Searches for Exotic new Physics at BaBar

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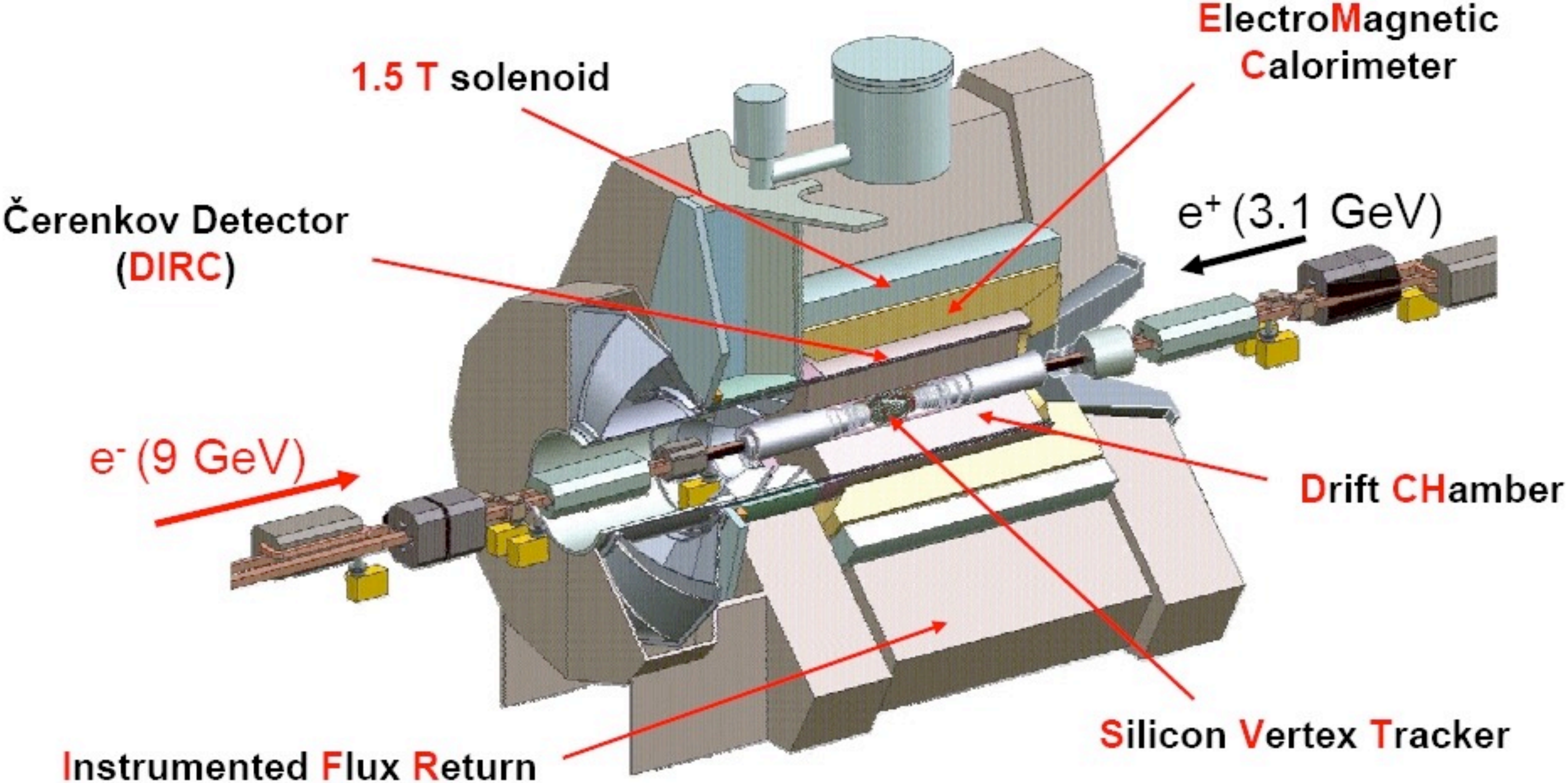
Outline

- BaBar Detector & Dataset
- Direct search for light Higgs and Dark Matter candidates
- Lepton Flavor Violation
  - LFV in τ decays
  - LFV in Υ decays
- Lepton Universality

The BaBar Detector



Dataset

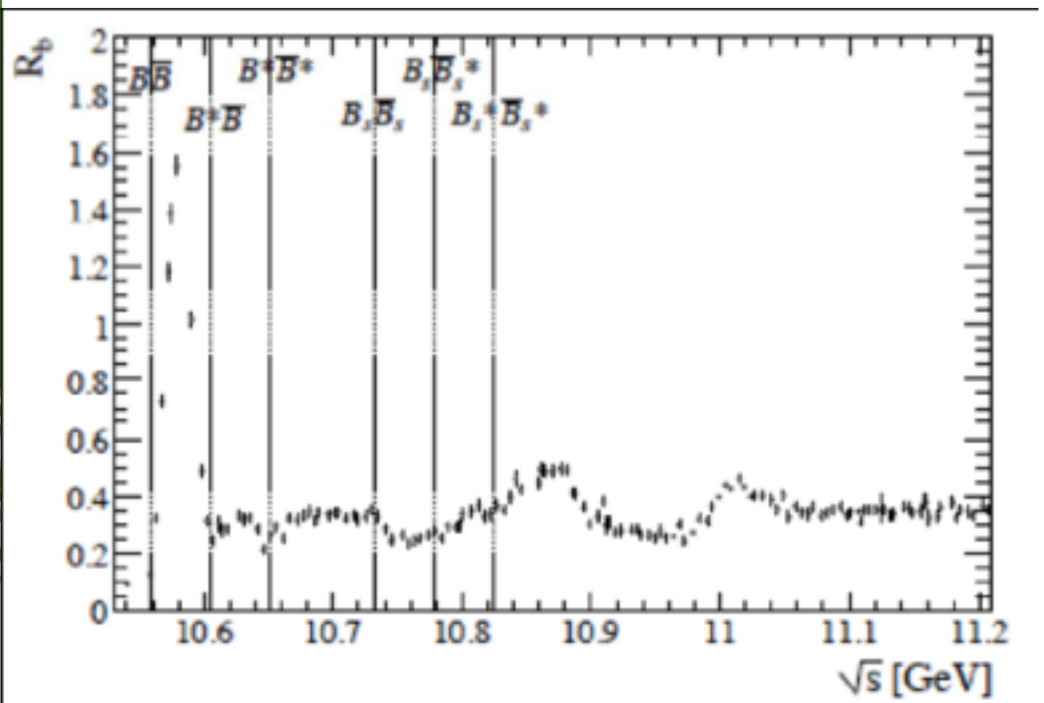
530 fb^{-1} recorded in the 9-years of operations

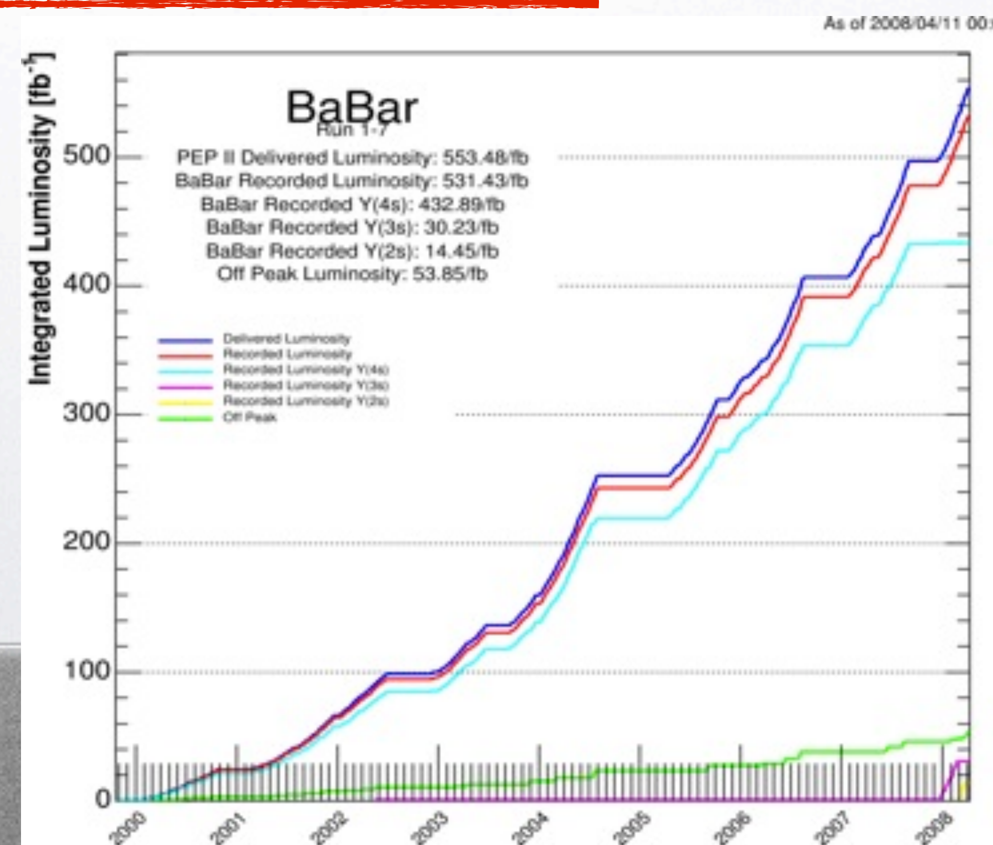
sample	fb^{-1}
$\Upsilon(4S)$	430
$\Upsilon(3S)$	30.2
$\Upsilon(2S)$	14.5
Off-$\Upsilon(nS)$	54

~470x10^6 BB pairs but also:
7x(Belle + CLEo) Υ(3S)
0.5x(Belle +CLEO) Υ(2S)

Not Only $B\bar{B}$ pairs:
690M $c\bar{c}$ pairs
500M $\tau^+\tau^-$ pairs

~4fb^{-1} collected above Υ(4S)





Search for light Higgs and Dark Matter Candidates

Theoretical Motivations

Higgs mechanism leads to EW breaking

BUT Higgs mass unstable after radiative corrections ⇒

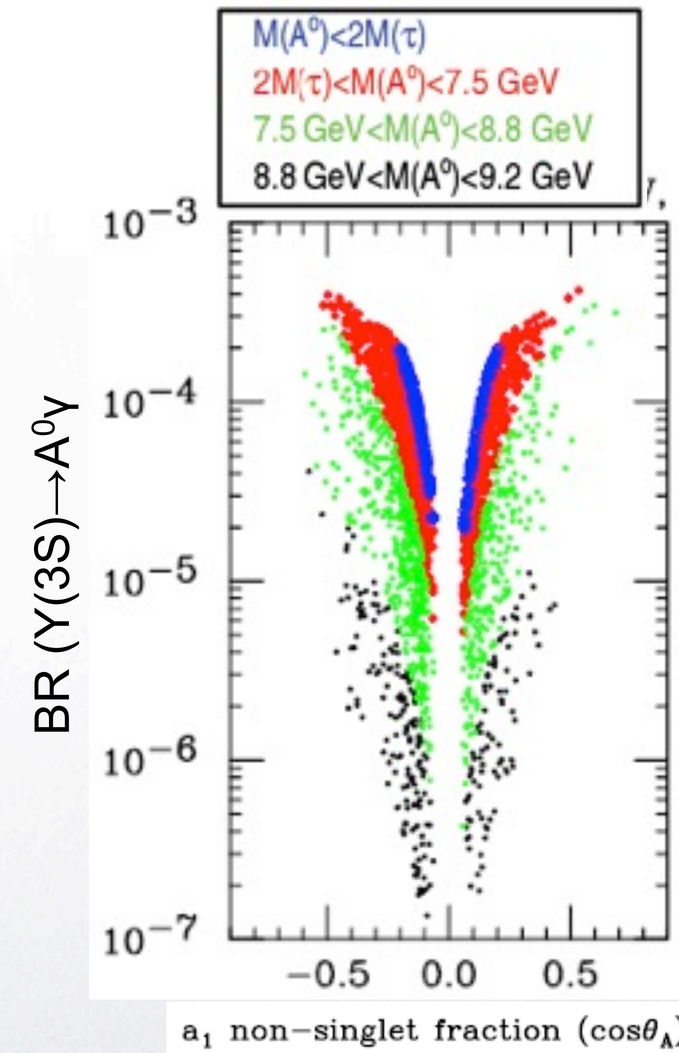
A solution: MSSM with two Higgs doublets

Need Fine tuning of EW scale

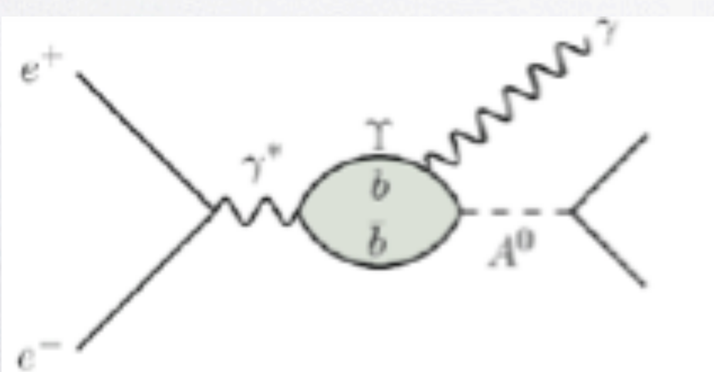
Solution: Higgs singlet (NMSSM) → Mixing of singlet with MSSM Higgs produces CP-odd A^0 PRD 76, 051105(2007)

Another interpretation is A^0 is an Axion like particle Phys.Rev.D79:075008,2009

Possible solution for both Dark Matter puzzle AND Higgs sector



Channels studied



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

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

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

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

Signature:

- two charged tracks, one identified as μ
- one energetic photon E_γ>200MeV
- Kinematic fit of γμμ vertex

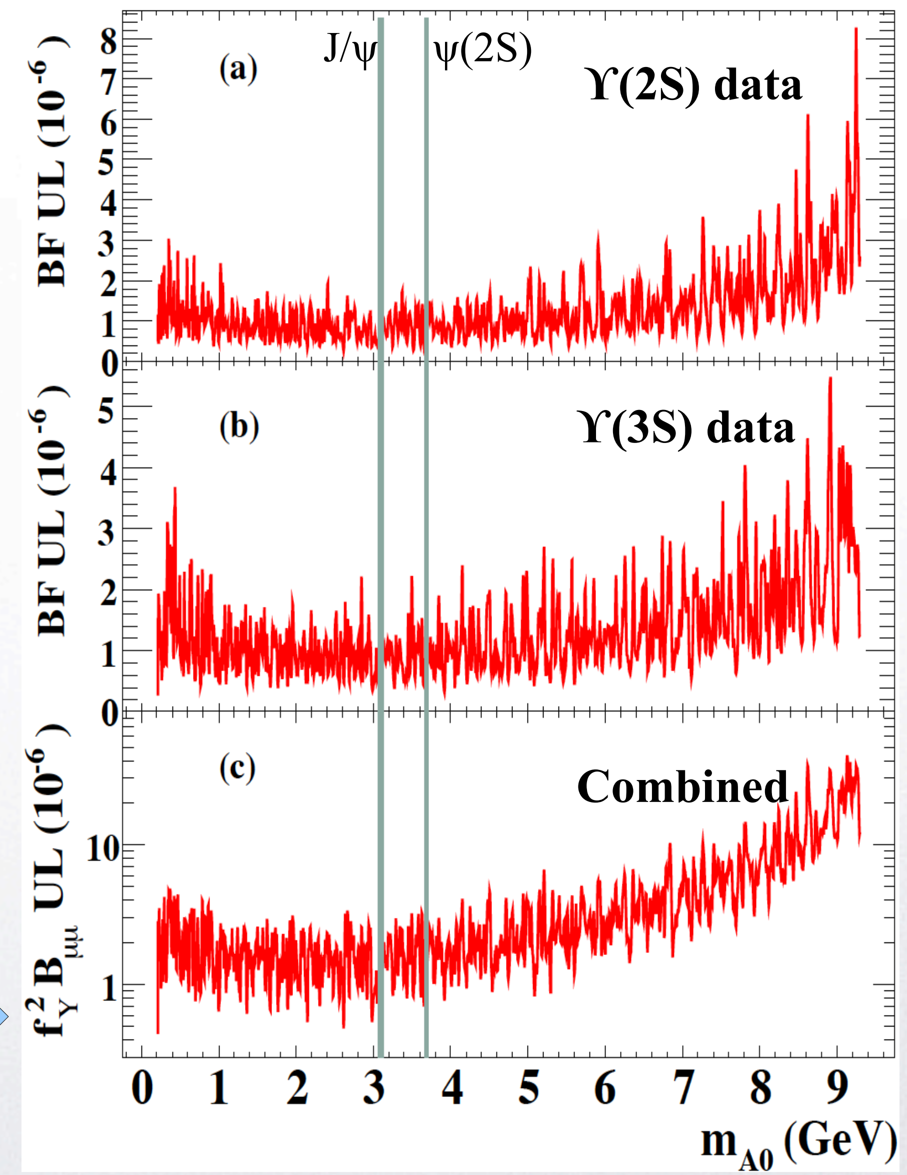
Analysis Method:

- Scan μμ invariant mass for A^0 peak evidence
- Background shapes taken from data
- Some resonances region excluded from the fit
- 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 fluctuations

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

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

PRL 103, 081803 (2009)



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

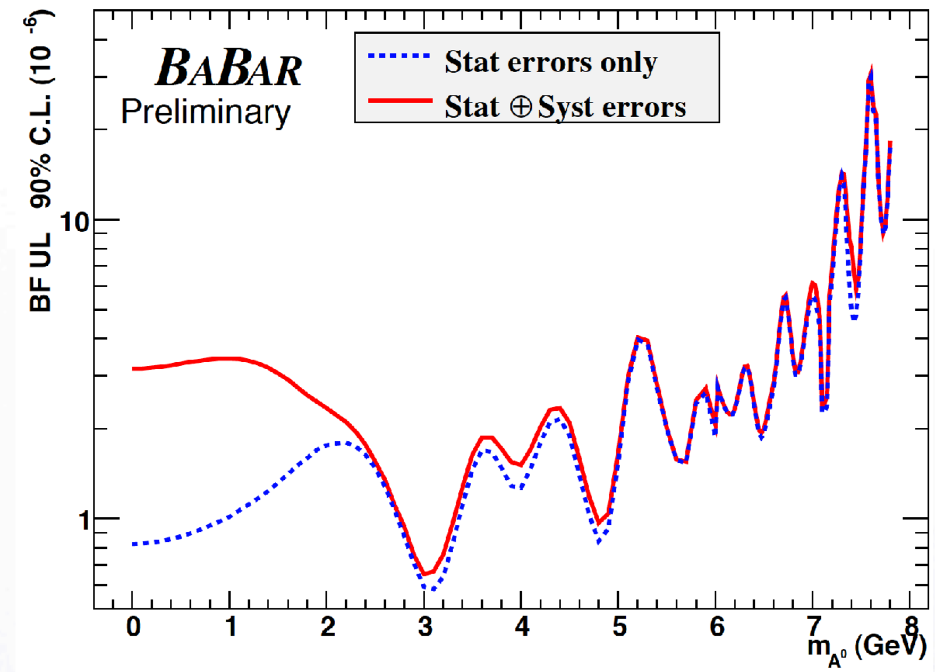
Dominant channel in scenarios with light LSP through $A^0\rightarrow\chi^0\chi^0$

Selection focused on search for monoenergetic peak from photon:

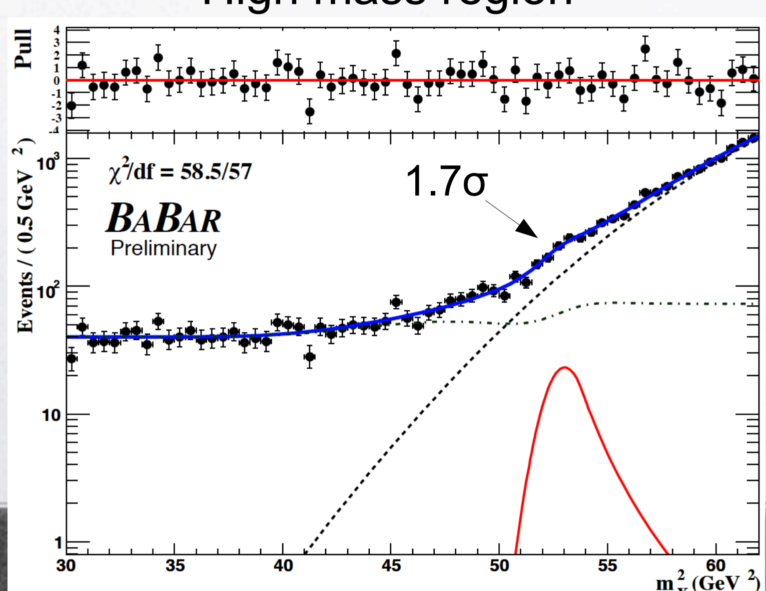
- photon fiducial and quality requirement
- requires single photon trigger, naturally split in low and high energy trigger (different bkgs: $ee\rightarrow\gamma\gamma$ and $ee\rightarrow\gamma(ee)$)

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

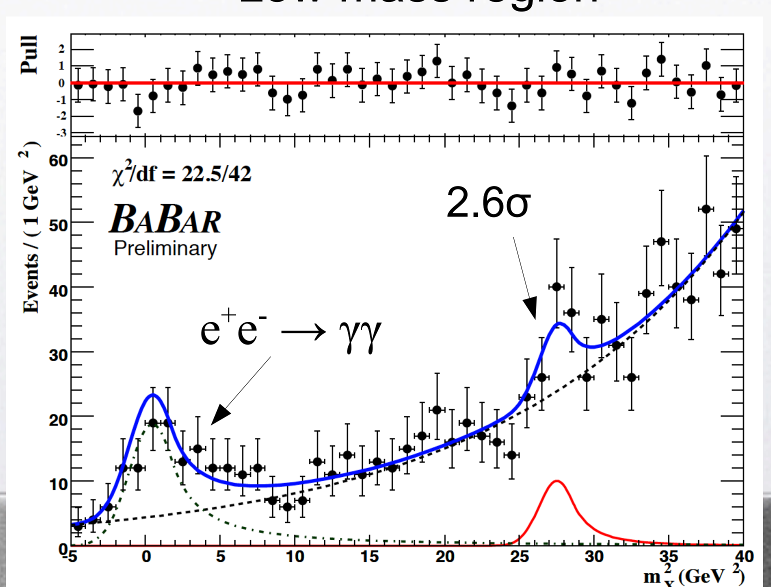
$$\mathcal{B}(\Upsilon(3S)\rightarrow\gamma A^0)\times\mathcal{B}(A^0)\rightarrow \text{invisible} < (0.7-31)\times10^{-6}(90\%CL) \qquad m_{A^0}\leq 7.8\text{GeV}$$



High mass region



Low mass region



arXiv:0808.0017 **preliminary**

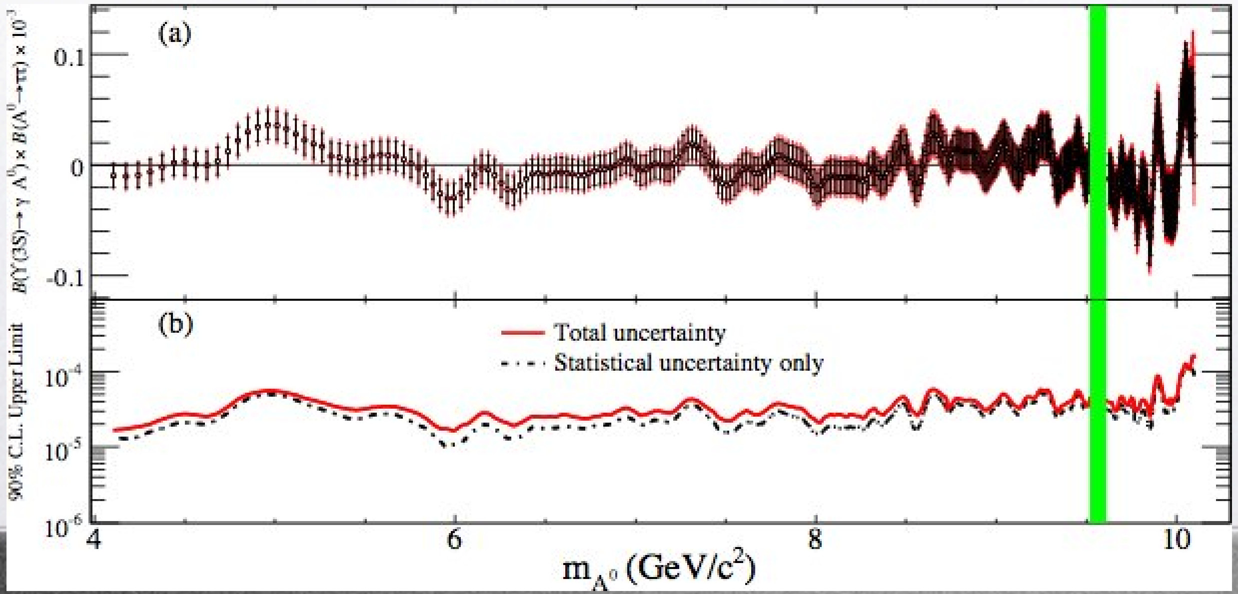
$\Upsilon(3S)\to\gamma A^0,\ A^0\to\tau^+\tau^-$

Signature:

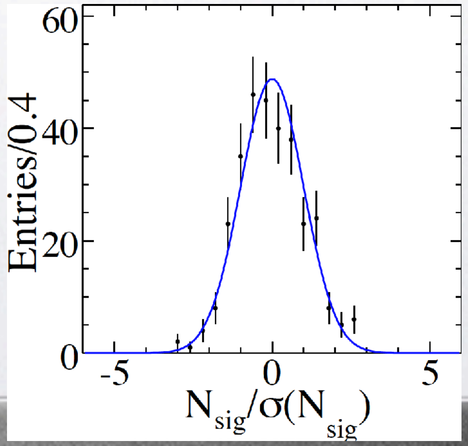
- Looking for $\tau^+\to e^+\nu\nu$ and $\tau^+\to\mu^+\nu\nu$
- E_γ > 100 MeV
- Exactly 2 tracks identified as leptons
- Missing energy precludes kinematic fit $\to A^0$ mass obtained from E_γ and known CM energy
- Bkg suppression provided by 8 kinematic and angular variables, optimized in 5 ranges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



PRL 103, 181801 (2009)



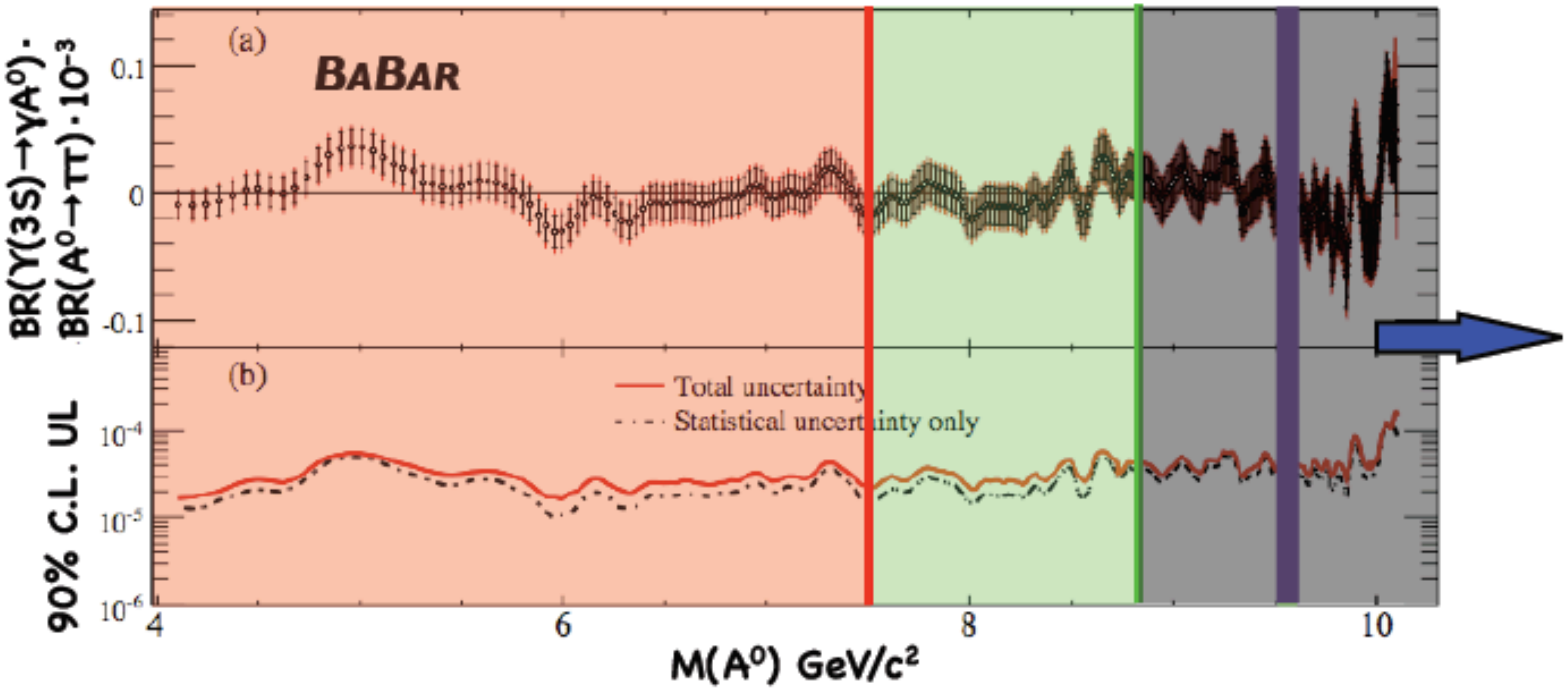
Constraints on NP

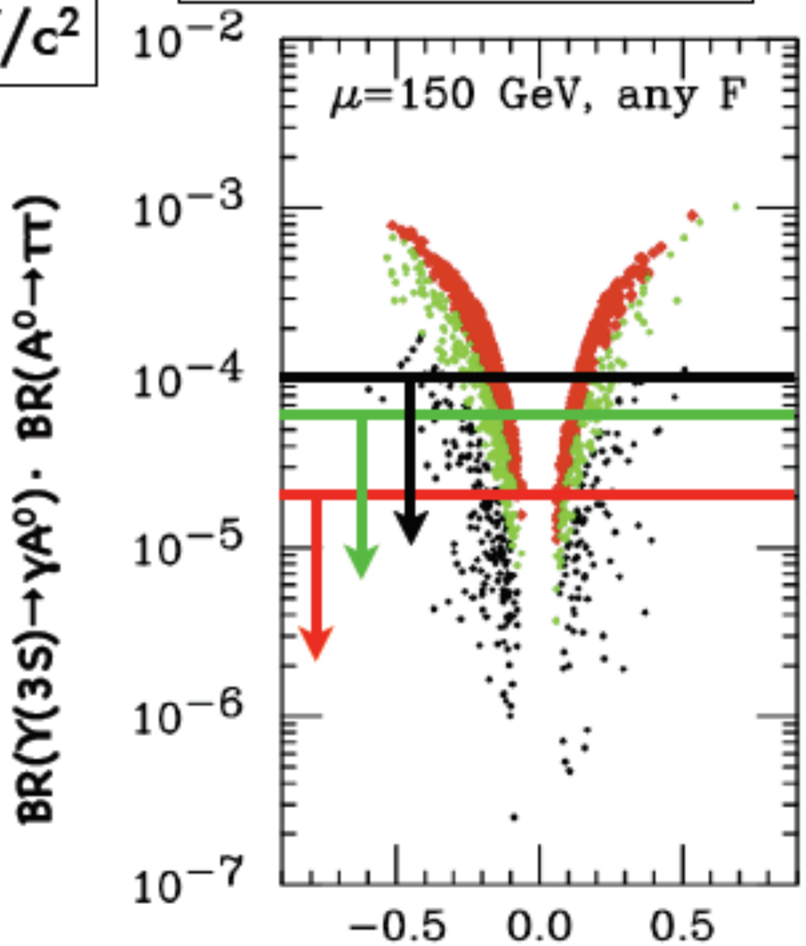
no excess signal for $\Upsilon(3S)\to\gamma A^0$, $A^0\to\tau^+\tau^-$
UL with 90% CL put

$$\mathcal{B}(\Upsilon(3S)\to\gamma A^0)\times\mathcal{B}(A^0)\to\tau^+\tau^-) < (1.5-16)\times10^{-5}(90\%CL)$$

$2M(\tau)<M(A^0)<7.5$ GeV/c^2
$7.5<M(A^0)<8.8$ GeV/c^2
$8.8<M(A^0)<2M(b)$ GeV/c^2

PRD 81, 075003 (2010)



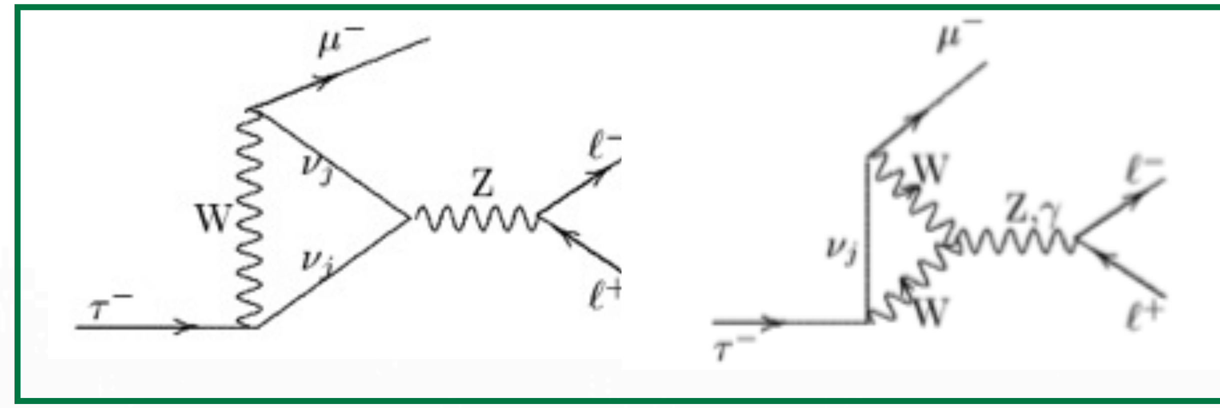


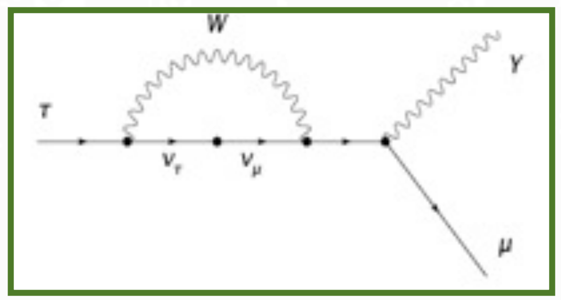
Lepton Flavor Violation

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. $BR_{SM}(\tau\rightarrow\mu\gamma) < 10^{-54}$).

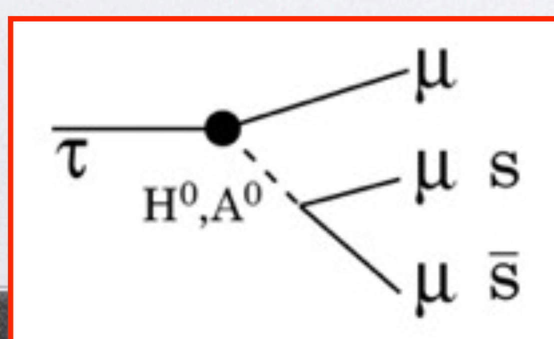


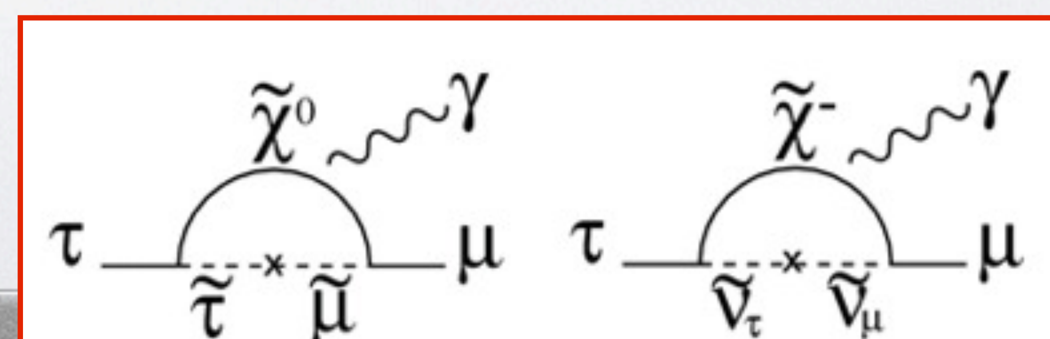


If detected with present datasets, LFV would imply New Physics.

Many New Physics models predict τ LFV BR up to present experimental limits.

If detected in more than one channel it providesuseful information on NP flavor structure, by looking at LFV BF Ratios. [PhysRevD.76.013004]

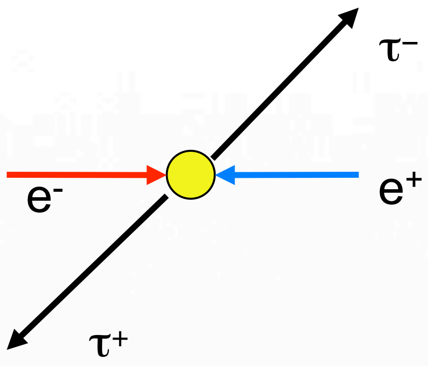




Analysis strategy

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:

- All selection optimized for best UL

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

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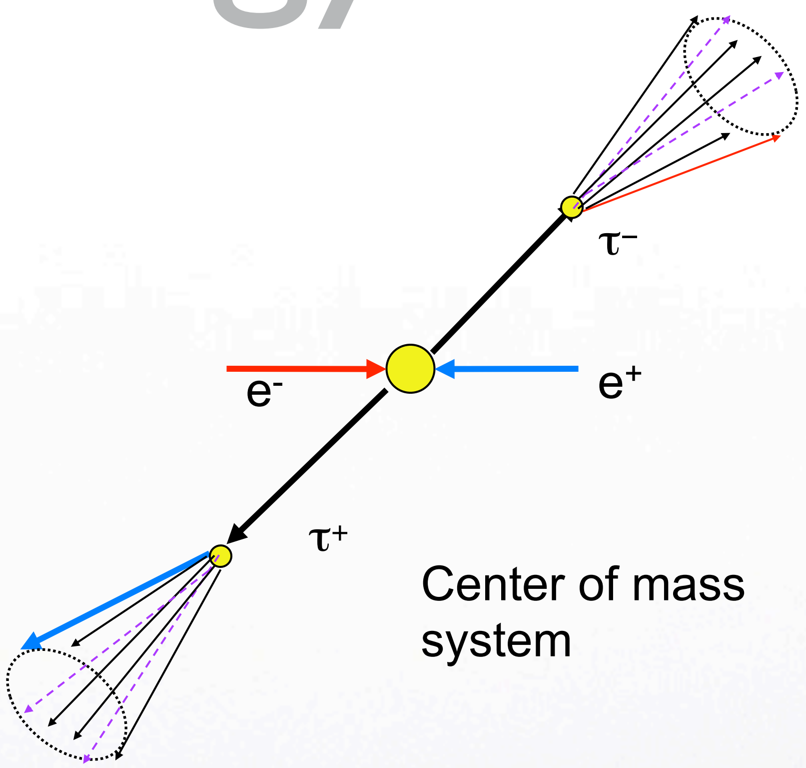

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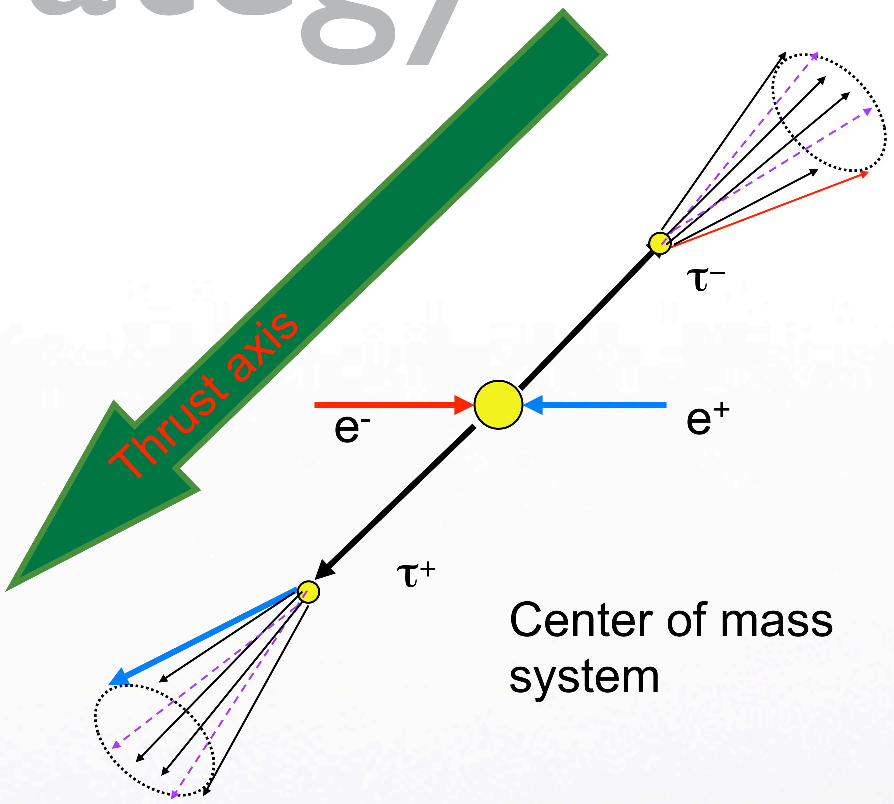

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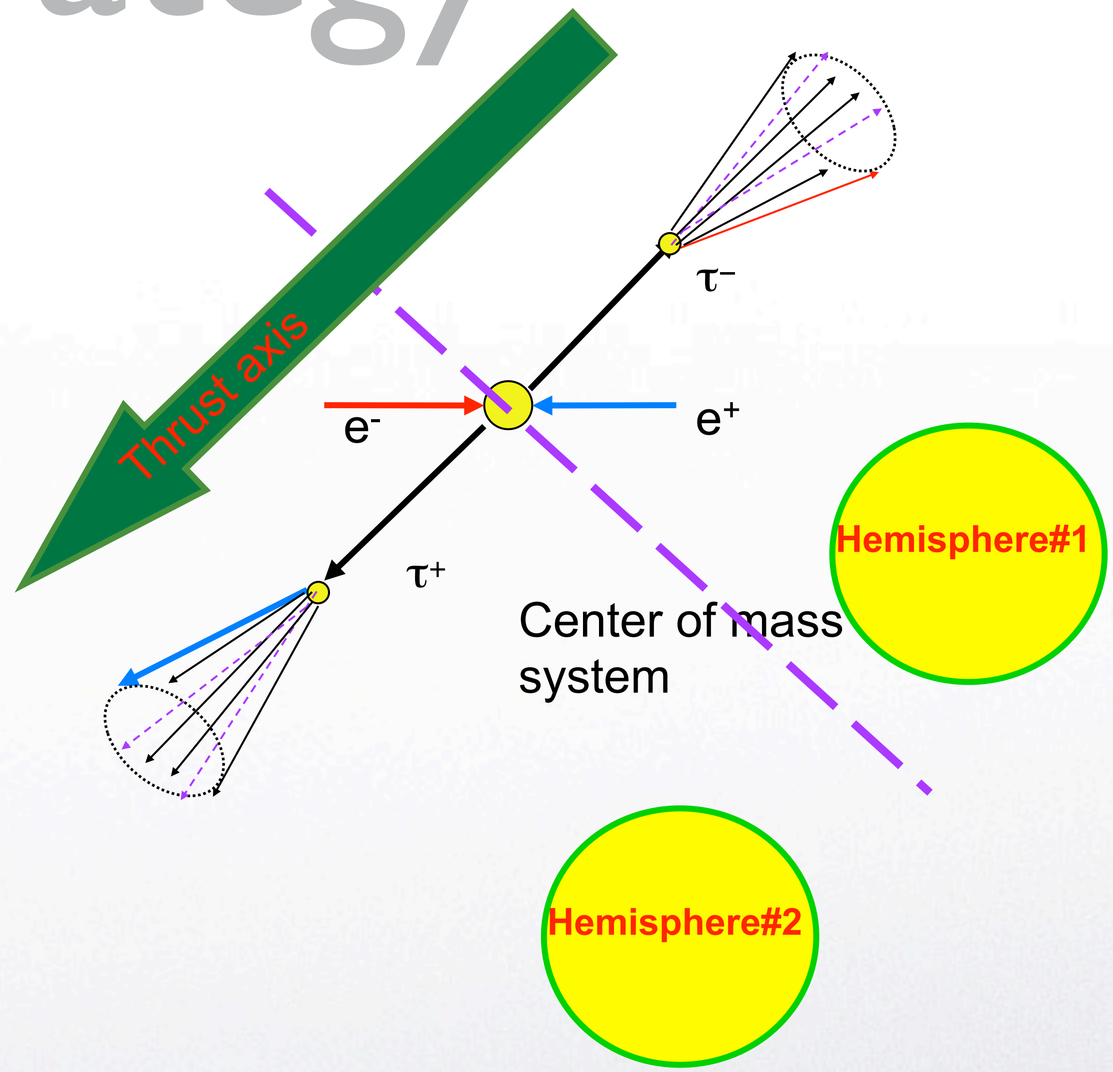

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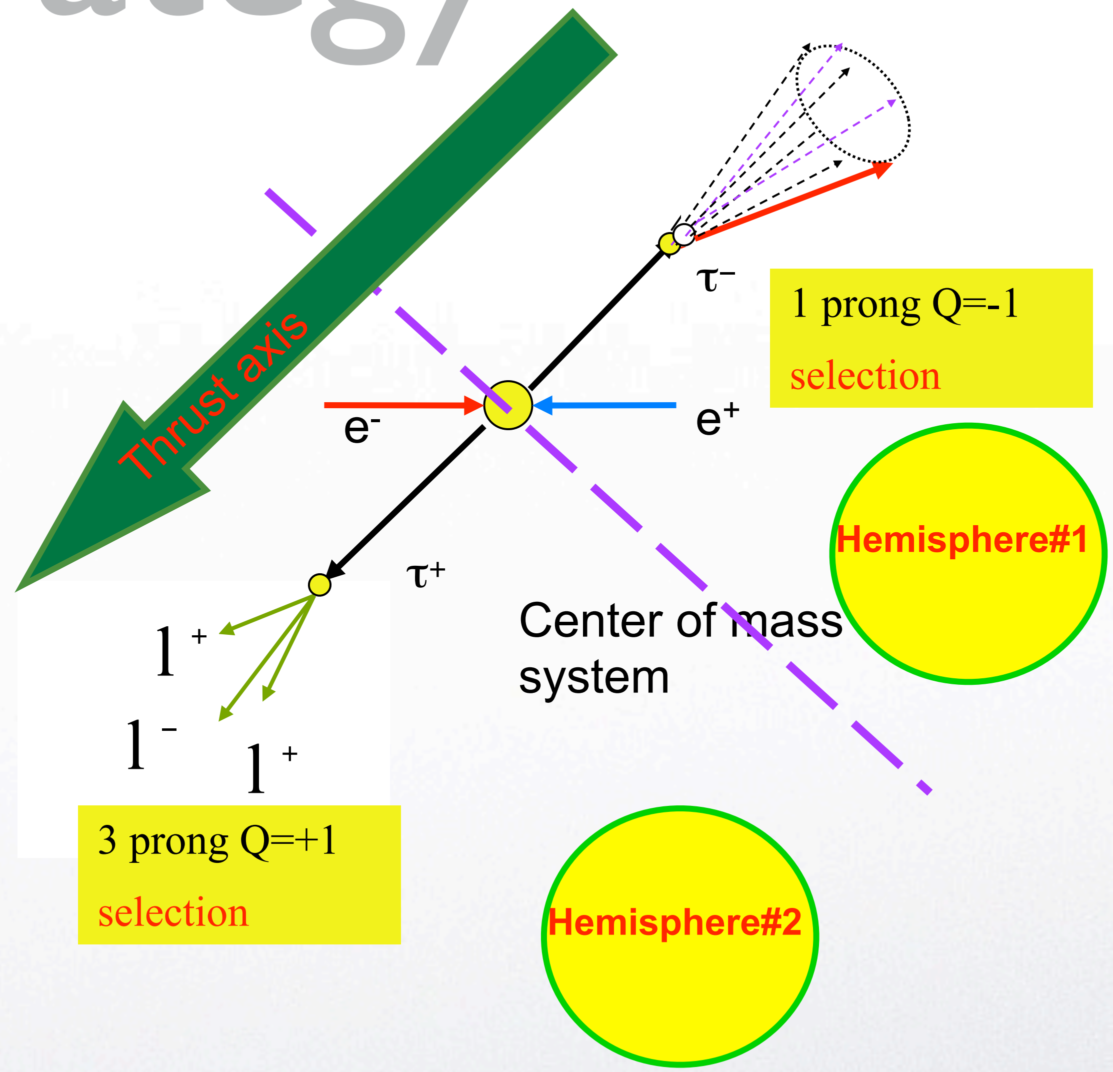


Recent Results

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

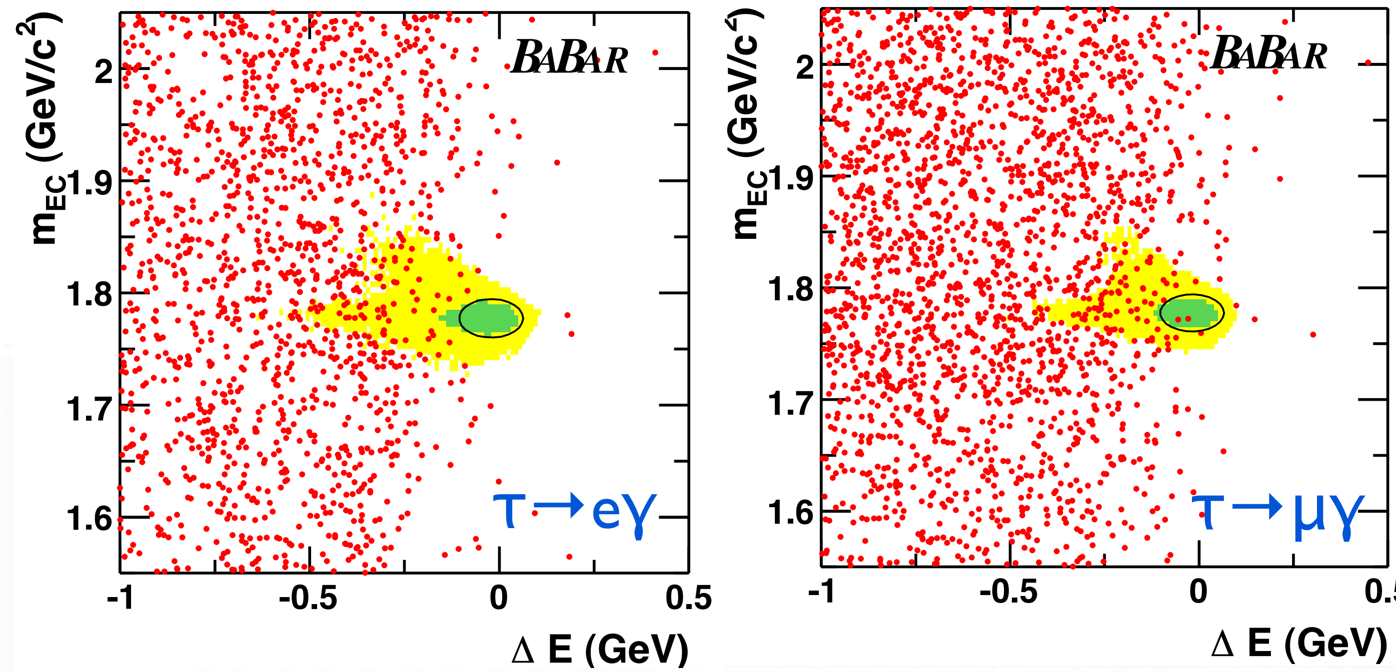
480M τ-pairs

PRL104,021802(2010)

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

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

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



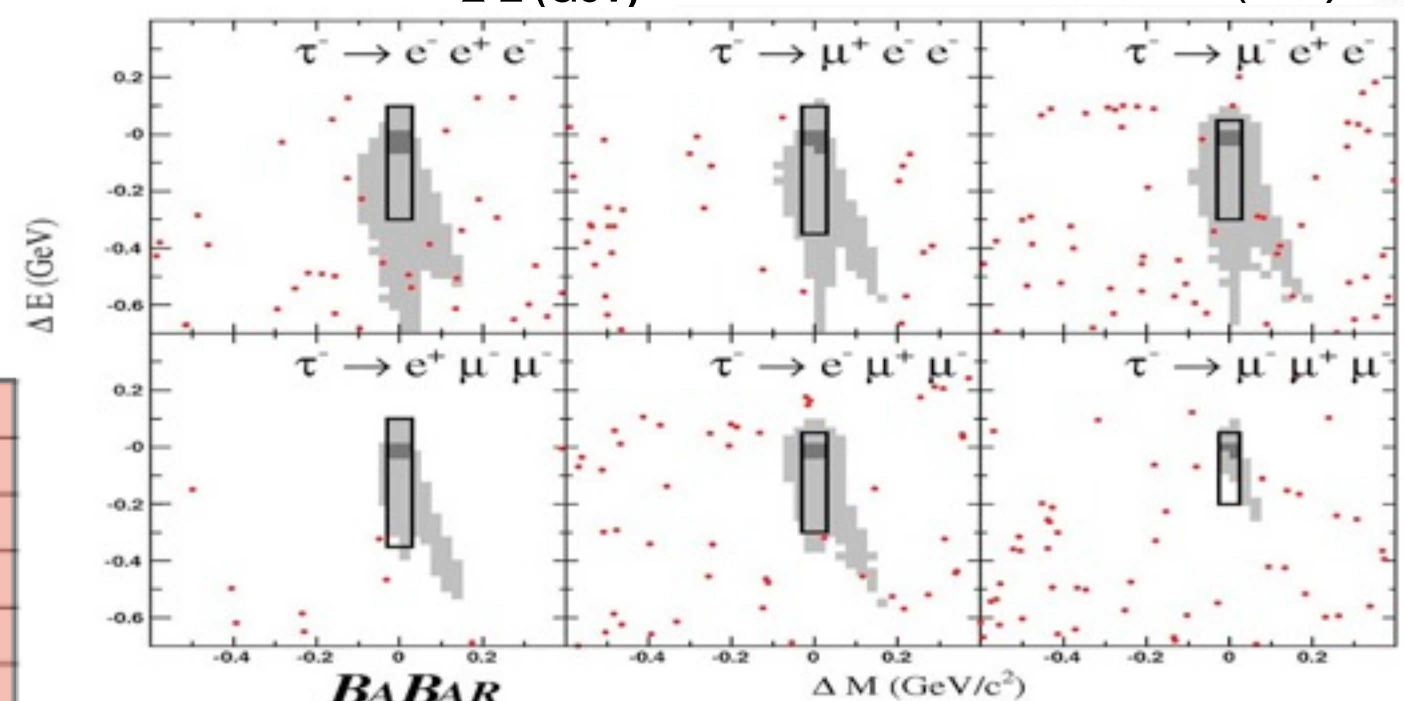
$\tau \to \ell\ell\ell, \ell = \mu, e$

430M τ-pairs

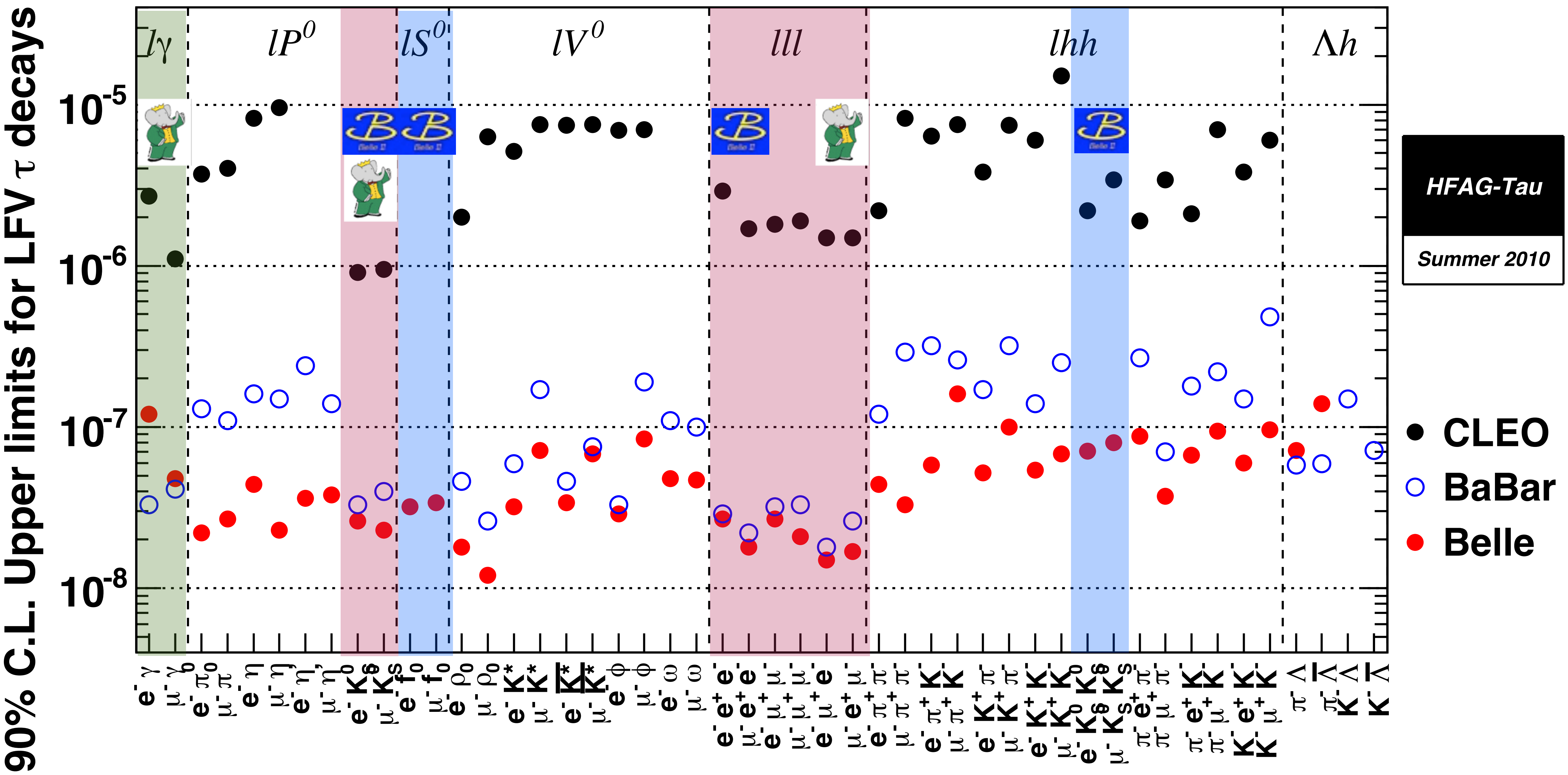
Phys.Rev.D81:111101,2010

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}



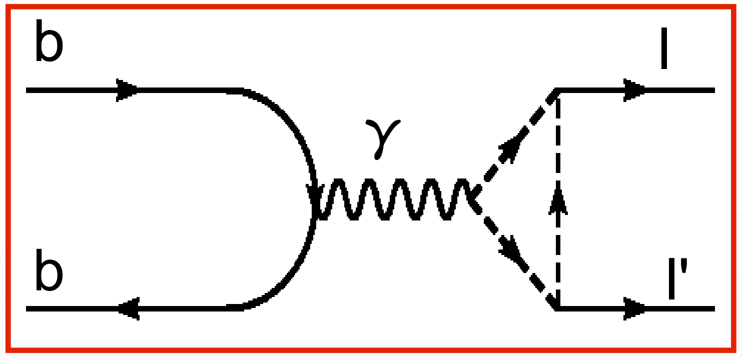
A Broader look



Recent Results: BaBar only Belle only BaBar + Belle

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 $\mu\tau$

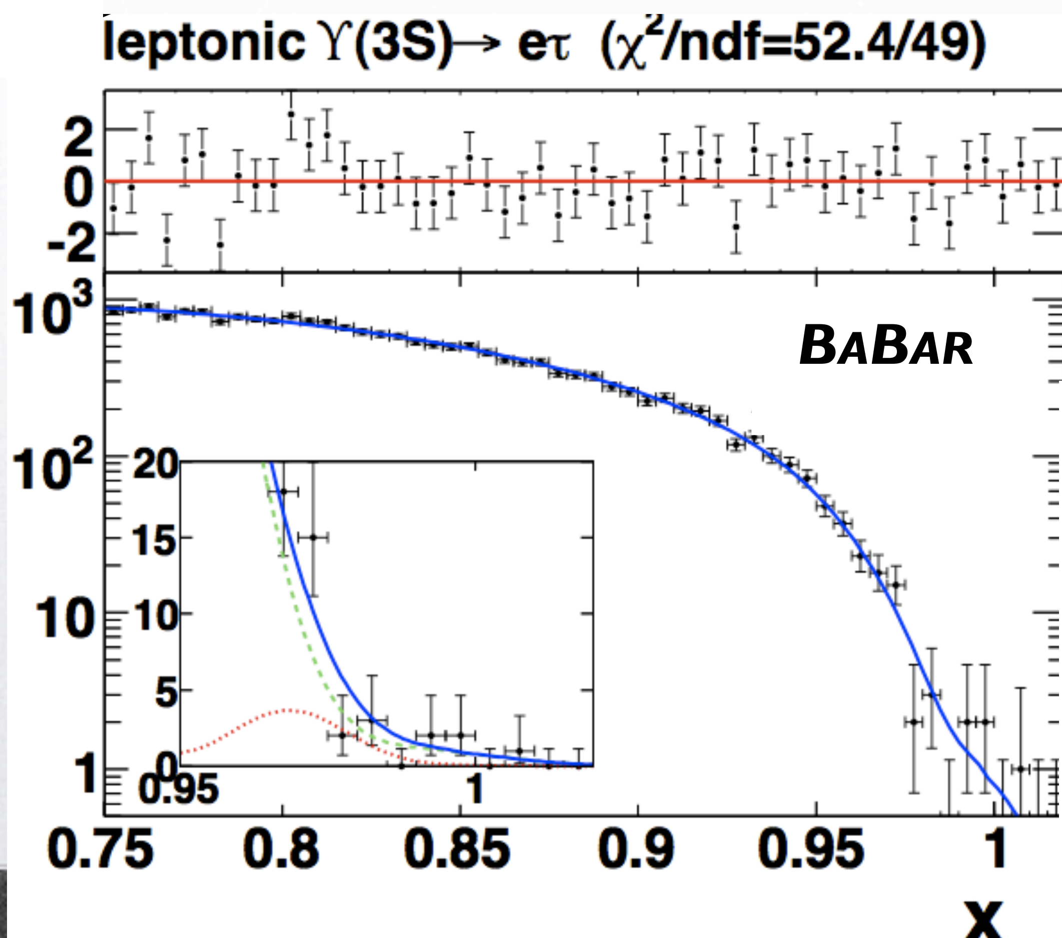
- Dominant background events:
  - Bhabha and μ-pair (through particle mis-ID)
  - τ-pairs ($e^{+}e^{-}\to\tau^{+}\tau^{-}$)
  - Multiple π and additional γ

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

PRL 104, 151802 (2010)

LFV in Υ decays - Results

- Discriminating variable: x = primary lepton momentum / CM beam energy
- Unbinned extended maximum likelihood fit to determine signal and background yields
- 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

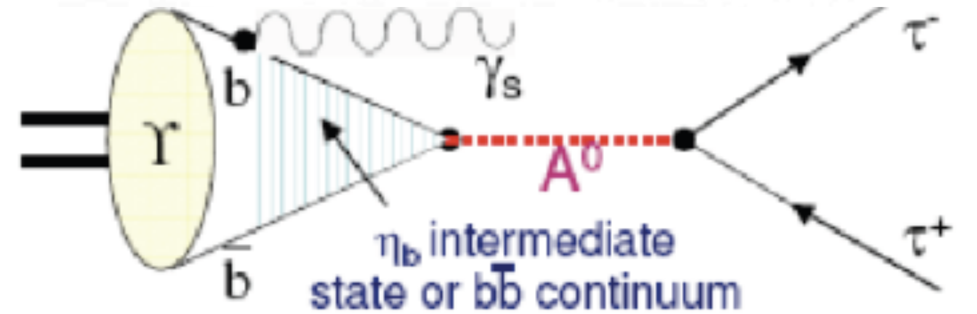
	$\mathcal{B}(10^{-6})$	UL (10^{-6})	Improvement
$\mathcal{B}(\Upsilon(2S) \to e^{\pm}\tau^{\mp})$	$0.6^{+1.5+0.5}_{-1.4-0.6}$	< 3.2	First
$\mathcal{B}(\Upsilon(2S) \to \mu^{\pm}\tau^{\mp})$	$0.2^{+1.5+1.0}_{-1.3-1.2}$	< 3.3	$\times 5.5$
$\mathcal{B}(\Upsilon(3S) \to e^{\pm}\tau^{\mp})$	$1.8^{+1.7+0.8}_{-1.4-0.7}$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

Lepton Universality

Theory

In SM the interactions between gauge bosons and leptons do not depend on lepton flavor

Hence $R_{\ell\ell'} = \dfrac{\mathcal{B}(\Upsilon(1S) \to \ell\ell)}{\mathcal{B}(\Upsilon(1S) \to \ell'\ell')}$



expected to be ~1 in SM, except for phase space ($R_{\tau\mu}$=0.992)

In NSSM: deviation from R_{ll} comes from the presence of A^0 and mediate the decay

$$\Upsilon(1S) \to \eta_b\gamma, A^0 \leftrightarrow \eta_b \to \ell^+\ell^-$$
$$\Upsilon(1S) \to A^0\gamma, A^0 \to \ell^+\ell^-$$

If photon is not detected lepton pair abscribed to A^0

It can result in a deviation from SM → NP effect

Effect more evident if the lepton is a τ (4% effect)

Int.J.Mod.Phys.A19, 2183 (2004);
PL B653, 67 (2007);
JHEP 0901, 061 (2009)

Analysis Strategy

$\Upsilon(1S)$ tagged with $\Upsilon(3S)\rightarrow\pi^+\pi^-\Upsilon(1S)$ with $\Upsilon(1S)\rightarrow\mu\mu/\tau\tau$

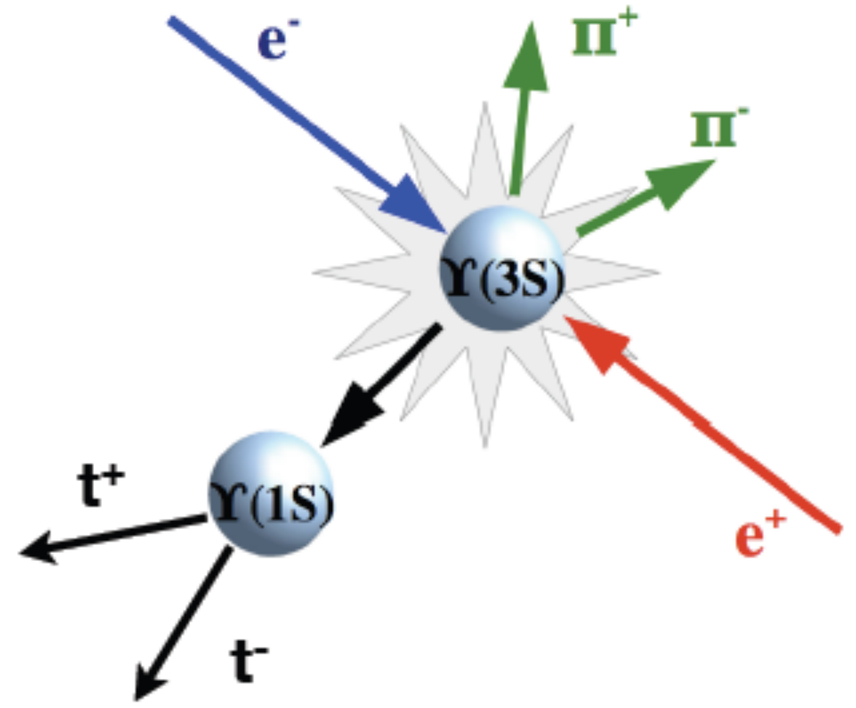
- BF ($\Upsilon(3S)\rightarrow\pi^+\pi^-\Upsilon(1S)$) ~4.5%
- Only 1 prong τ decay selected
- Exactly 4 tracks in the final state

No selection on extra photons

Separate selection for $\Upsilon(1S)\rightarrow\mu\mu$ (ε~45%) and $\Upsilon(1S)\rightarrow\tau\tau$ (ε~17%)

Bkg classified in light $q\bar{q}$, τ-pairs, QED events, $\Upsilon(1S)$ decays

Multivariate approach for $\Upsilon(1S)\rightarrow\tau\tau$ selection, efficiency and signal yields extracted with signal MC



t is either μ or τ decay product

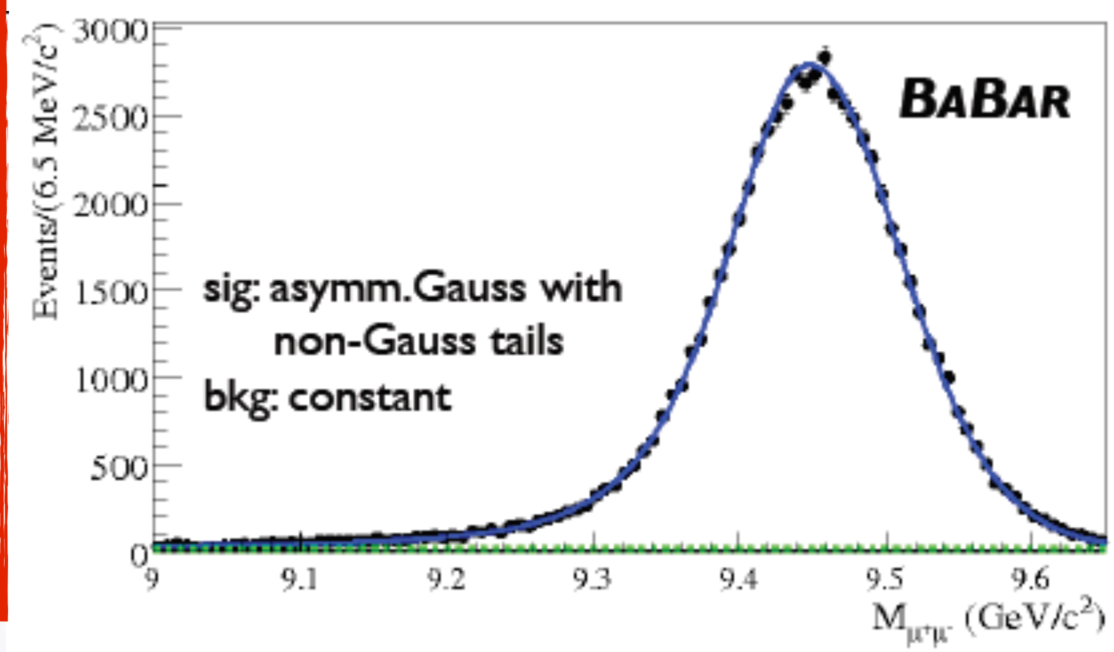
Signal Extraction

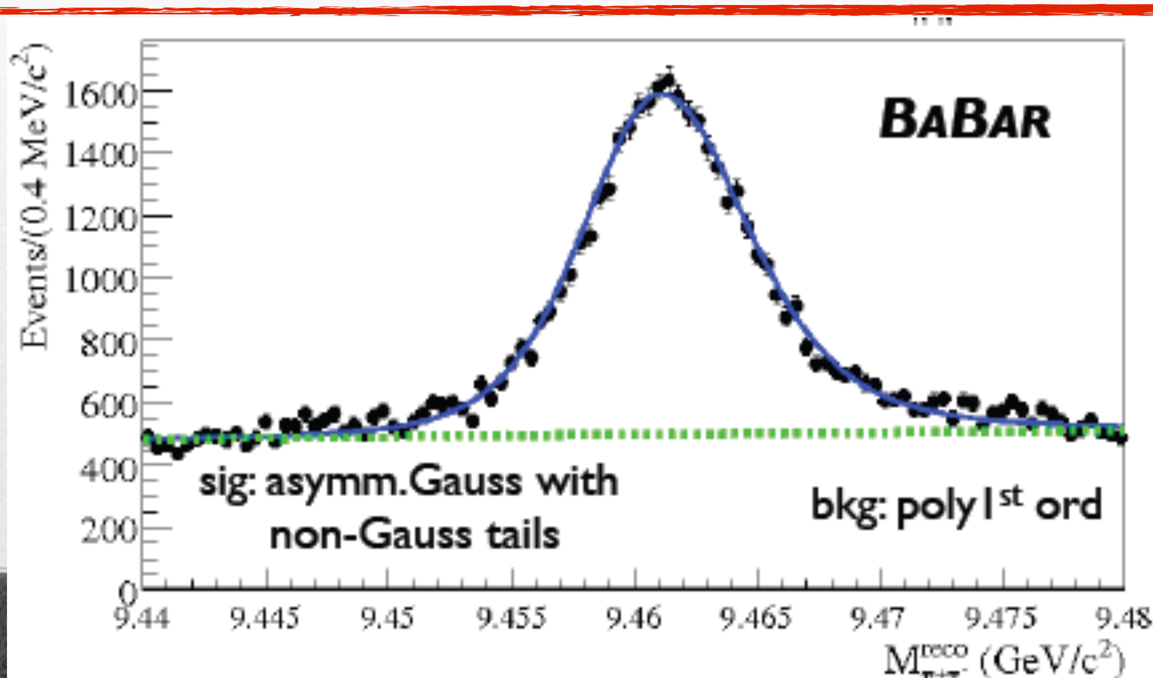
Extended Unbinned maximum likelihood fit: 2D for $\mu\mu$ ($M_{\pi\pi}$ and $M_{\mu\mu}$) and 1D for $\tau\tau$ ($M_{\pi\pi}$)

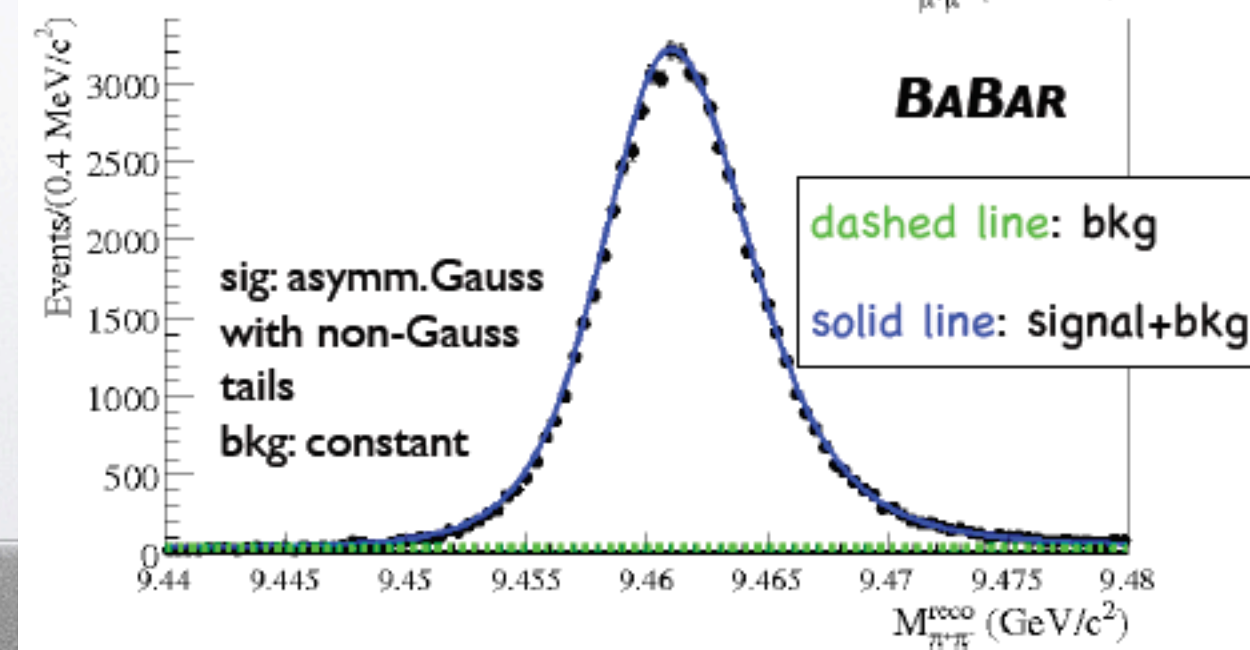
PDF chosen from data subsample (10%) which is discarded in final analysis

Fit performed simultaneously in the 2 datasets

$R_{\tau\mu}$ returned from the fit







Results

Improvement in precision w.r.t. previous CLEO measurement

$R_{\tau\mu}(\Upsilon(1S)) = 1.02 \pm 0.02_{stat} \pm 0.05_{syst}$

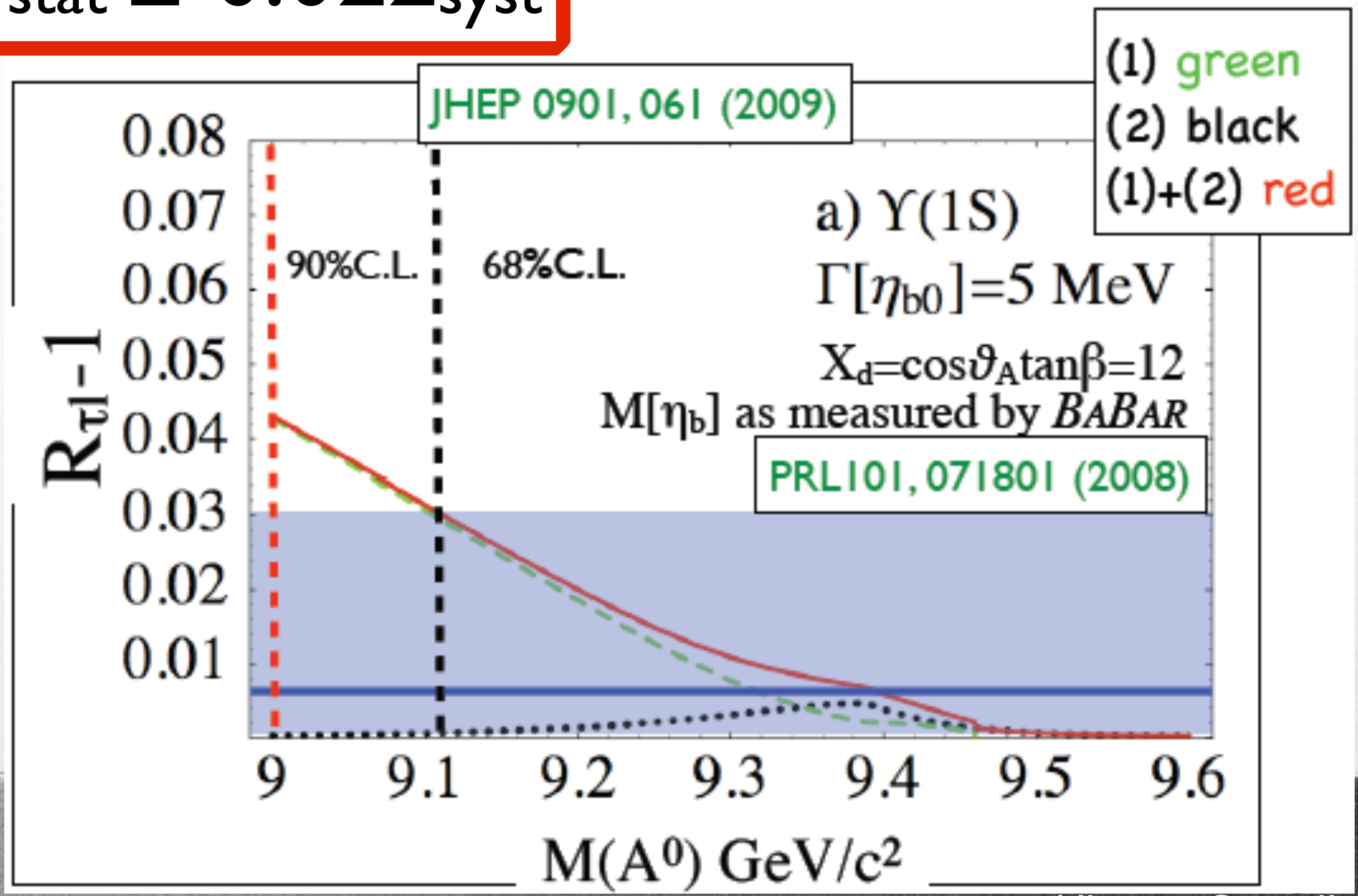
Main systematics (up to 2.2%): selection efficiency, muon PID, signal and bkg shape model, peaking background yield, trigger efficiency

$$R_{\tau\mu}(\Upsilon(1S)) = 1.005 \pm 0.013_{stat} \pm 0.022_{syst}$$

PRL 104, 191801 (2010)

No significant difference w.r.t. SM expectation.

Exclusion of $M(A^0) < 9$GeV @90% CL



Conclusion

- 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