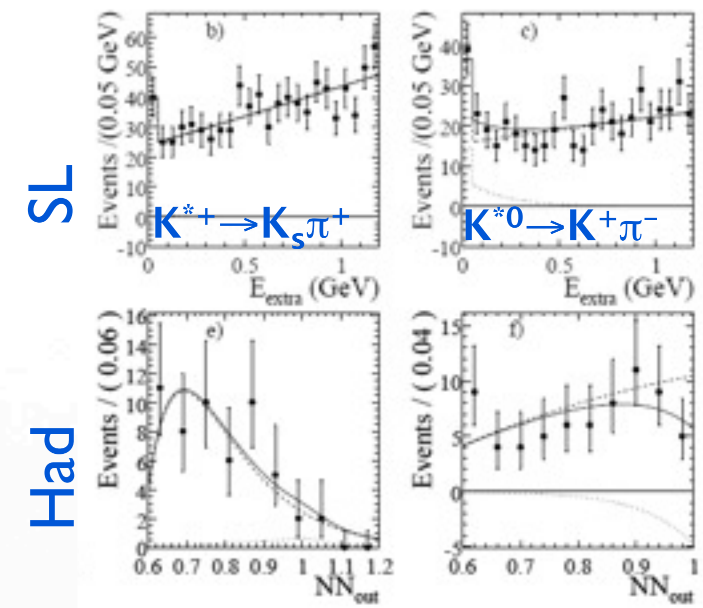
413 fb^{-1}

PRD 78, 072007

Combined results from the SL and HAD recoil analyses:

- SL analysis
  - Selection optimized by maximizing Punzi figure of merit
  - Yield extraction: fit to E_{extra}
- HAD analysis
  - Loose preselection: most discriminant variables used for NN
  - Yield extraction: fit to NN output distribution

First model independent analysis



	$B^+ \to K^{\star +}\nu$	$B^0 \to K^{\star}\nu\nu$	$B \to K^{\star}\nu\nu$
HAD	21×10^{-5}	11×10^{-5}	
SL	9×10^{-5}	18×10^{-5}	
Combined	8×10^{-5}	12×10^{-5}	8×10^{-5}

$B \to K \nu\nu$

413 fb^{-1}

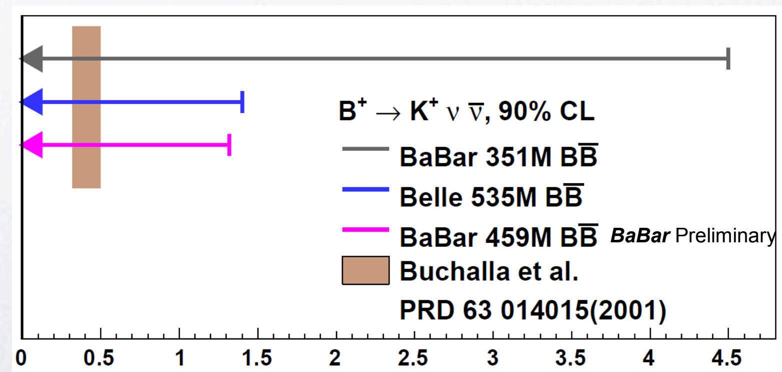
Preliminary Result

K^+ mode: made a full BR measurement and partial BR measurement: $p_{CM}(K^+) < 1.5$ GeV and $p_{CM}(K^+) < 1.5$ GeV

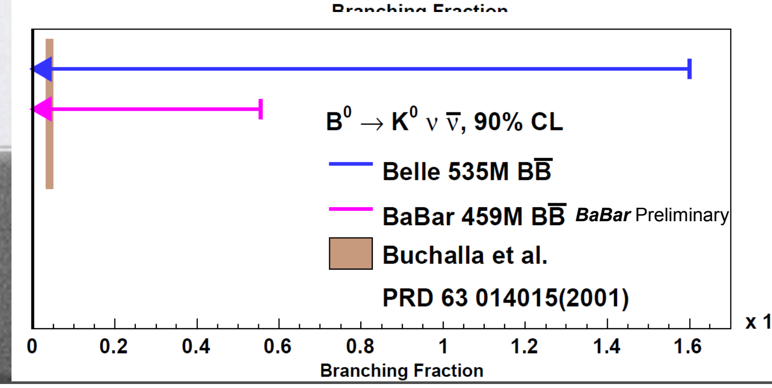
BDT used to enhance the signal (26 variables for K^+, 38 for K_S)

Find cut value for BDT output to maximize efficiency on MC

Number of predicted and observed bkg events used to evaluate BR



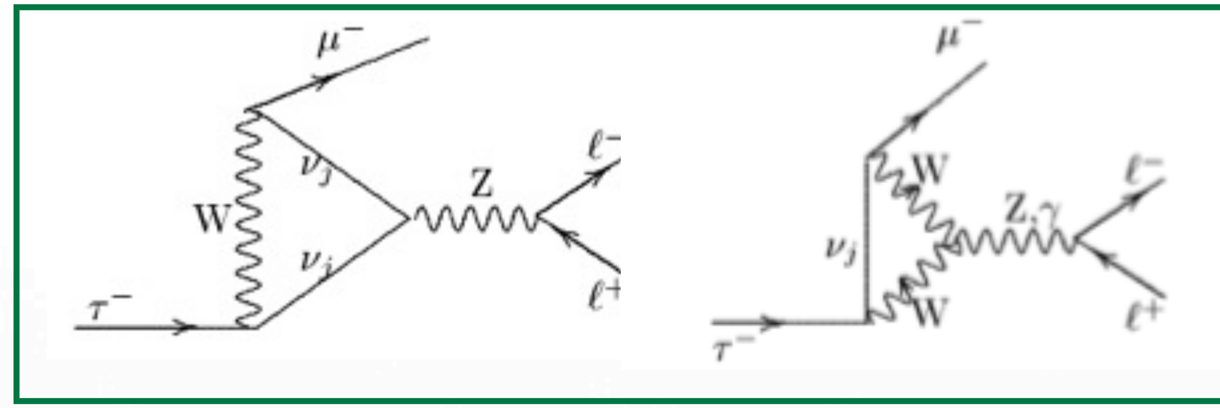
CL	K^+	K^0	K^+ & K^0	For $p^*(K^+)$<1.5 GeV/c	For $p^*(K^+)$>1.5 GeV/c
90%	1.3×10^{-5}	5.6×10^{-5}	1.4×10^{-5}	3.1×10^{-5}	0.89×10^{-5}
95%	1.6×10^{-5}	6.7×10^{-5}	1.7×10^{-5}	4.6×10^{-5}	1.1×10^{-5}



Lepton Flavor Violation in τ Decays and $\Upsilon(2\text{-}3S)$ Decays

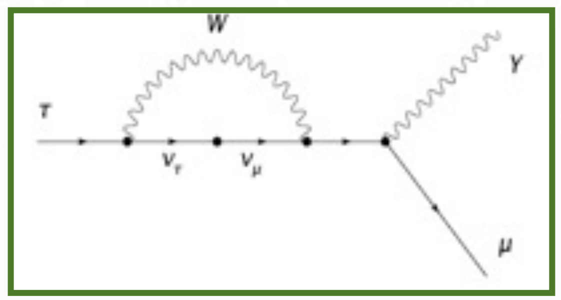
LFV in τ decays theory

SM allows LFV: observed in neutral sector.



In charged sector may happen via loops with small expected BR (e.g. $BR_{SM}(\tau \to \mu\gamma) < 10^{-54}$).

Even less in $\tau \to 3l$

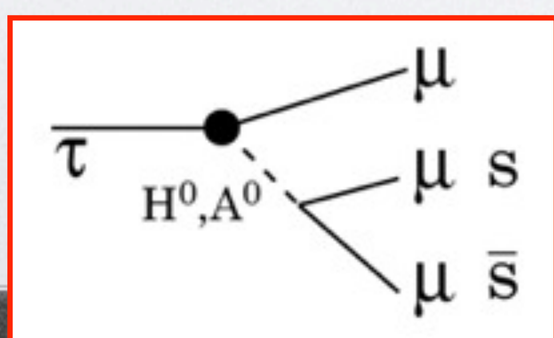


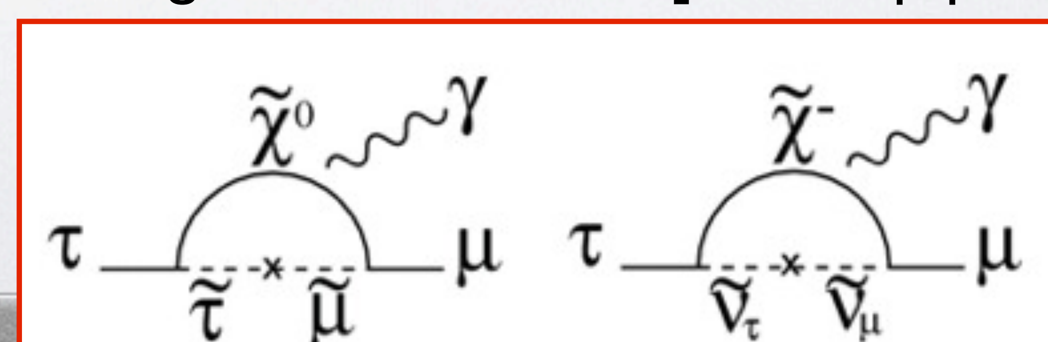
If detected, LFV would imply New Physics with present (and near future) luminosities.

Many New Physis models predict τ LFV BR up to [$O(10^{-8})$].

If detected in more than one channel it provides

Useful information on NP flavor structure, by looking at LFV BF Ratios. [arxiv:hep-ph0610344v3]

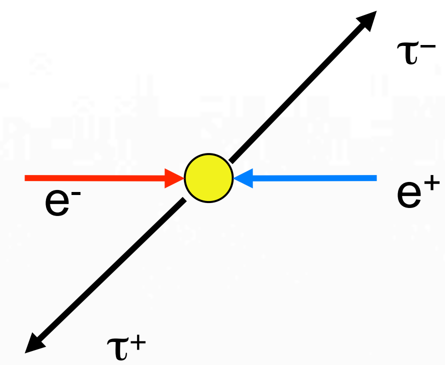




Analysis strategy

Low multiplicity events selected and event space divided in two hemispheres using thrust.

- Signal side: tracks and neutrals coming from LFV decay
- Tag side: standard 1-prong decay (also 3-prong in $\tau \to \mu\gamma$)



Center of mass system

Blind analysis performed

Background reduced using PID, kinematical informations, multivariate algorithms ($\tau \to \mu\gamma$) optimization different for each channel:

- BaBar: optimizes for Best UL
- Belle: optimizes for best discovery significance

Number of expected background events estimated from non blinded sidebands. UL estimated using frequentist approach including systematics errors.

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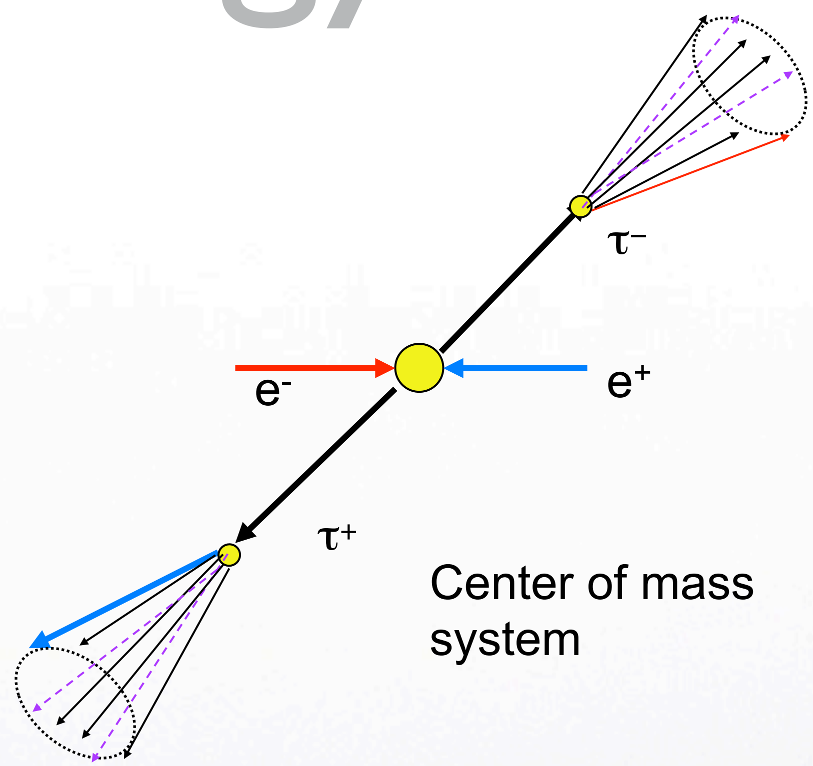

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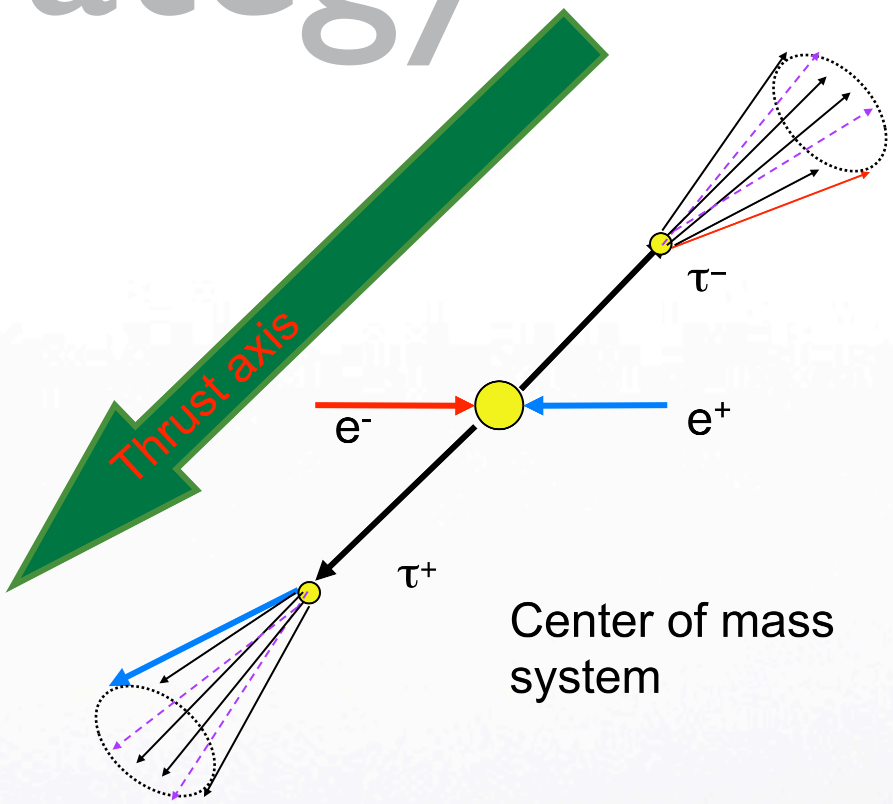

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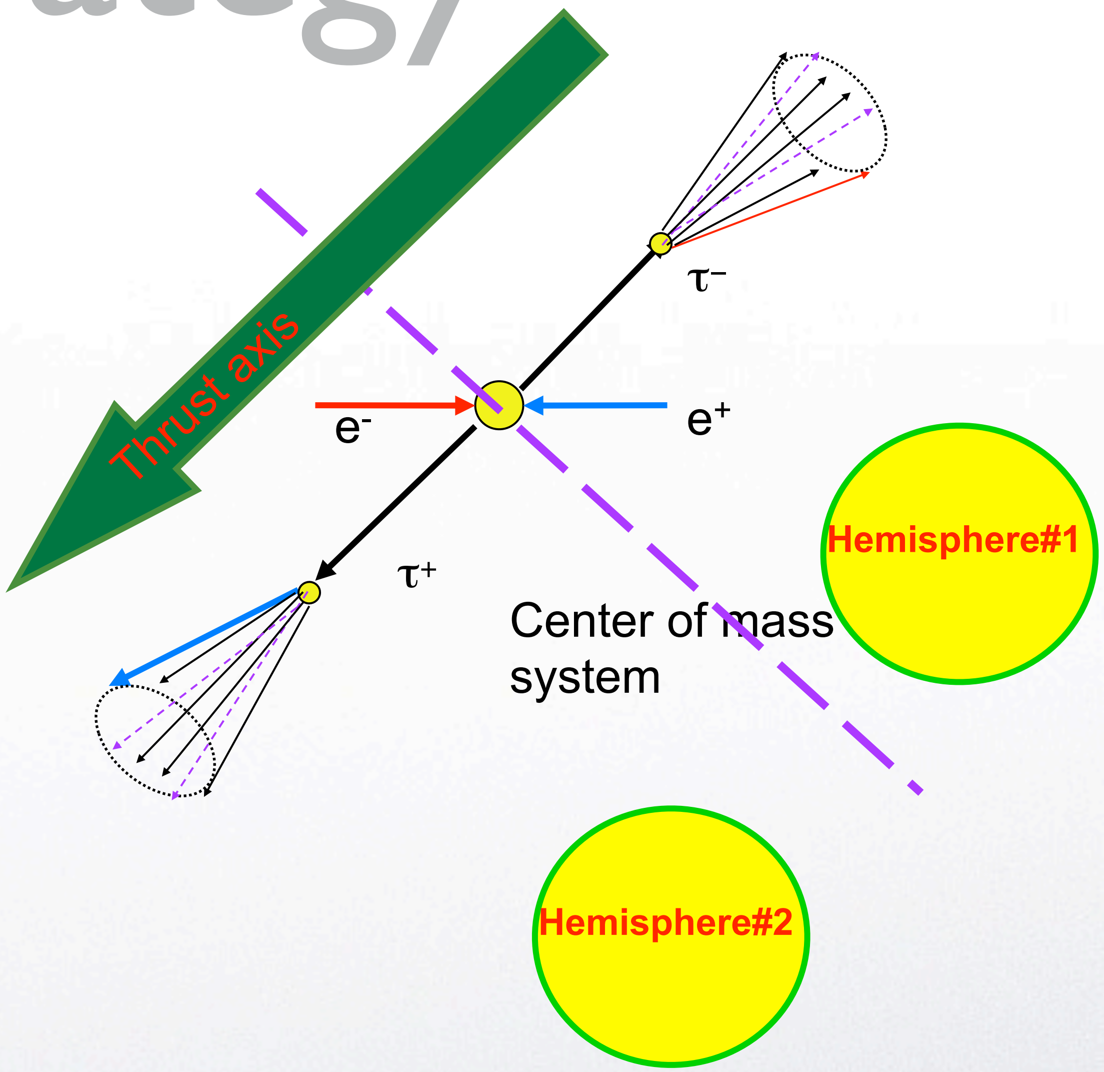

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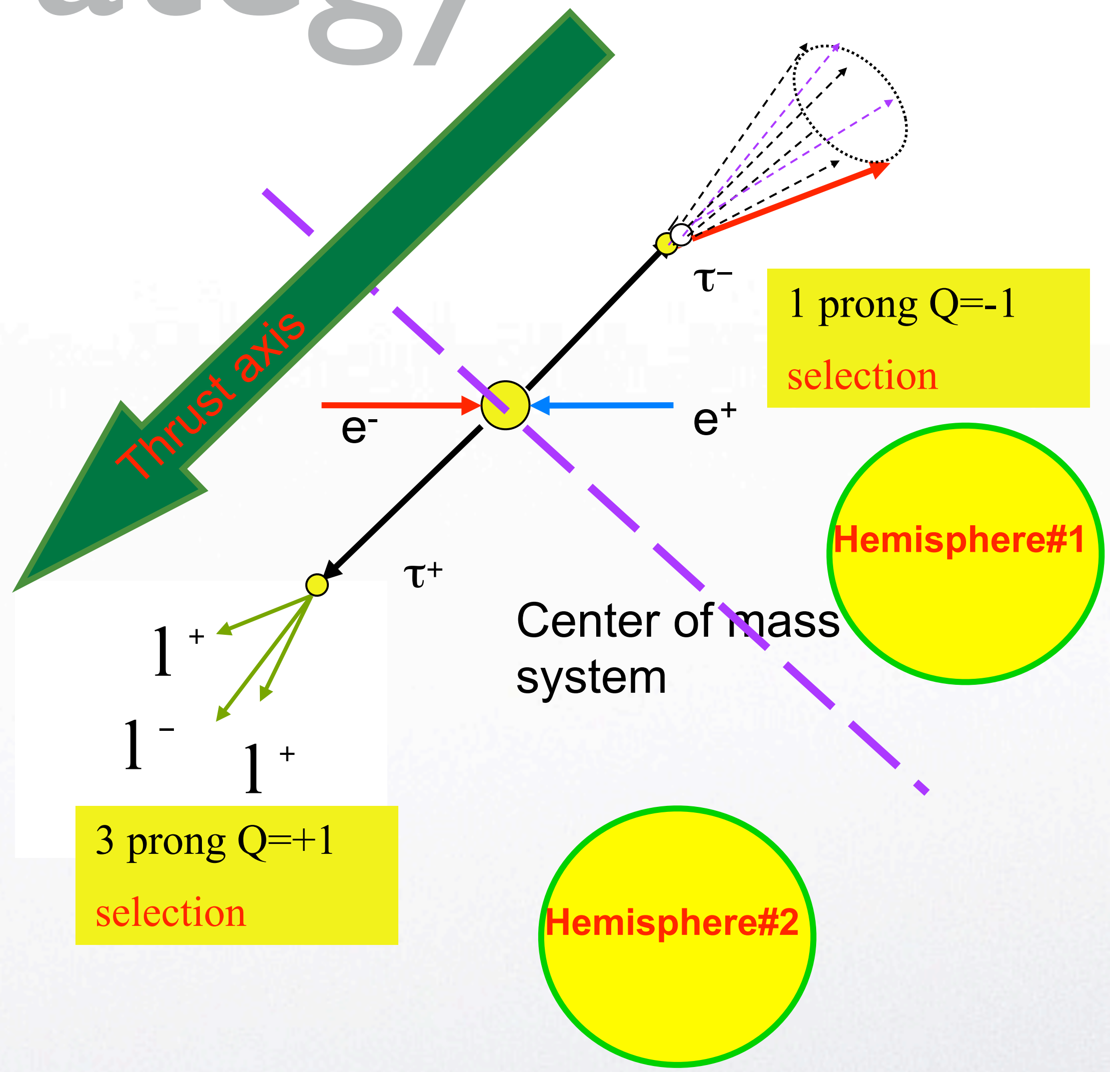

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Results from Babar

$\tau \to \ell\gamma, \ell = \mu, e$

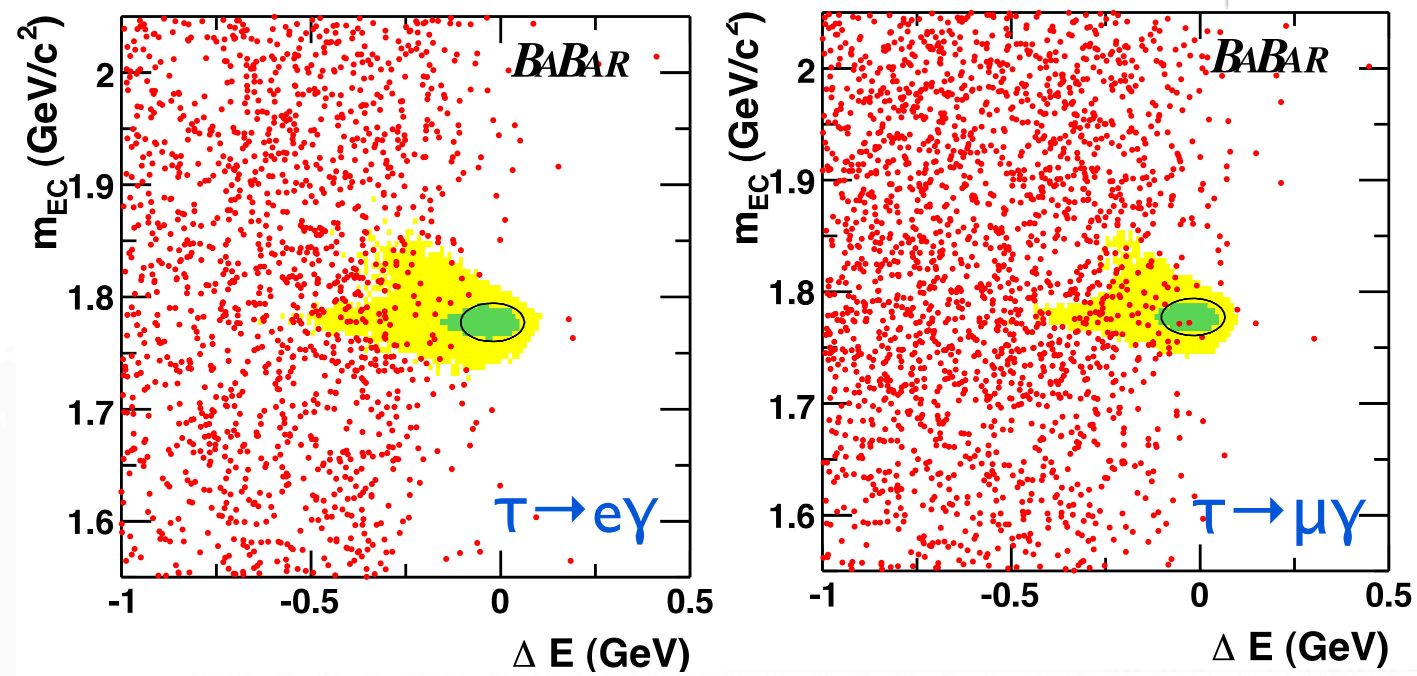
480M τ-pairs

PRL104,021802(2010)

Full BaBar dataset (Υ(nS) + off-peak) used
NN used to reduce backgrounds
Both 1-prong and 3-prong tags used

$\mathcal{B}\ (\tau^{\pm} \to e^{\pm}\gamma) < 3.3 \times 10^{-8}$

$\mathcal{B}\ (\tau^{\pm} \to \mu^{\pm}\gamma) < 4.4 \times 10^{-8}$



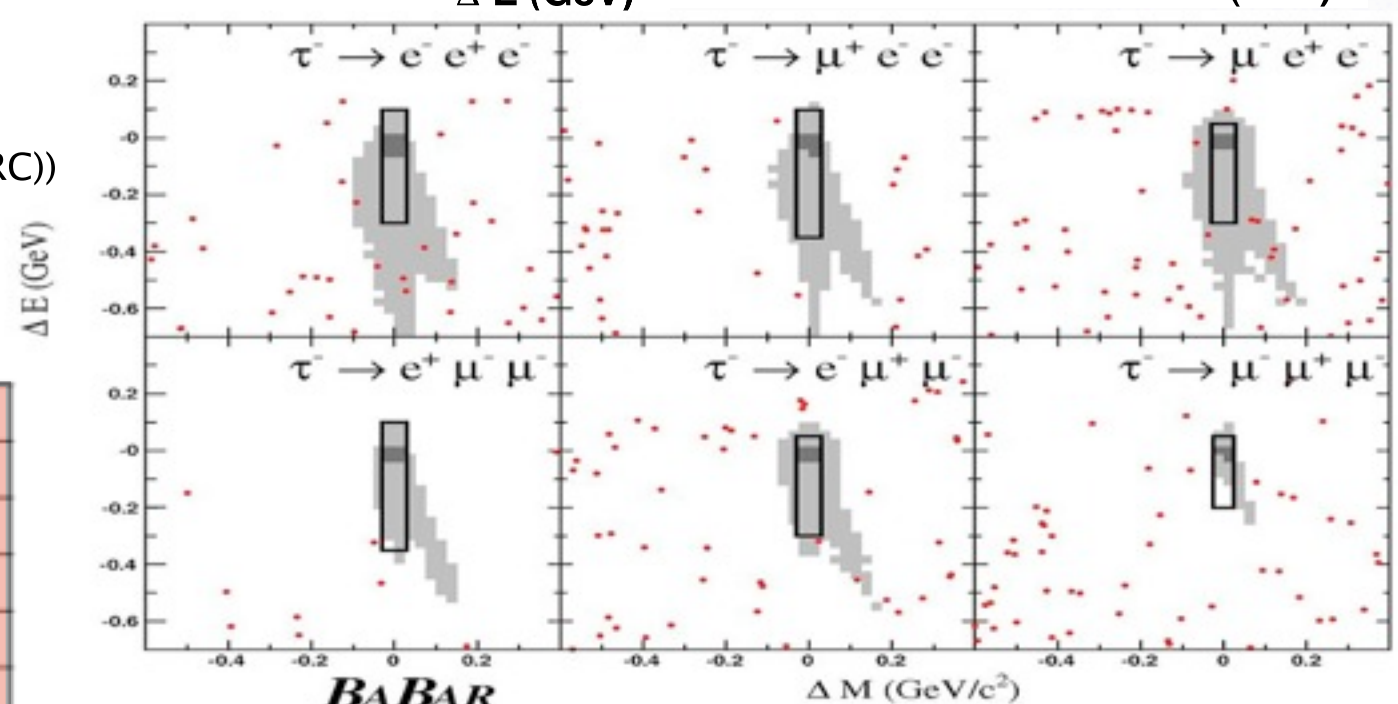
$\tau \to \ell\ell\ell, \ell = \mu, e$

430M τ-pairs

arXiv: 1002.4550 (sub. PRD(RC))

Systematic uncertainties dominated by PID
Efficiencies 6-13% depending on channel

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}

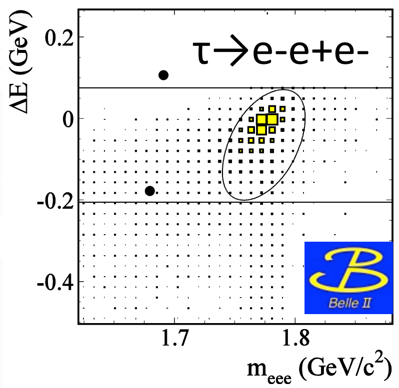


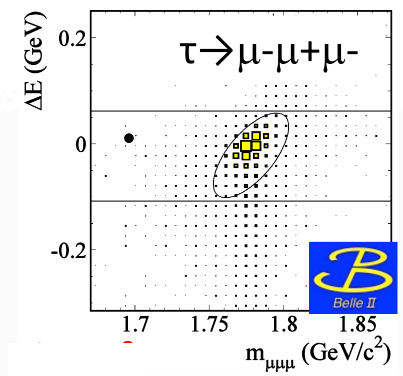
Results from Belle

$\tau \to \ell\ell\ell, \ell = \mu, e$

790M τ-pairs

arXiv:1001.3221 (sub. PLB)





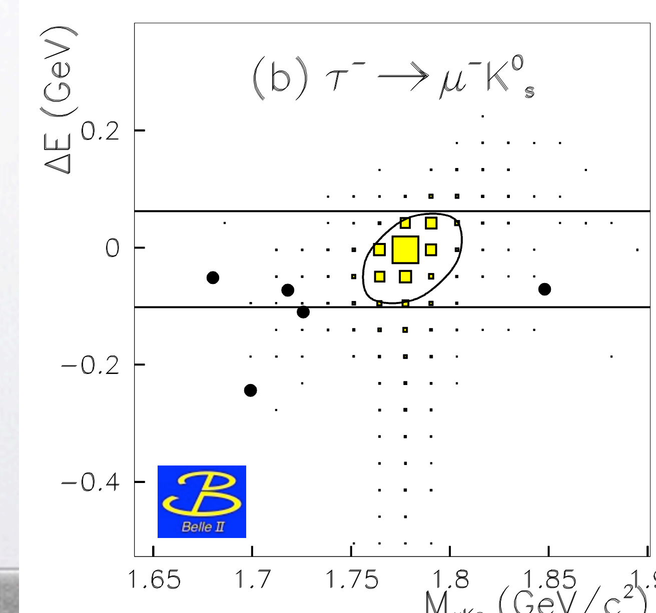
Improved sensitivities along integrated luminosity

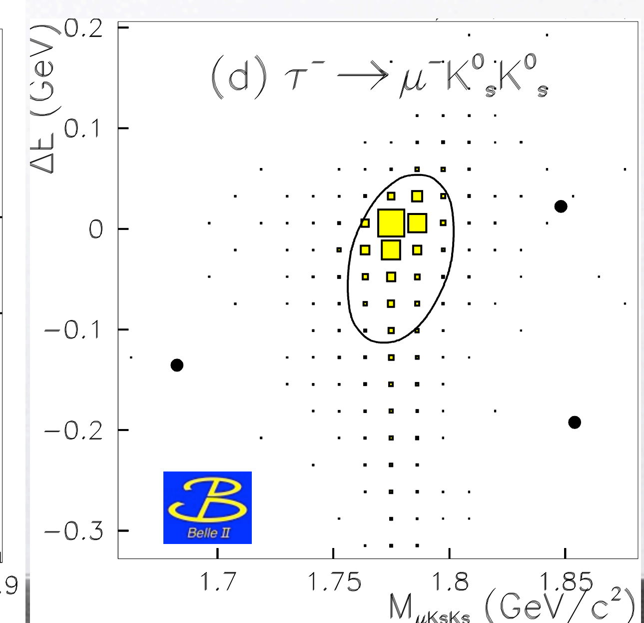
Mode	ε (%)	N_{BG}^{EXP}	σ_{syst} (%)	UL ($\times 10^{-8}$)
$e^-e^+e^-$	6.0	0.21+-0.15	9.8	2.7
$\mu^-\mu^+\mu^-$	7.6	0.13+-0.06	7.4	2.1
$e^-\mu^+\mu^-$	6.1	0.10+-0.04	9.5	2.7
$\mu^-e^+e^-$	9.3	0.04+-0.04	7.8	1.8
$\mu^-e^+\mu^-$	10.1	0.02+-0.02	7.6	1.7
$e^-\mu^+e^-$	11.5	0.01+-0.01	7.7	1.5

$\tau \to \ell K_S, \tau \to \ell K_S K_S$

610M τ-pairs

arXiv:1003.1183v1



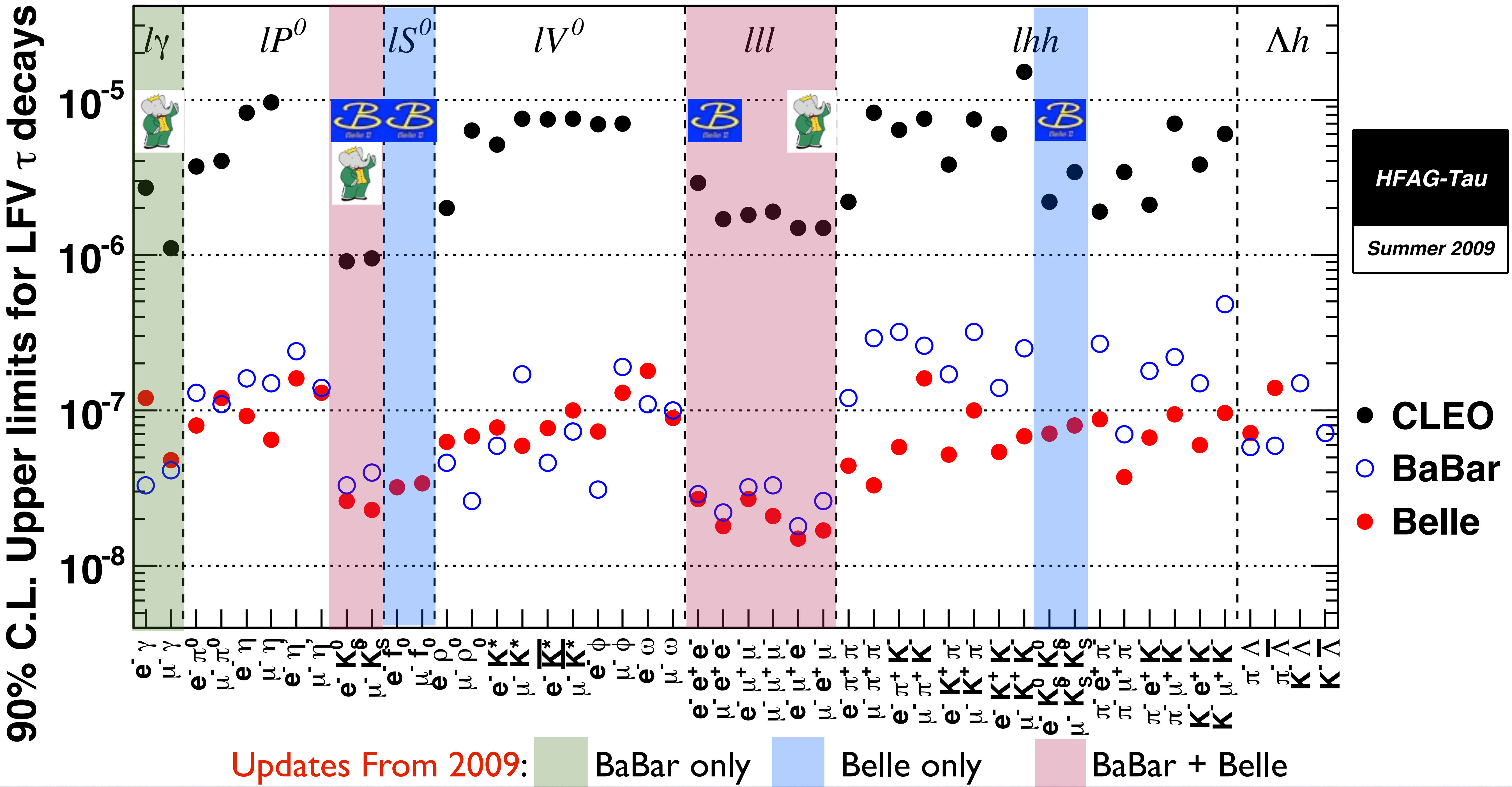


Main bkg contribution from fake lepton + real K_S coming from uds events

Dominant systematics: K_S reconstruction

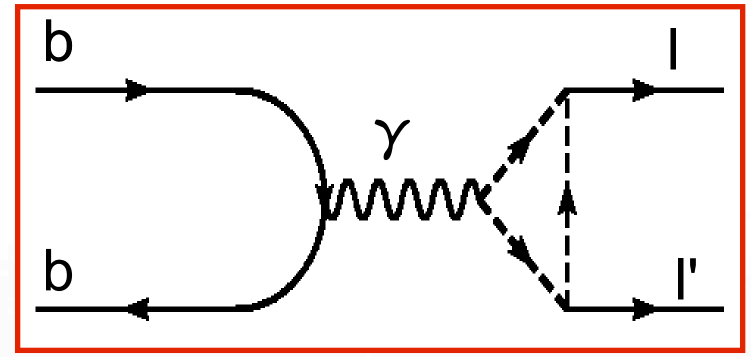
Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{obs}	s_{90}	$\mathcal{B}$ ($\times 10^{-8}$)
$\tau^- \to e^- K^0_S$	10.2	0.18±0.18	6.6	0	2.25	2.6
$\tau^- \to \mu^- K^0_S$	10.7	0.35±0.21	6.8	0	2.10	2.3
$\tau^- \to e^- K^0_S K^0_S$	5.82	0.07±0.07	11.2	0	2.44	7.1
$\tau^- \to \mu^- K^0_S K^0_S$	5.08	0.12±0.08	11.3	0	2.40	8.0

τ-LFV searches



LFV in Υ decays - strategy

BaBar collected a large sample at Υ(3S) and Υ(2S) ⇒ good sensitivity to Υ(nS)→ll' processes



Four channels studied:
Υ(2S)→μτ, Υ(2S)→eτ
Υ(3S)→μτ, Υ(3S)→eτ

Signature:

- 1 primary lepton
- 1τ detected through leptonic (e or μ) or hadronic ($\pi^{\pm}+\pi^0(+\pi^0)$) decays

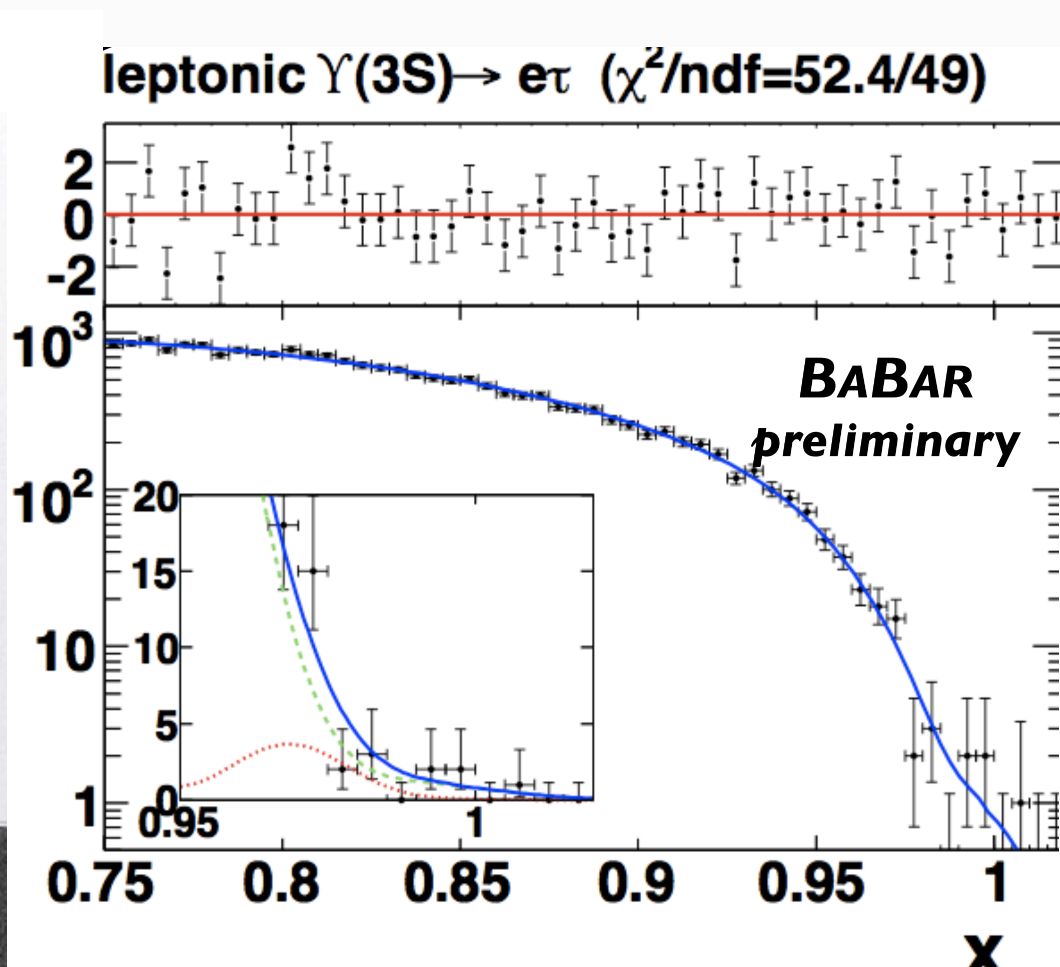
Process	τ decay	channel
Υ(3,2S) $\to e\tau$	$\tau \to \mu\nu\bar{\nu}$	leptonic $e\tau$
Υ(3,2S) $\to e\tau$	$\tau \to \pi^{\pm}\pi^0\nu$ / $\pi^{\pm}\pi^0\pi^0\nu$	hadronic $e\tau$
Υ(3,2S) $\to \mu\tau$	$\tau \to e\nu\bar{\nu}$	leptonic $\mu\tau$
Υ(3,2S) $\to \mu\tau$	$\tau \to \pi^{\pm}\pi^0\nu$ / $\pi^{\pm}\pi^0\pi^0\nu$	hadronic $\mu\tau$

- Dominant background events:
  - Bhabha and μ-pair (through particle mis-ID)
  - τ-pairs ($e^+e^-\to\tau^+\tau^-$)
  - Multiple π and additional γ

- Selection partially common to the 4 channels, partyally specific (PID, τ-daughters kinematics)

LFV in Υ decays - Results

- Discriminating variable: x = primary lepton momentum / beam energy
- Unbinned extended maximum likelihood fit to determine signal and background yelds
- PDF chosen for all backgrounds:
  - signal (peaks at $x = x_{MAX} \sim 0.97$)
  - τ-pairs (smooth, end-point at x_{MAX})
  - Bhabha/μ-pairs (peaks x~1)
  - hadrons (smooth, end-point at x_{MAX})



BR calculated from signal and bkg yelds

$$\mathcal{B} = N_{SIG}/(\varepsilon_{SIG} \times N_{\Upsilon(nS)})$$

Systematics mainly from PDF shapes choice, errors accounted in UL

	$\mathcal{B}(10^{-6})$	UL (10^{-6})	Improvement
$\mathcal{B}(\Upsilon(2S) \to e^\pm\tau^\mp)$	$0.6^{+1.5+0.5}_{-1.4-0.6}$	< 3.2	First
$\mathcal{B}(\Upsilon(2S) \to \mu^\pm\tau^\mp)$	$0.2^{+1.5+1.0}_{-1.3-1.2}$	< 3.3	$\times 5.5$
$\mathcal{B}(\Upsilon(3S) \to e^\pm\tau^\mp)$	$1.8^{+1.7+0.8}_{-1.4-0.7}$	< 3.2	First
$\mathcal{B}(\Upsilon(3S) \to \mu^\pm\tau^\mp)$	$-0.80.2^{+1.5+1.4}_{-1.5-1.3}$	< 3.3	$\times 3.7$

Preliminary

Search for Higgs-Like Particle in $\Upsilon(2\text{-}3S)$ Decays

Theoretical Motivations

Higgs mechanism lead to EW breaking

BUT Higgs mass unstable after radiative corrections ⇒

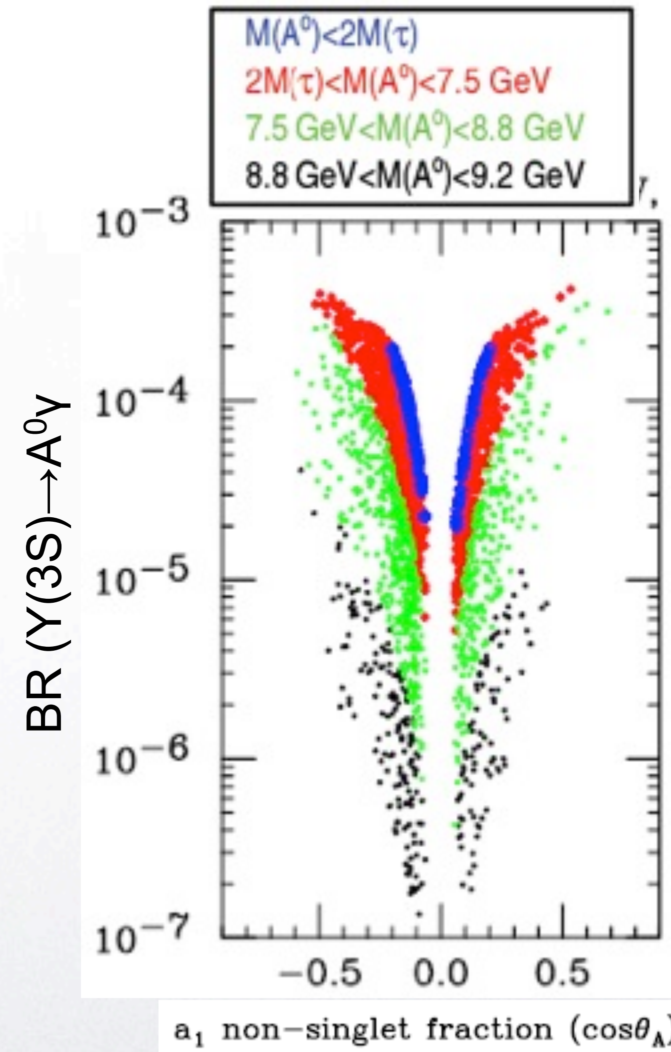
A solution: MSSM with two Higgs doublets

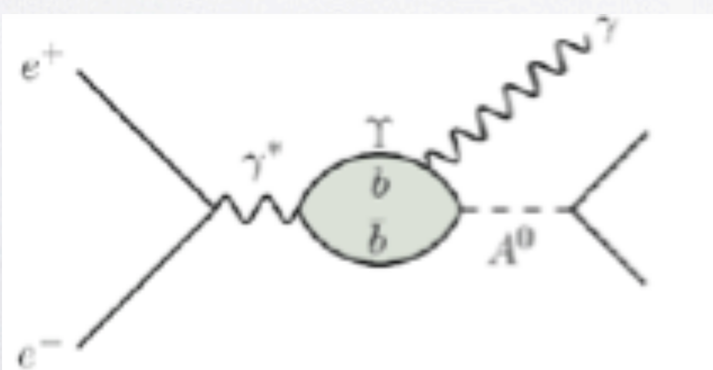
Need Fine tuning of EW scale

Solution: Higgs singlet (NMSSM) → Mixing of singlet with MSSM Higgs produces CP-odd A^0 PRD 76, 051105(2007)

Another interpretation is A^0 is an Axion like particle arXiv: 0810.5397[hep-ex]

Possible solution for both Dark Matter puzzle AND Higgs sector





Channels studied

$\Upsilon(3S,2S) \to \gamma A^0 \quad A^0 \to \mu^+\mu^-$

$\Upsilon(3S) \to \gamma A^0 \quad A^0 \to \tau^+\tau^-$

$\Upsilon(3S) \to \gamma A^0 \quad A^0 \to$ invisible

$\Upsilon(3S,2S) \to \gamma A^0,\ A^0 \to \mu^+\mu^-$

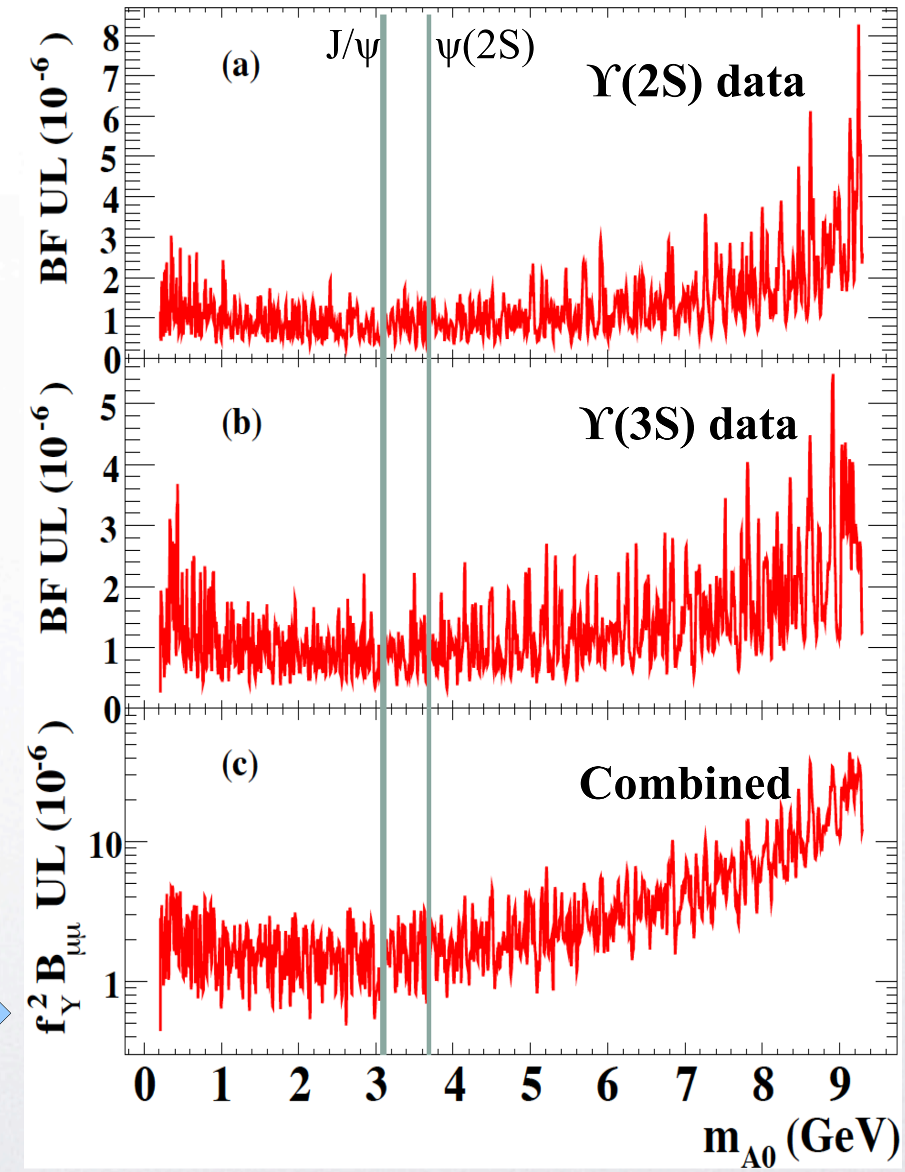
Signature:

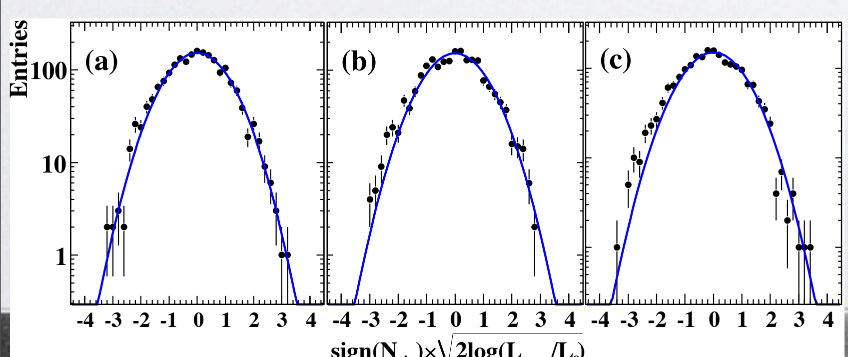
- two charged tracks, one identified as μ
- 1 energetic photon $E_\gamma > 200$ MeV
- Kinematic fit of γμμ vertex

Analysis Method:

- Scan μμ invariant mass for A^0 peak evidence
- Background shapes taken from data accounting for known resonances
- Fit in 300 MeV window in 2-5 MeV steps (1951 points)
- Scan range 0.212 GeV < m_{A^0} < 9.3 GeV
- Fluctuation observed (max = 3.1σ) consistent with expected statistical flucuations

PRL 103, 081803 (2009)





Effective Yukawa coupling of A^0 to bound state b-quark

$$\frac{\mathcal{B}(\Upsilon(nS) \to \gamma A^0)}{\mathcal{B}(\Upsilon(nS) \to l^+l^-)} = \frac{f_\Upsilon^2}{2\pi\alpha}\left(1 - \frac{m_{A^0}^2}{m_{\Upsilon(nS)}^2}\right)$$

$\Upsilon(3S)\to\gamma A^0,\ A^0\to\tau^+\tau^-$

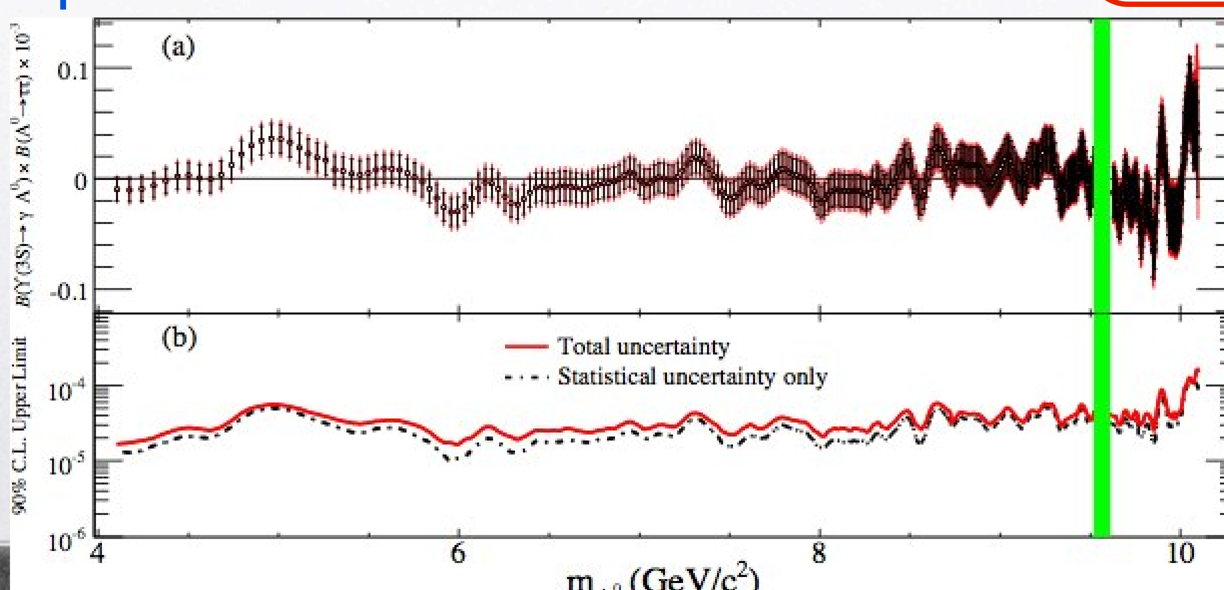
Signature:

- Looking for $\tau^+\to e^+\nu\nu$ and $\tau^+\to\mu^+\nu\nu$
- E_γ > 100 MeV
- Exactly 2 tracks identified as leptons
- Missing energy precludes kinematic fit $\to A^0$ mass obtained from E_γ and known CM energy
- Bkg suppression provided by 8 kinematic and angular variables, optimized in 5 ranges of E_γ
- Bkg mostly due to radiative τ-pair production and 2 photons processes

Method:

- Scans for peaks in E_γ spectrum in the range 4.03 GeV < m_{A^0} < 10.10 GeV (307 points)
  - signal represented as peaking contribution of known width
  - simultaneous fit to $ee\gamma$, $\mu\mu\gamma$, and $e\mu\gamma$

$$\mathcal{B}(\Upsilon(3S)\to\gamma A^0)\times\mathcal{B}(A^0)\to\tau^+\tau^-) < (1.5-16)\times 10^{-5}(90\%CL)$$



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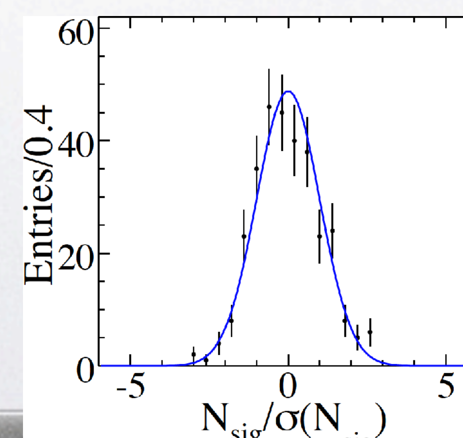


$\Upsilon(3S)\to\gamma A^0$, $A^0\to$invisible I

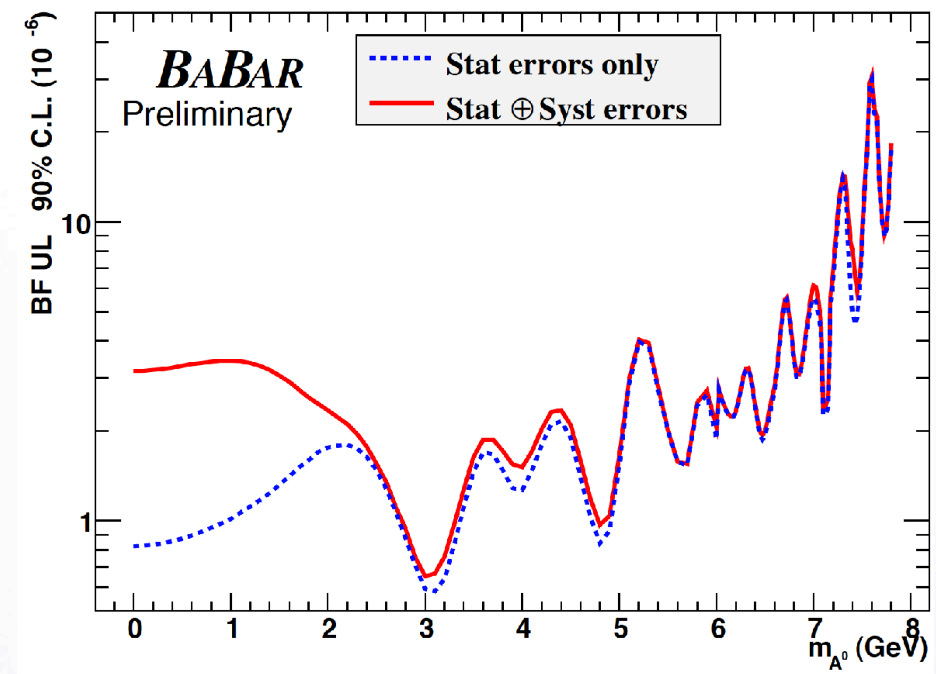
Dominant channel in scenarios with light LSP through $A^0\to\chi^0\chi^0$

Selection focused on search for monoenergetic peak from photon:

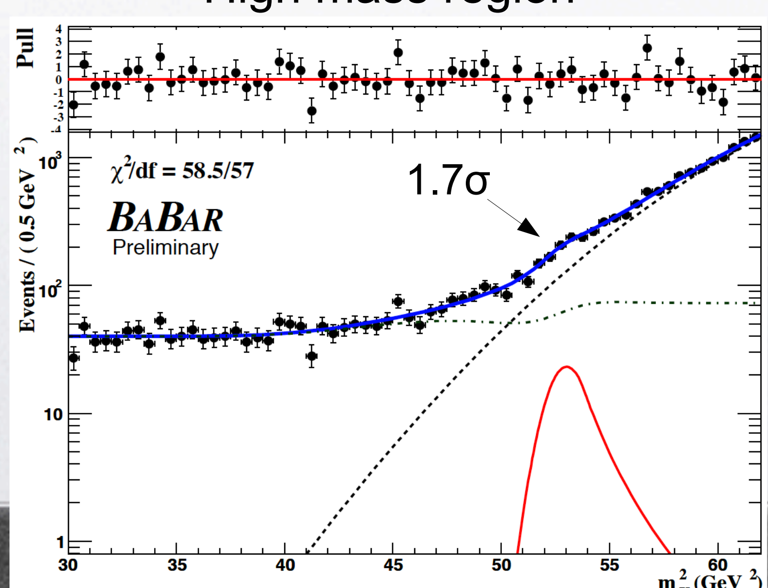
- photon fiducial and quality requirement
- requires single photon trigger, naturally split in low and high energy trigger (different bkgs: $ee\to\gamma\gamma$ and $ee\to\gamma(ee)$)

Signal extracted from unbinned maximum likelyhood fit to m_X^2 in steps of 0.1 GeV

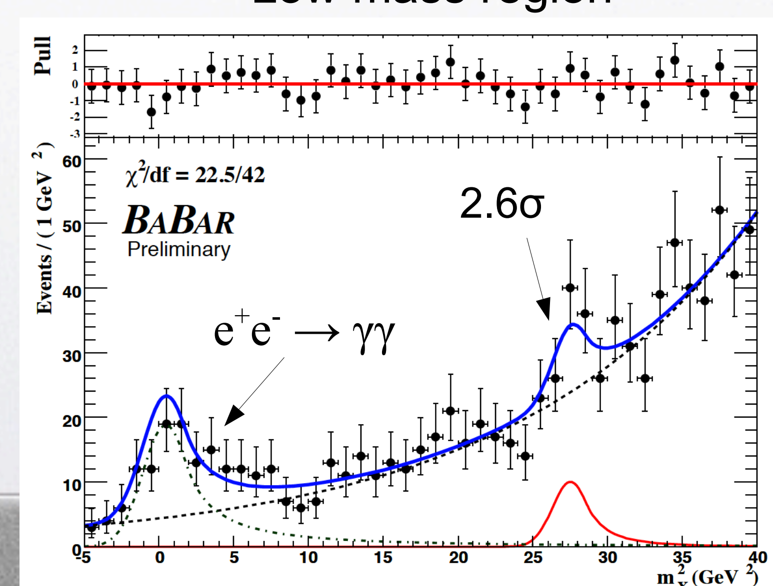
$$\mathcal{B}(\Upsilon(3S)\to\gamma A^0)\times\mathcal{B}(A^0)\to\text{invisible} < (0.7-31)\times10^{-6}(90\%CL) \qquad m_{A^0}\leq 7.8\text{GeV}$$



High mass region



Low mass region



arXiv:0808.0017 **preliminary**

Conclusions

- B-Factories have proven to be versatile machines for the search for new physics in over a decade
- New physics may be looked for through different processes ranging from B physics, τ decays and $\Upsilon(nS)$ decays
- Thanks to the high luminosity achieved and the constant development of new analysis tecniques results have greatly improved over the years
- Many bounds on NP models parameters were set thanks to B-Factories
- Many new results were presented in the last year and many more are incoming

Thanks for your attention

Back up