New Physics Searches at B-Factories

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Low-Energy Searches for New Physics

- Direct searches for light degrees of freedom
  - Low-mass Higgs and dark matter candidates
- Indirect searches for > TeV New Physics
  - Precision measurements: look for small deviations from the Standard Model
    - ☞ Deviations go as $\sim \frac{\alpha_{NP}}{\alpha_{SM}} \left(\frac{M_{SM}}{M_{NP}}\right)^n$
    - ☞ Examples: $B^+ \to \tau^+ \nu$
  - Processes suppressed in the Standard Model: symmetry violations, rare decays
    - ☞ Examples: Lepton Flavor/Baryon number Violation
  - Not covered: CP violation (see Yosuke Yusa's talk) and many rare decay searches at B Factories

Direct Searches for Low-Mass New Physics

- Models inspired by astrophysical and astro-particle observations (c.f. Joe Silk's plenary)
  - Strongest hint: INTEGRAL 511 keV anomaly
  - Also positron, γ-ray excess in PAMELA, FERMI
  - Hints of low-mass direct DM detection (DAMA, CoGeNT, CRESST)
    - ☞ Typical models: low-mass (<10 GeV) gauge bosons and/or scalars (Higgses)
    - ☞ Predict branching ratios in Upsilon decays: $10^{-6} - 10^{-4}$

A puzzle in the center of the galaxy

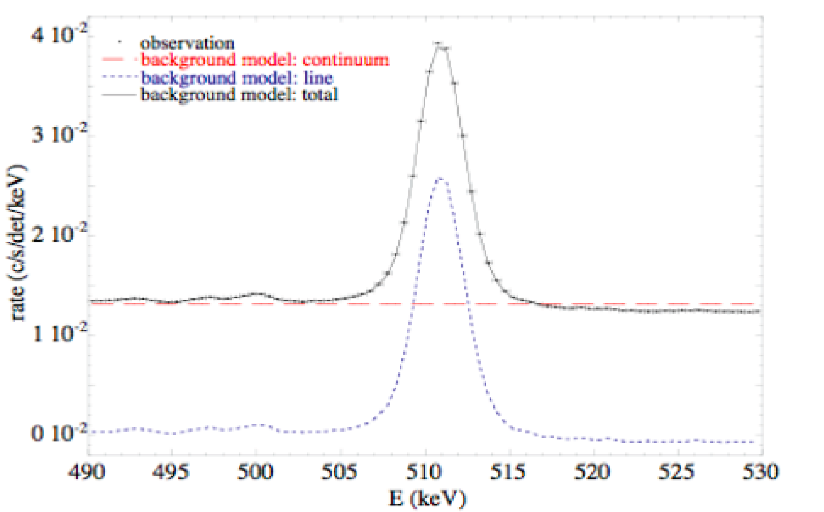
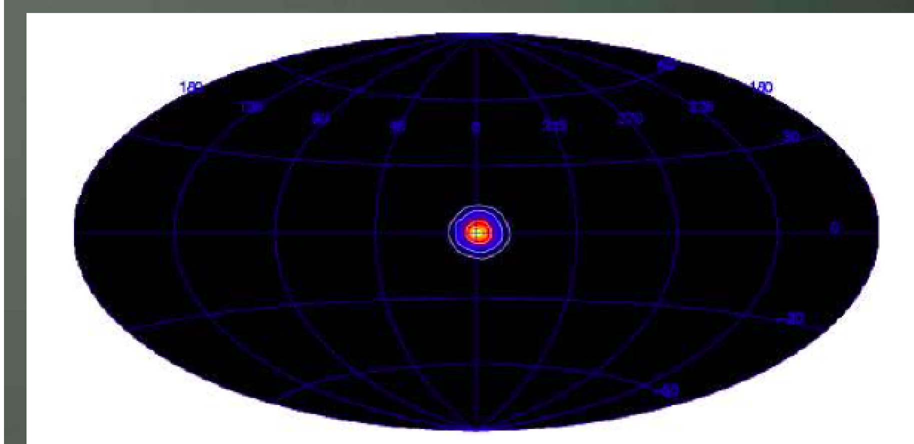


Fig. 1. Raw spectrum and background model components.

INTEGRAL source

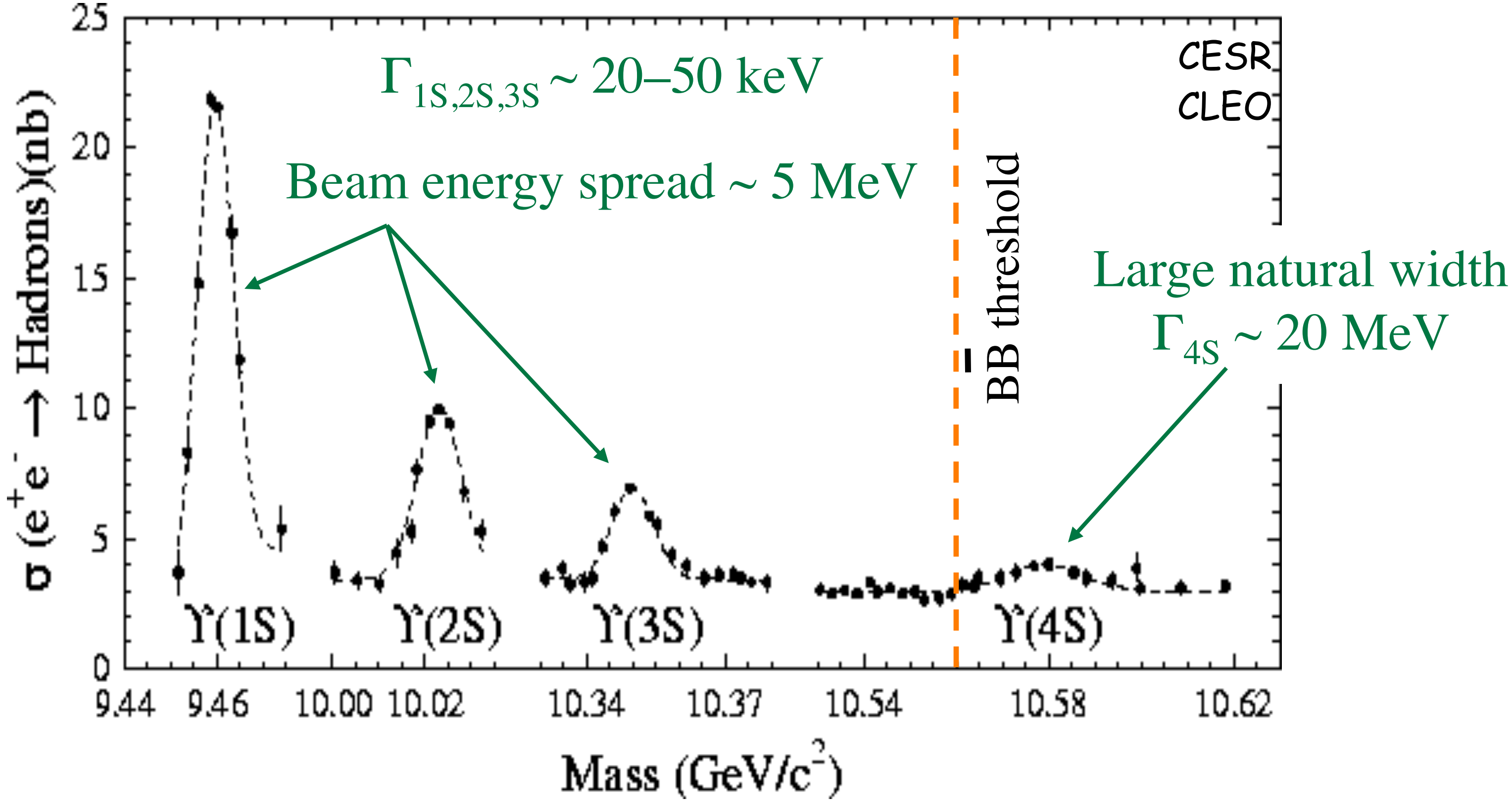


- Not consistent with point source
  - (needed 7 in 1yr data)

Courtesy N.Weiner

Upsilon Resonances

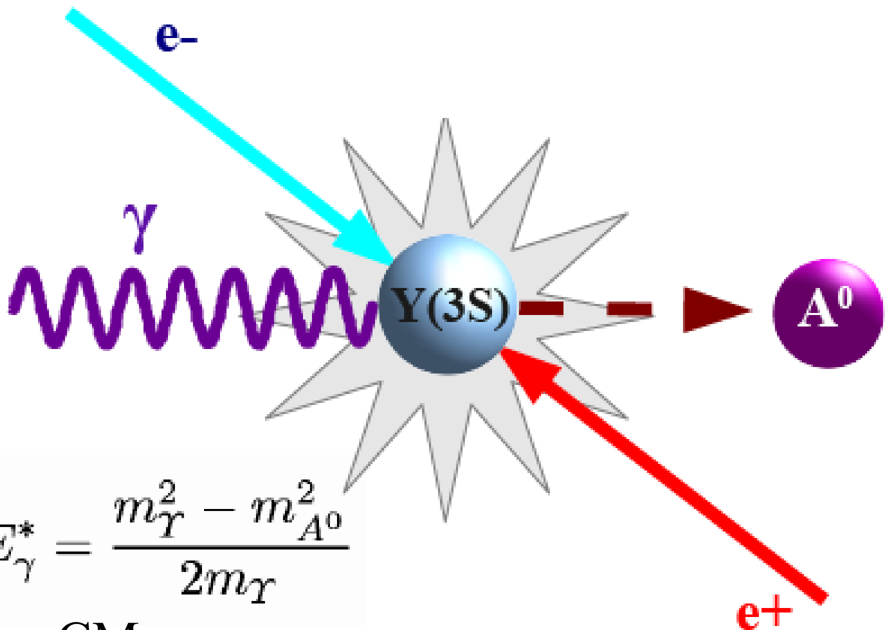
- Electron-Positron collider: $e^+e^- \to \gamma^* \to \Upsilon(nS)$



For any bottomonium process $BF_{nS}=\Gamma_{nS}/\Gamma_{tot} >> BF_{4S}$, n=1,2,3

Significantly better sensitivity to direct production of light degrees of freedom @ narrow resonances

Searches for a Light Higgs in BaBar



$$E^*_\gamma = \frac{m^2_\Upsilon - m^2_{A^0}}{2m_\Upsilon}$$

CM energy

Well-understood initial state (narrow Υ(2S) or Υ(3S) resonance)

Fully or partially reconstructed final state, depending on the decay pattern of A^0

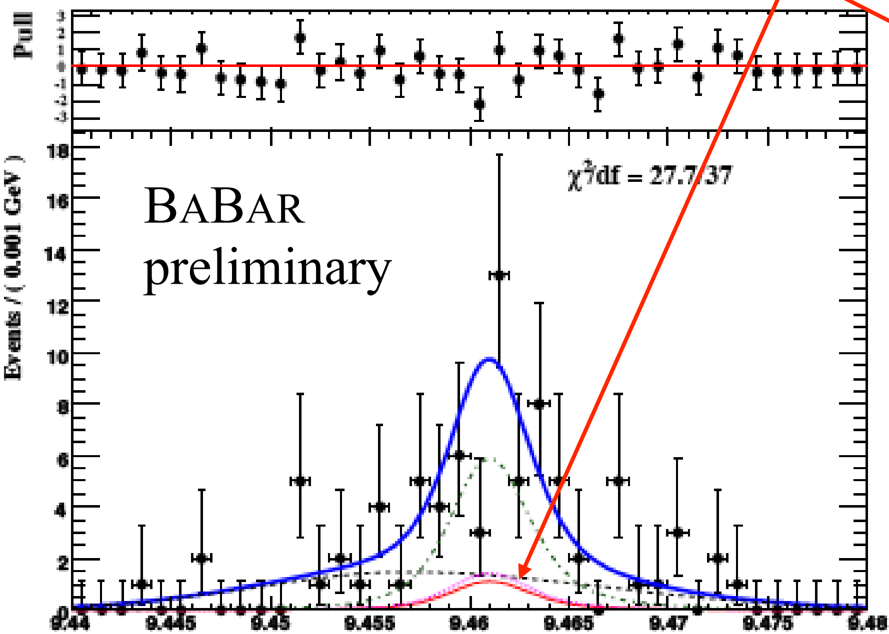
Key experimental signature: monochromatic photon in the Center-of-Mass (CM) frame

BaBar results:

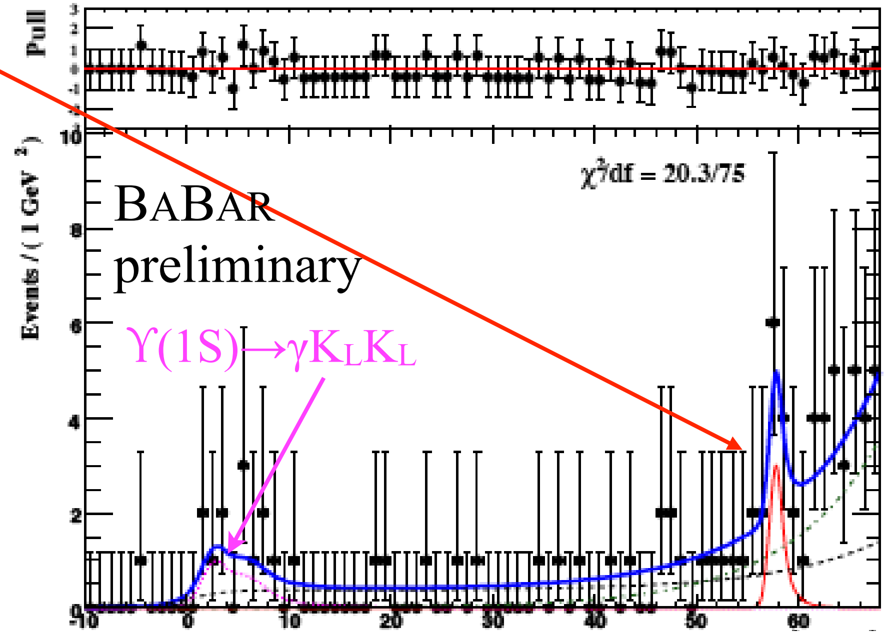
- ✔ $A^0 \to \mu^+\mu^-$, PRL **103**, 081803 (2009)
- ✔ $A^0 \to \tau^+\tau^-$, PRL **103**, 181801 (2009)
- ✔ $A^0 \to$ invisible (light dark matter), arXiv:1007.4646, submitted to PRL

Example: $\Upsilon(2S)\to\pi^+\pi^-\Upsilon(1S)$, $\Upsilon(1S)\to\gamma A^0$, $A^0\to$invisible

Most significant peak in missing mass: m_{A0}=7.58 GeV, 2.0σ significance



π+π- Recoil Mass [GeV]

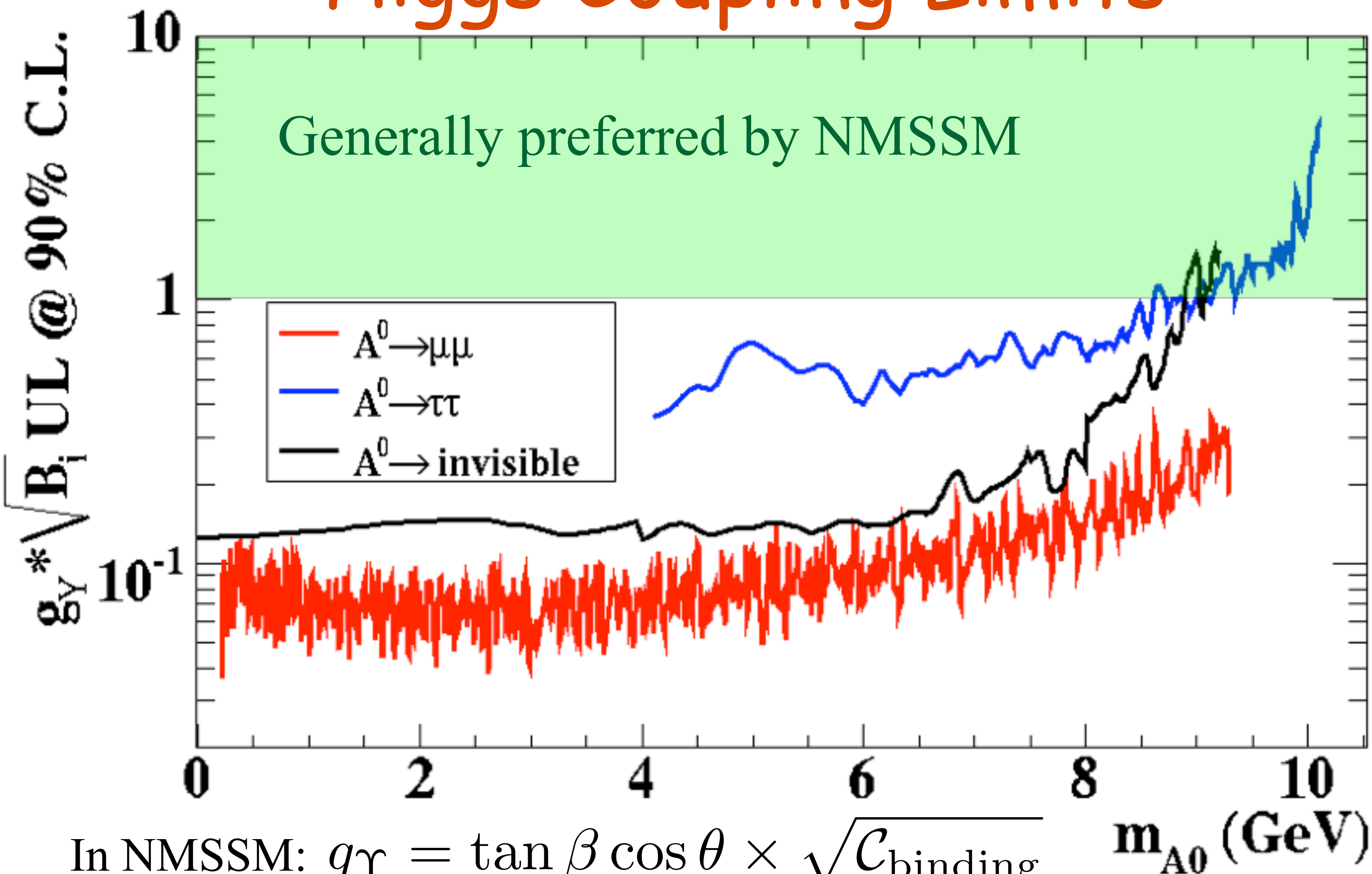


Missing Mass Squared[GeV^2]

>30% probability to observe a peak of this significance *anywhere* in m_{A0}<9.2 GeV range

arXiv:1007.4646

Higgs Coupling Limits

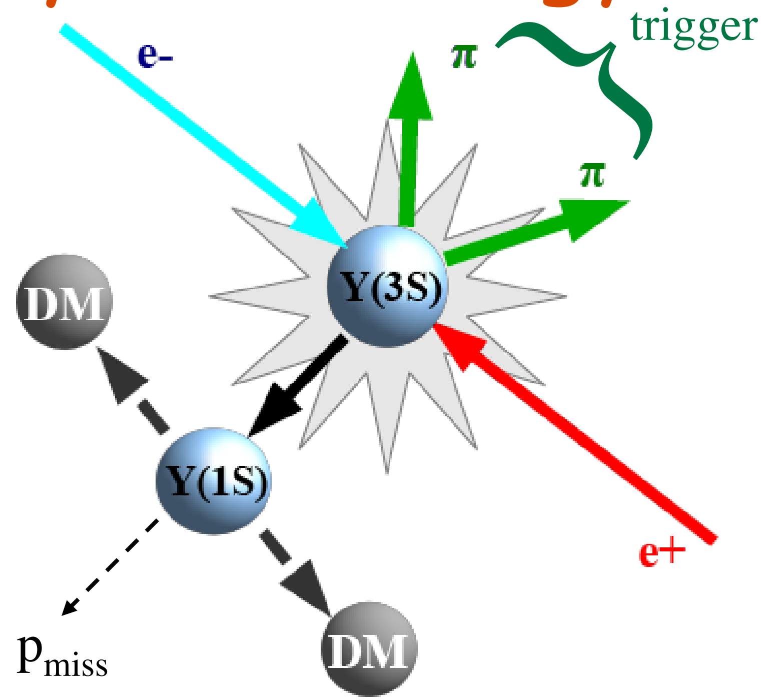


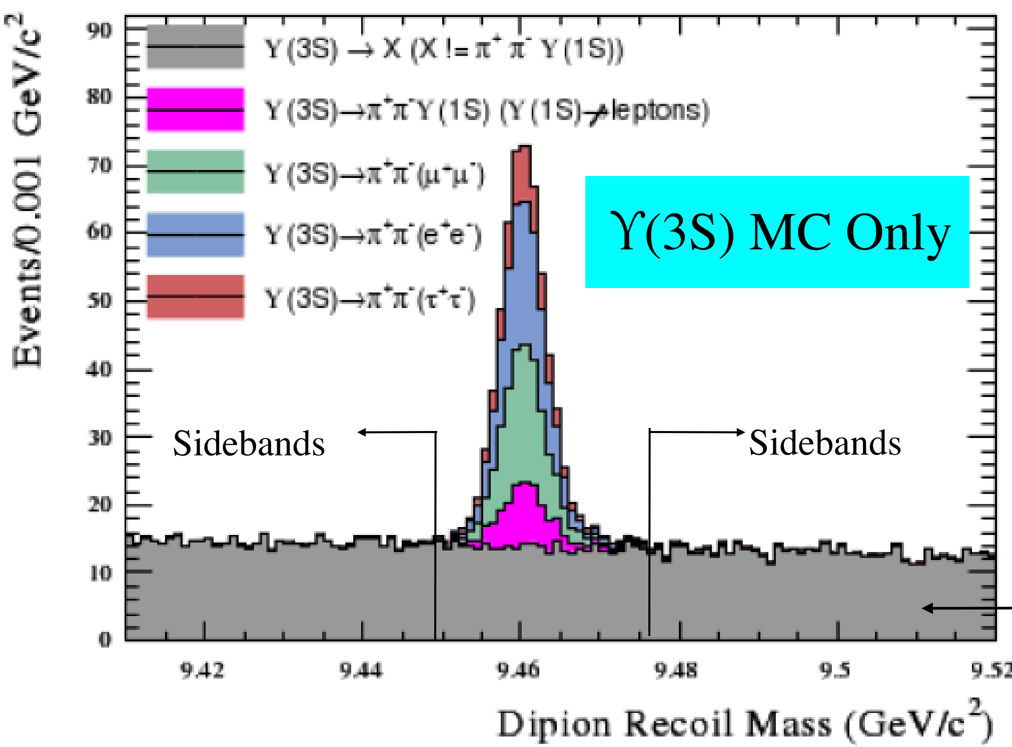
In NMSSM: $g_\Upsilon = \tan\beta\cos\theta \times \sqrt{C_{\text{binding}}}$

Also place significant constraints on other models, e.g. axion-like states, dark photons (from $e^+e^- \to \gamma\phi$)

Υ(1S)→invisible: Analysis Strategy

Leverage the charged dipion transition to the Υ(1S) (4.48%) to suppress background





$$m^2_{recoil} = s + m^2_{\pi\pi} - 2E_{\pi\pi}\sqrt{s}$$

Additional non-peaking backgrounds from $e^+e^- \to \gamma^*\gamma^* \to e^+e^-\pi^+\pi^-$ not included

ϒ(1S)→invisible: Signal Extraction

Maximum likelihood fit to 2-track "invisible" sample

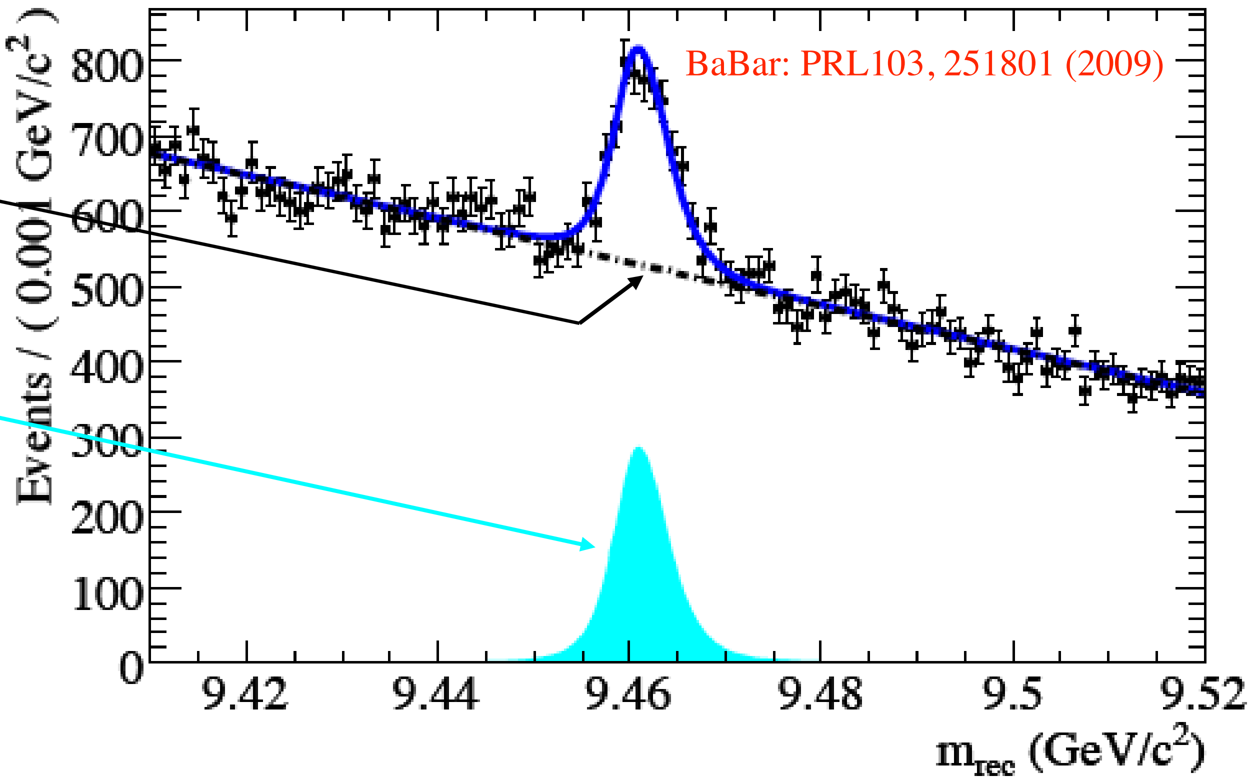
Non-peaking background:

✔ Float all parameters and yield

Peaking Component:

✔ Fix shape, float yield

Contains peaking background and signal



BR(ϒ(1S)→invisible) = [–1.6 ± 1.4 (stat.) ± 1.6 (syst.)]$\times 10^{-4}$

BR(ϒ(1S)→invisible) < 3.0$\times 10^{-4}$ @ 90% C.L. [BaBar PRL**103**, 251801 (2009)]

BR(ϒ(1S)→invisible) < 2.5$\times 10^{-3}$ @ 90% C.L. [Belle PRL98, 132001 (2007)]

Also: BR(ϒ(1S)→γχχ)<[0.5-24]$\times 10^{-5}$ @ 90% C.L. for m_χ<4.5 GeV [BaBar Preliminary, arXiv:1007.4646]

Gauge Bosons in the "Dark Sector"

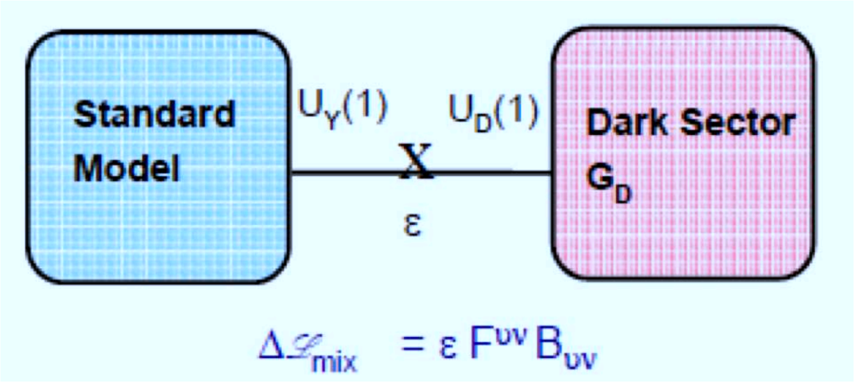
Models motivated by γ-ray and positron emission from the galactic center (INTEGRAL, PAMELA, ATIC, etc)

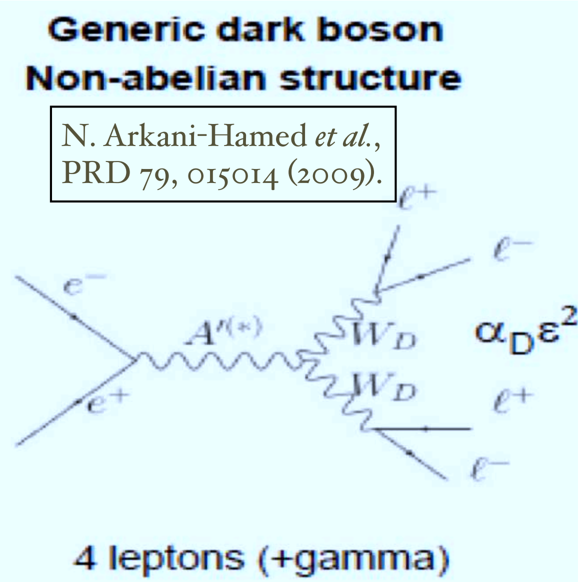
Dark matter particles in ~TeV range, but new gauge bosons in ~GeV range

Coupling to leptons due to small mixing between SM and DS

New gauge bosons decay to lepton pairs, anti-proton production forbidden by kinematics or suppressed → explains PAMELA/ATIC features

Search for low-mass states in e^+e^- annihilation @ B-Factories

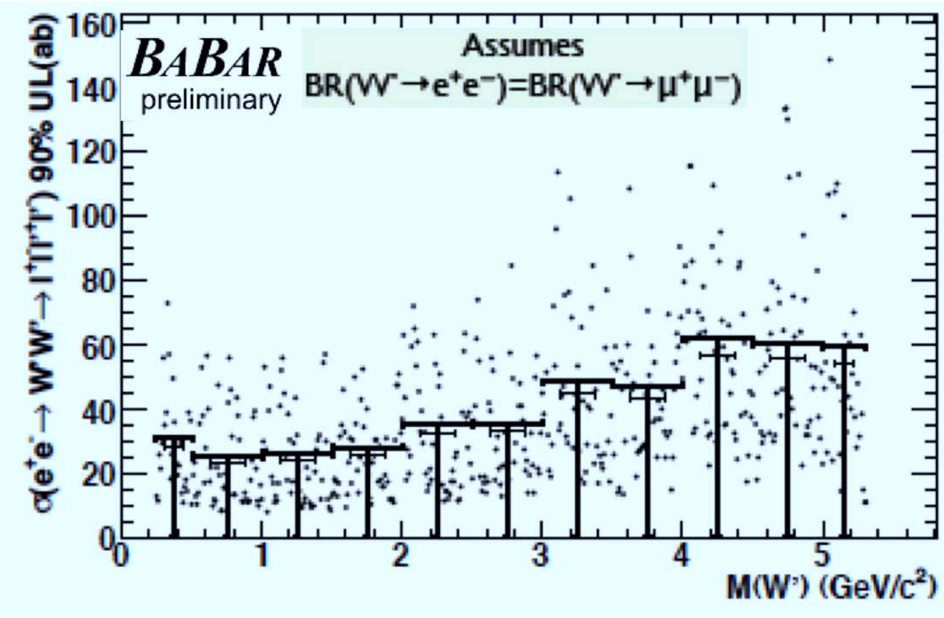


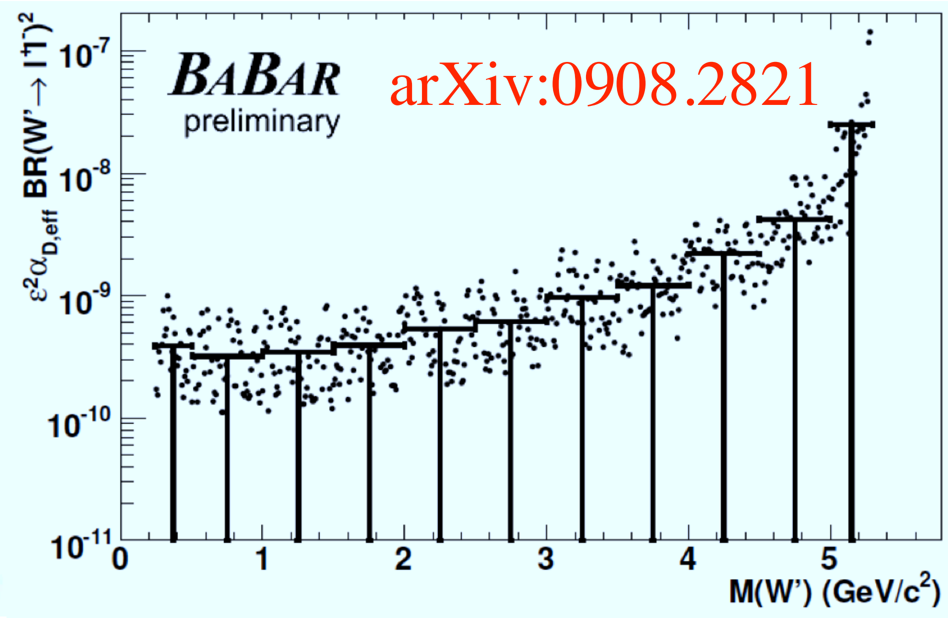


Direct Search for Dark Sector

Look for $e^+e^- \to l^+l^-l^+l^-$ final states (4e, 2e,2μ,4μ) as a function of two-lepton mass

Full BaBar dataset (~540 fb^{-1})



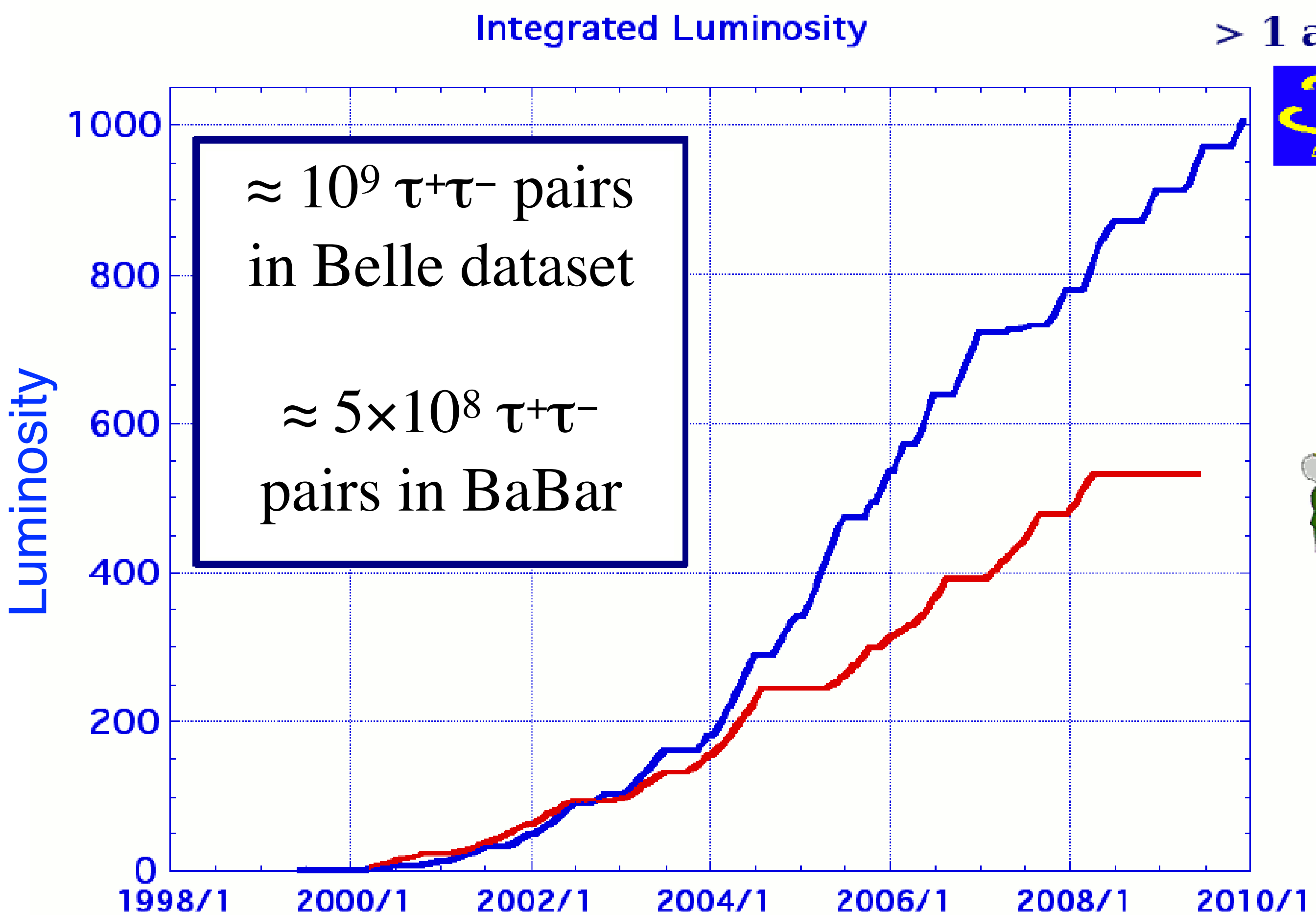


$$\sigma(e^+e^- \to W'W' \to l^+l^-l'^+l'^-) < (25 - 60)\ \text{ab}$$

Some of the smallest cross section ULs measured @ B-Factories

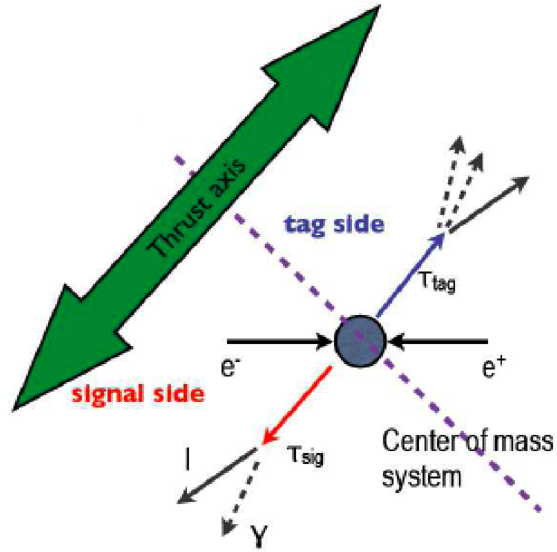
Tau Factories

$> 1\ ab^{-1}$!



Largest tau decay samples to date: high statistics searches for Lepton Flavor Violation in tau decays and other rare processes

LFV Search Strategy



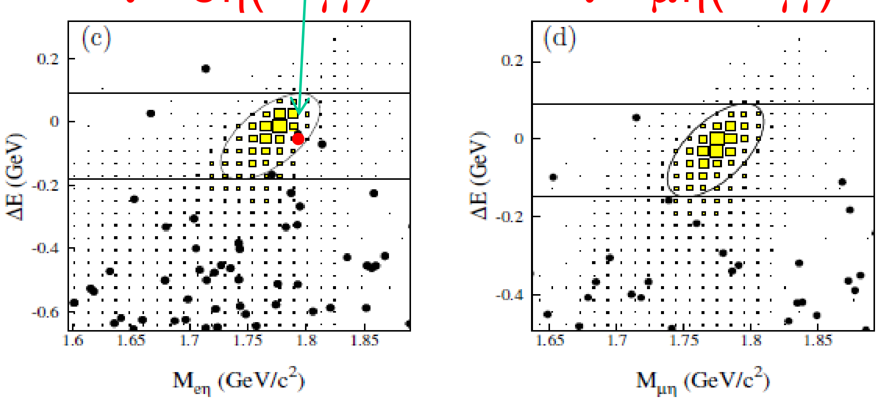
- Select a large clean sample of "tag" tau decays
  - Clean leptonic and hadronic tau decays: "1-prong" and "3-prong"
    - ☞ $\tau \to e\nu\nu$, $\tau \to \mu\nu\nu$, $\tau \to \pi\nu$, $\tau \to \rho\nu$, $\tau \to 3\pi\nu$
- Look for LFV decays of the "other" τ
  - Typically a fully-reconstructed final state
    - ☞ $\tau \to e\gamma$, $\tau \to \mu\gamma$, $\tau \to lll$, $\tau \to lh^0$
- Take advantage of kinematics (known beam energy):

$$\Delta E \equiv E^*_{rec} - E^*_{beam};$$

$$\Delta M_{ec} \equiv M_{rec} - m_\tau = \sqrt{\frac{E^{*\,2}_{beam}}{c^4} - \frac{|\vec{p}^{\,*}_{3l}|^2}{c^2}} - m_\tau$$

✓Very clean environment (nearly background-free in many modes)

Example: $\tau^+ \to l^+ \eta$



No excess

After event selection

Expected # of BG (0.0-1.4)events

- 1 event eη(→γγ)
- 0 events others

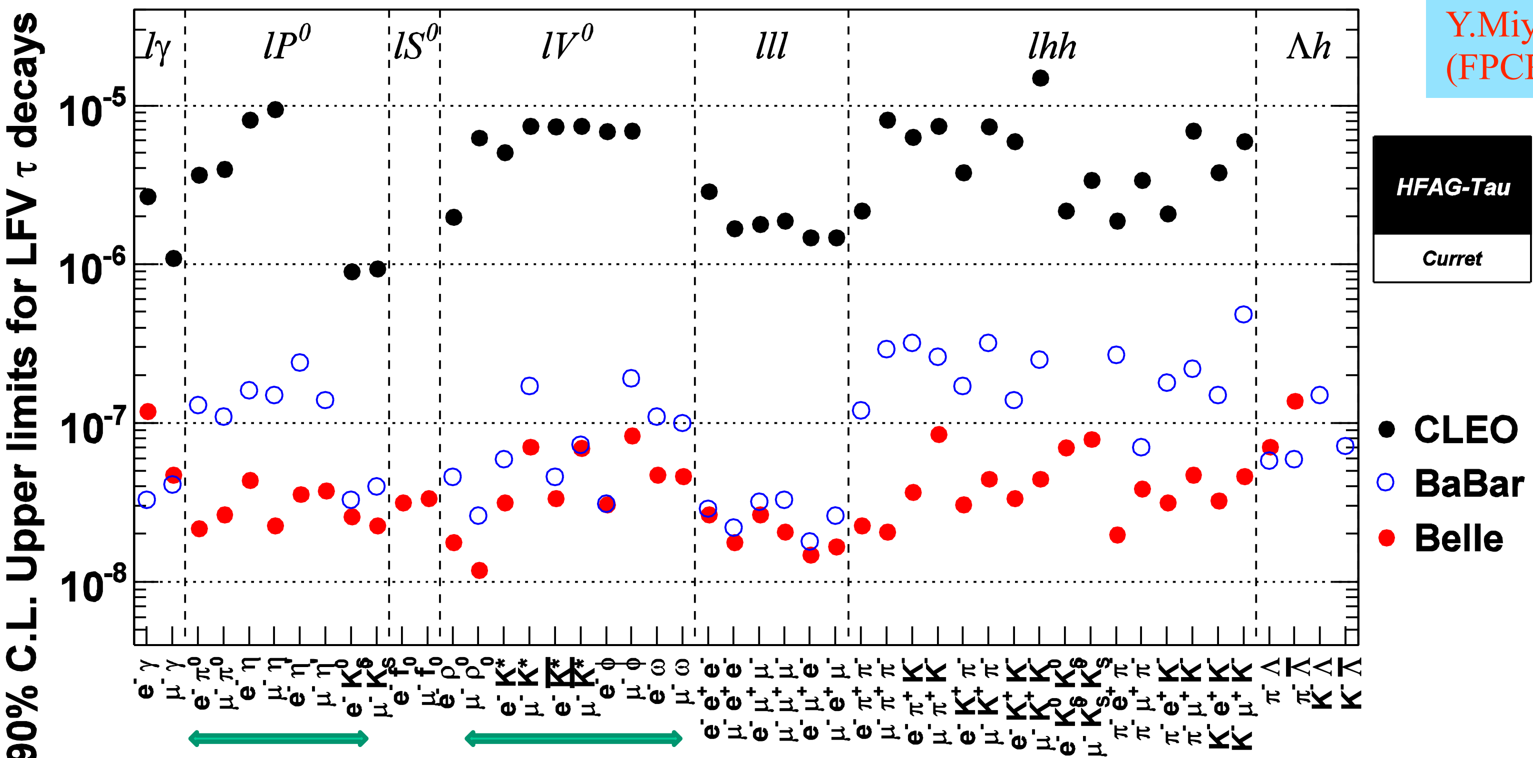
Br(τ→lP⁰)<(2.2-4.4)x10⁻⁸ @90%C.L.(preliminary)

Y.Miyazaki (FPCP 2011)

τ→	Eff.	N_{BG}^{exp}	UL(10^{-8})	τ→	Eff.	N_{BG}^{exp}	UL(10^{-8})
μη(→γγ)	8.2%	0.63±0.37	3.6	μη'(→ππη)	8.1%	$0.00^{+0.16}_{-0.00}$	10
μη(→πππ^0)	6.9%	0.23±0.23	8.6	μη' (→ρ^0γ)	6.2%	0.59±0.41	6.6
μη(comb.)			**2.3**	**μη' (comb.)**			**3.8**
eη(→γγ)	7.0%	0.66±0.38	8.2	eη' (→ππη)	7.3%	0.63±0.45	9.4
eη(→πππ^0)	6.3%	0.69±0.40	8.1	eη' (→ρ^0γ)	7.5%	0.29±0.29	6.8
eη(comb.)			**4.4**	**eη' (comb.)**			**3.6**
μπ^0(→γγ)	4.2%	0.64±0.32	**2.7**	**eπ^0(→γγ)**	4.7%	0.89±0.40	**2.2**

Summary of LFV in Tau Decays

Y.Miyazaki (FPCP'11)



New Belle results

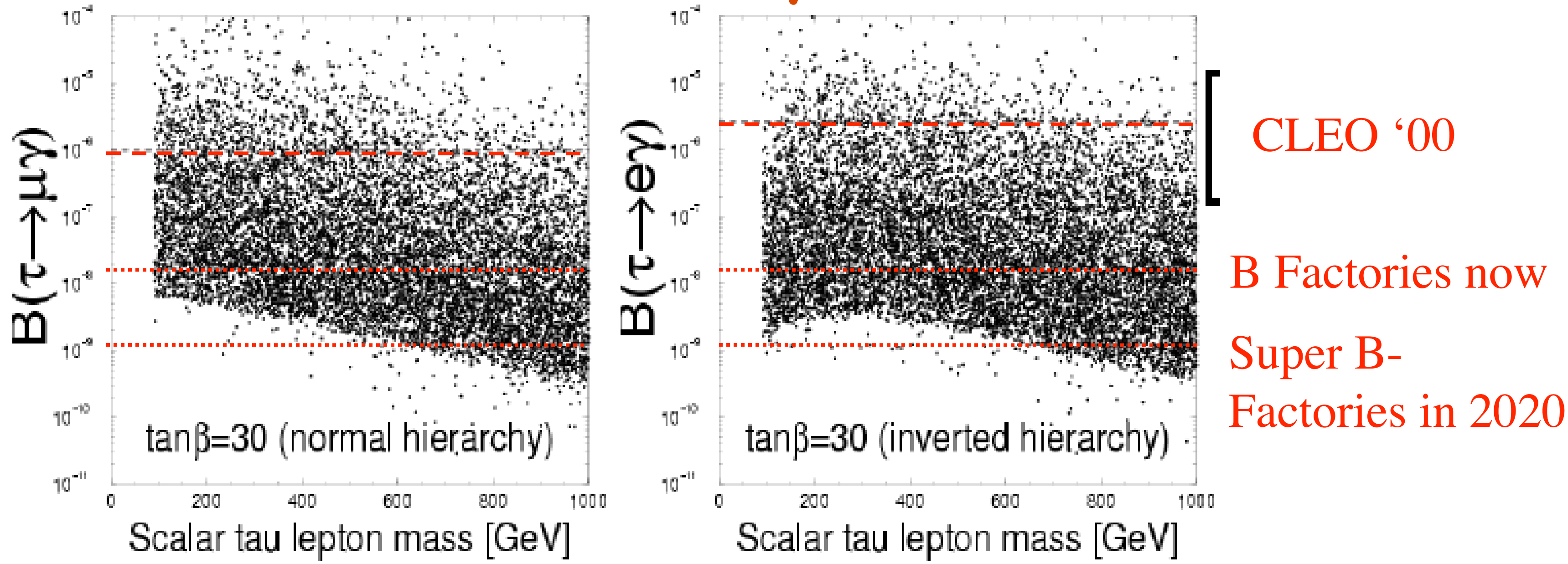
Also related: LFV in Upsilon decays:

Limits new (bblτ) contact terms @ 1.6-1.7 TeV

[BaBar: PRL104, 151802 (2010)]

	$\mathcal{B}$ (10^{-6})	UL (10^{-6})
$\mathcal{B}(\Upsilon(2S) \to e^{\pm}\tau^{\mp})$	$0.6^{+1.5+0.5}_{-1.4-0.6}$	< 3.2
$\mathcal{B}(\Upsilon(2S) \to \mu^{\pm}\tau^{\mp})$	$0.2^{+1.5+1.0}_{-1.3-1.2}$	< 3.3
$\mathcal{B}(\Upsilon(3S) \to e^{\pm}\tau^{\mp})$	$1.8^{+1.7+0.8}_{-1.4-0.7}$	< 4.2
$\mathcal{B}(\Upsilon(3S) \to \mu^{\pm}\tau^{\mp})$	$-0.8^{+1.5+1.4}_{-1.5-1.3}$	< 3.1

LFV and New Physics Models



Model examples:

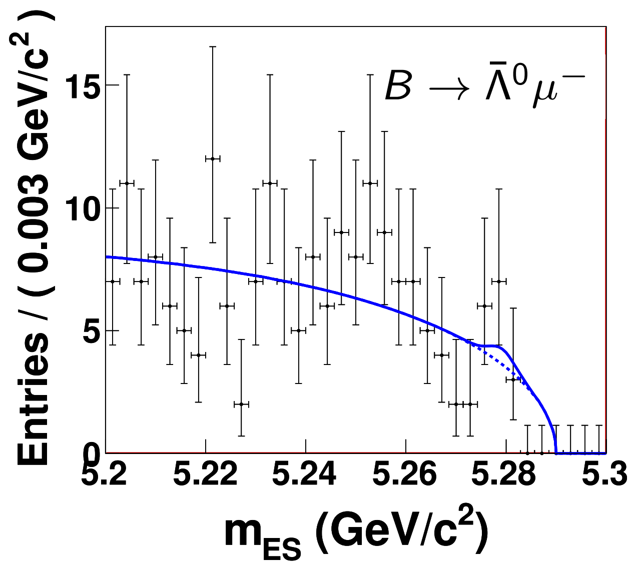
	$\mathcal{B}(\tau \to \ell\gamma)$	$\mathcal{B}(\tau \to \ell\ell\ell)$
SUSY Higgs (PLB549(2002)159, PLB566(2003)217)	10^{-10}	10^{-7}
SM+Heavy Majorana ν_R (PRD66(2002)034008)	10^{-9}	10^{-10}
Non-Universal Z' (PLB547(2002)252)	10^{-9}	10^{-8}
SUSY SO(10) (NPB649(2003)189, PRD68(2003)033012)	10^{-8}	10^{-10}
mSUGRA+seesaw (EPJC14(2000)319, PRD66(2002)115013)	10^{-7}	10^{-9}

Non-trivial constraints on high-mass physics from LFV searches

Baryon Number Violation in B Decays

- BNV and LFV are related in some new physics models (e.g. B-L conserving leptogenesis)
  - Newest BaBar search: $B \to \Lambda_{(c)} l$
  - No observation, but first measurement of these modes

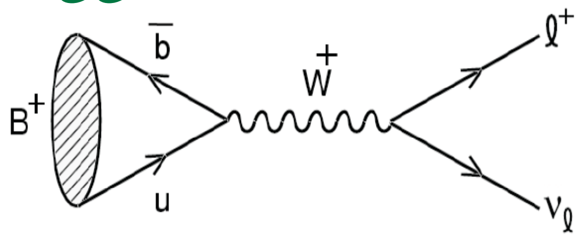
Decay mode	Upper limit
$B^0 \to \Lambda_c^+ \mu$	170×10^{-8}
$B^0 \to \Lambda_c^+ e$	500×10^{-8}
$B^- \to \Lambda^0 \mu$	6.0×10^{-8}
$B^- \to \Lambda^0 e$	8.2×10^{-8}
$B^- \to \bar{\Lambda}^0 \mu$	6.3×10^{-8}
$B^- \to \bar{\Lambda}^0 e$	3.1×10^{-8}



BaBar: PRD **83**, 091101 (2011)

Rare B Decays

- Powerful (indirect) probe of New Physics
  - Old smoking gun: $B^+ \to \tau^+\nu$, sensitive to charged Higgs



$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

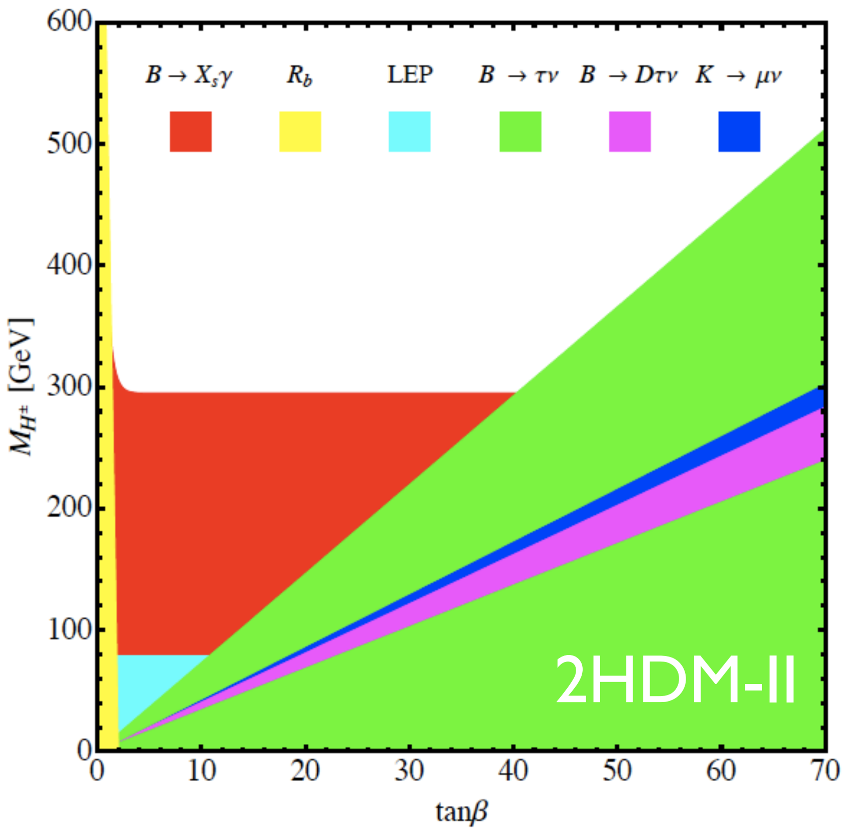
$$\mathcal{B}_{SM}(B^+ \to \tau^+\nu) = (0.80 \pm 0.20) \times 10^{-4}$$

(using f_B=190±13 MeV and V_{ub}=(3.5±0.4)×10^{-3}

Charged Higgs contribution:

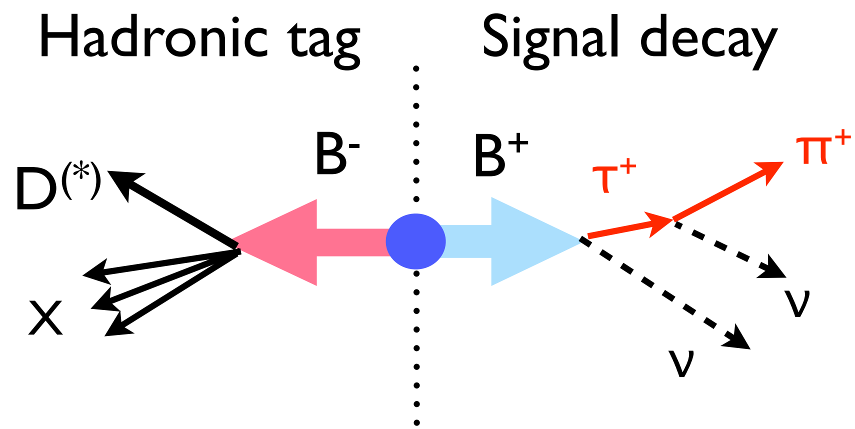
$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\mathsf{SM}} \times r_H$$

$$r_H = (1 - \frac{m_B^2}{m_H^2} \tan^2\beta)^2$$



$B^+ \to \tau^+ \nu$: Experimental Technique

- Reconstruct "the tag B" completely
  - ☞ efficiency ~0.2%
- Reconstruct leptonic and hadronic τ decay modes (~70% BF)
- Key discriminant: unassociated neutral energy E_{extra}
  - ❑ Look for excess of events @ E_{extra}~0

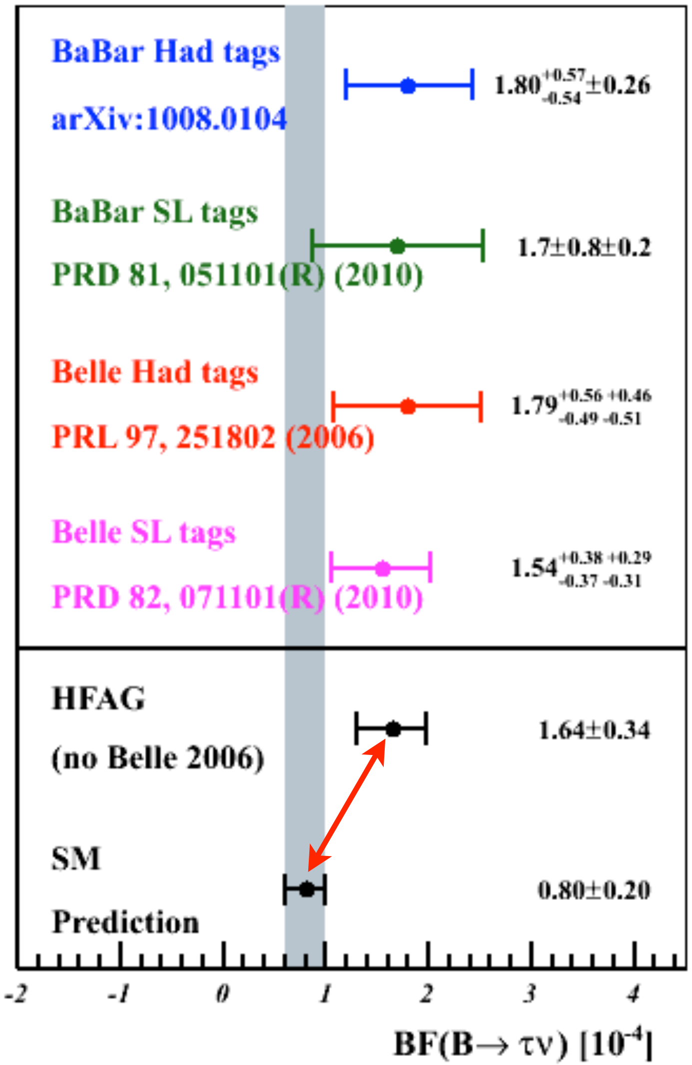


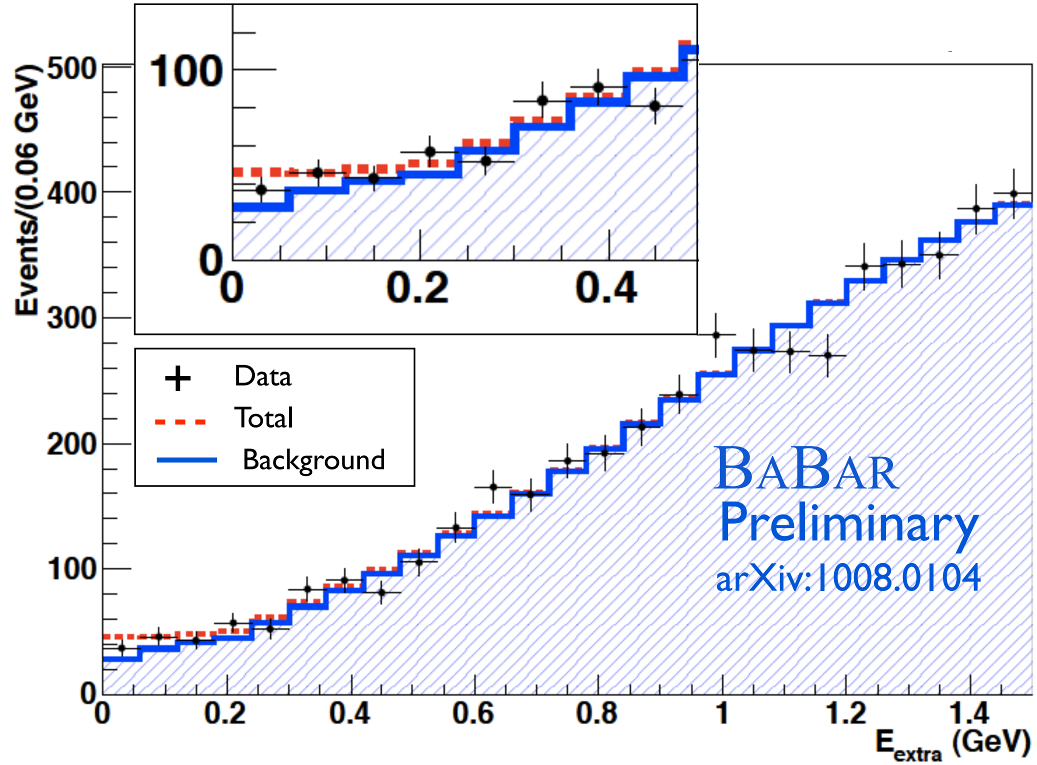
$$B^- \to D^{(*)0} X^-$$

$$\begin{aligned} D^0 &\to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^-\pi^+, \\ & \quad K^0_s\pi^0, K^0_s\pi^+\pi^-, K^0_s\pi^+\pi^-\pi^0 \\ & \quad K^+K^-, \pi^+\pi^- \\ D^{*0} &\to D^0\pi^0, D^0\gamma \end{aligned}$$

$$X = n\pi^{\pm} + mK + p\pi^0 + qK^0$$
$$n + m \leq 5, \quad m, p, q \leq 2$$

$B^+ \rightarrow \tau^+ \nu$: Results





~2σ difference wrt SM and ~3σ difference wrt CKM fits

Summary

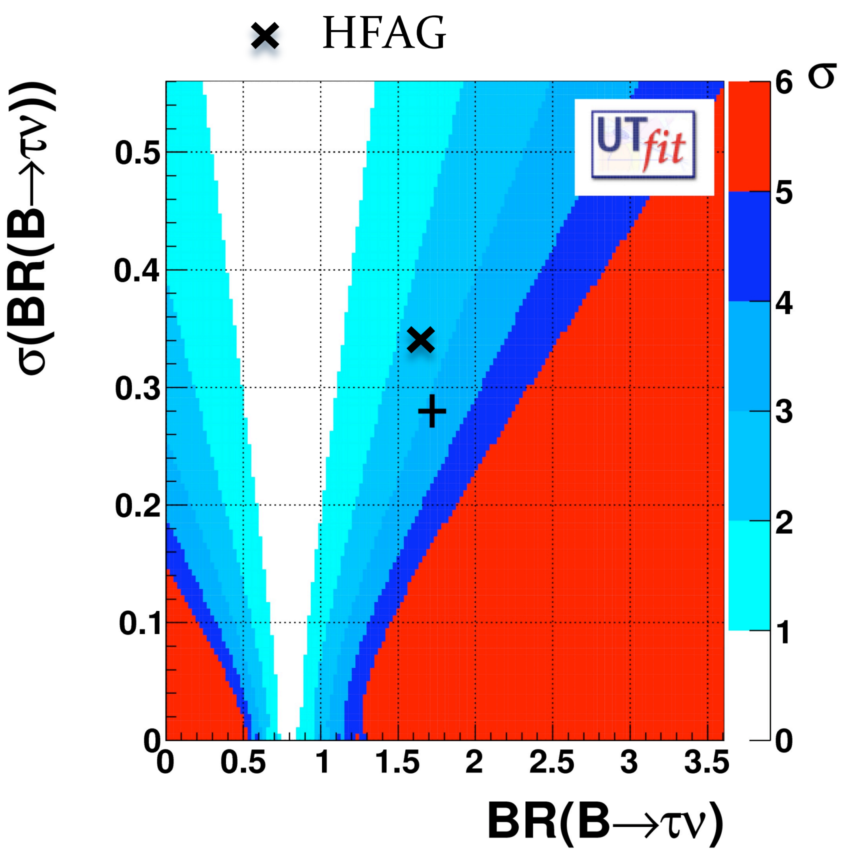
- B Factories continue to provide significant constraints on new physics models
  - Direct searches: unique sensitivity to low-mass new physics in high-statistics datasets
  - Indirect constraints: rare and forbidden decays set constraints on new physics in TeV scale, complementary to the LHC
- Super B Factories will increase statistics by ~100
  - Combined with LHC discoveries, these measurements provide unique information on the dynamics and flavor structure of new physics

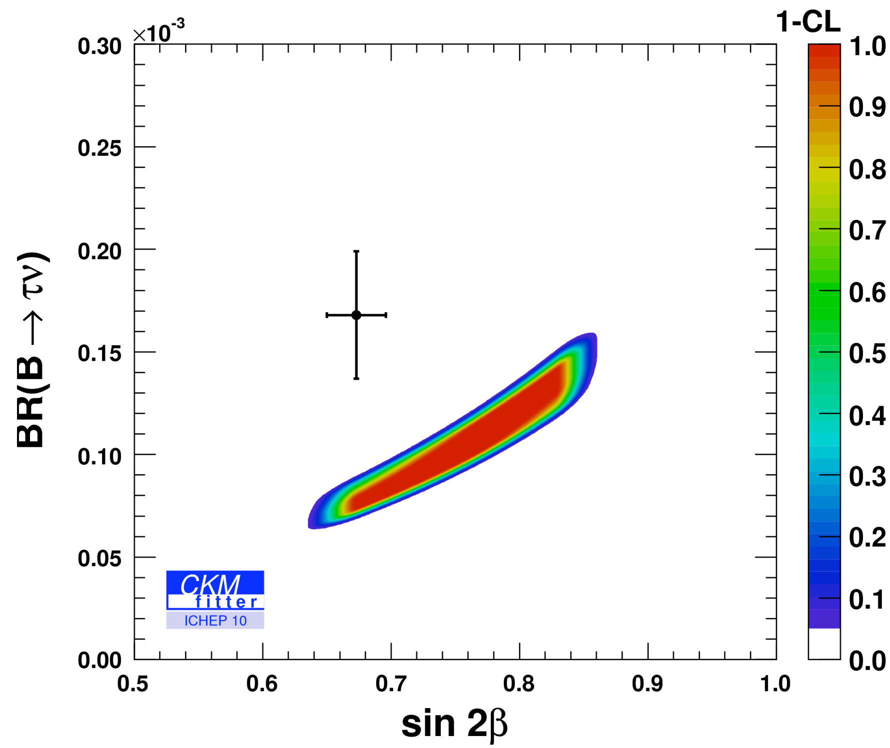
Backup

$B^+ \to \tau^+ \nu$ vs CKM Fits

www.utfit.org

ckmfitter.in2p3.fr





G. De Nardo, FPCP 2011