Rencontres de Moriond - EW Interactions and Unified Theories
La Thuile, March 14-21, 2015

Latest results from B factories

LPNHE PARIS

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On behalf of the **BELLE *and BABAR*** collaborations

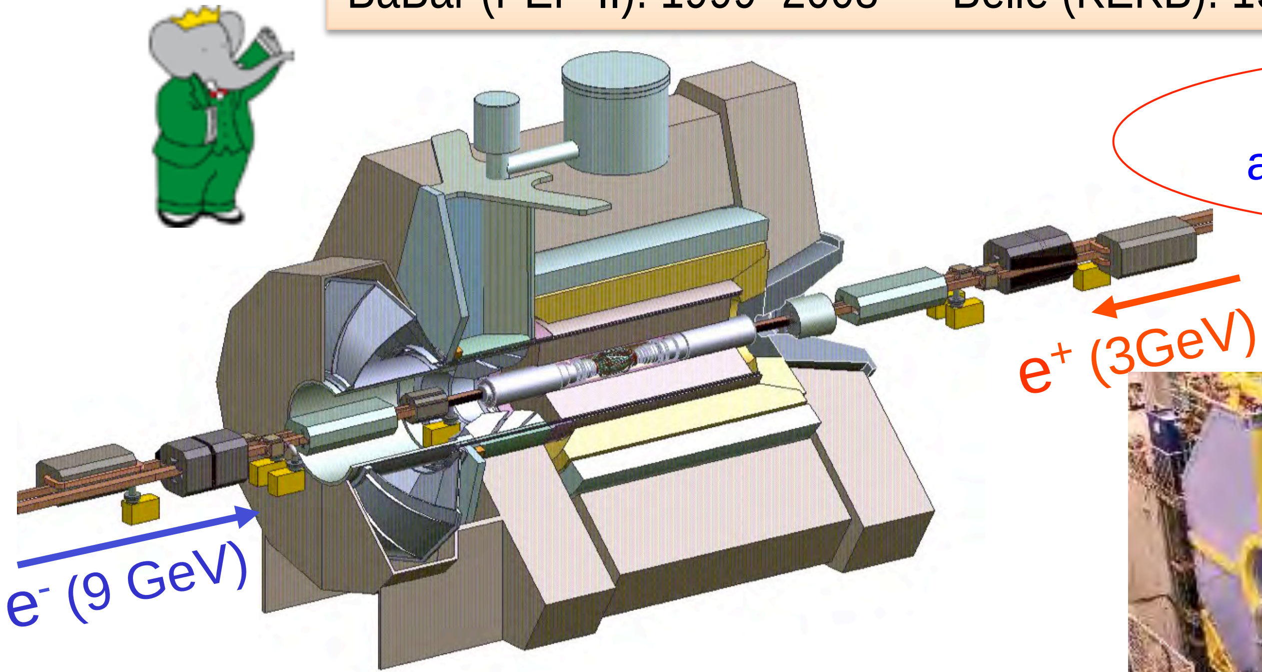
BELLE

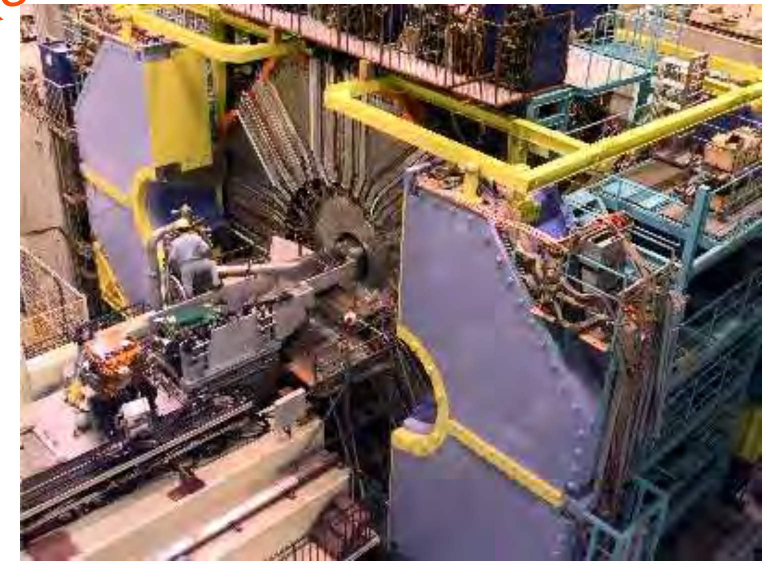
BABAR

The B factories: BaBar and Belle

BaBar (PEP-II): 1999–2008 Belle (KEKB): 1999-2010

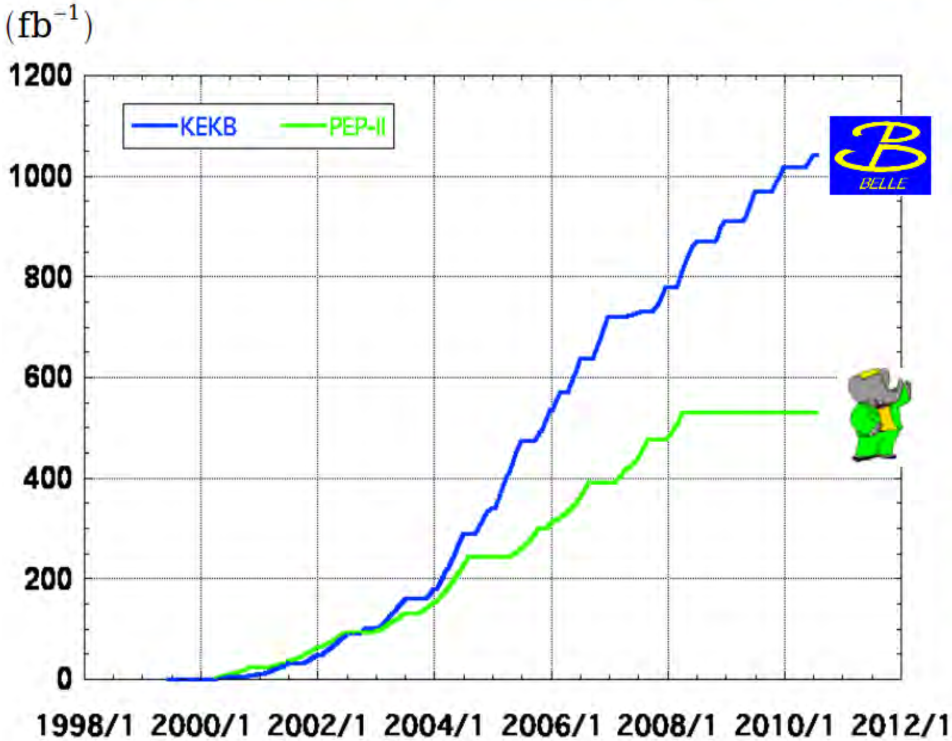
PEP-II and KEKB:
asymmetric e^+e^- beams





BaBar and Belle are well suited for the measurements presented here : hermetic detectors, clean environment, excellent PID, good K_S and π^0 reconstruction

The BaBar and Belle datasets



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan

~ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

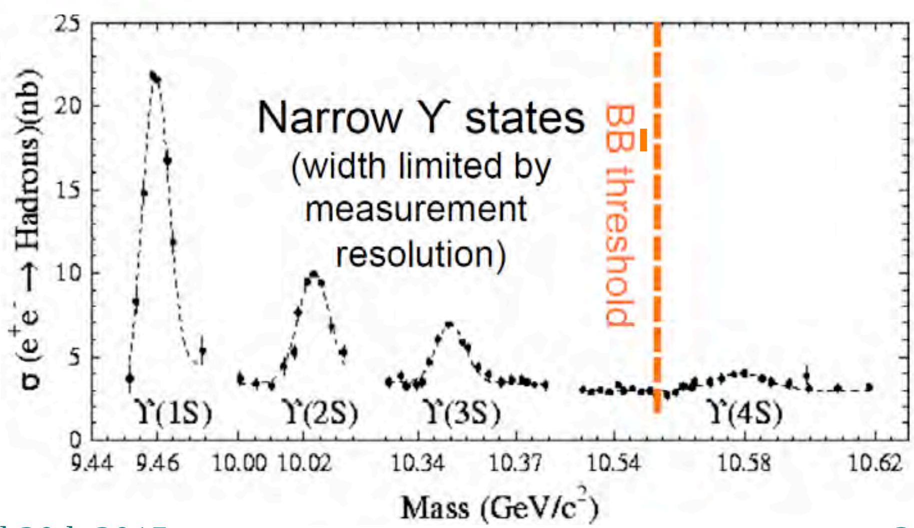
$\Upsilon(4S)$: 433 fb^{-1}

$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

~ 54 fb^{-1}



Introduction and overview

- Search for long-lived particles
- Search for light Higgs resonance
- CP asymmetry in B^0-$\bar{B}^0$ mixing

- Branching fraction of $\bar{B}\rightarrow X_s\,\gamma$
- Branching fraction of $B\rightarrow\tau\nu$
- Search for $B_s^0\rightarrow\gamma\gamma$ and Branching fraction of $B_s^0\rightarrow\phi\gamma$

Two strategies to probe new physics

- Direct searches of new low mass states (~ few GeV/c^2)
- New physics (NP) could significantly alter BF and CP asymmetries
  $\Rightarrow$ perform **precision measurements**, confront standard model (SM) predictions

Both strategies constrain the parameter space of new physics models

Long-lived particles

Search for Long-Lived Particles in e^+e^- Collisions

arXiv:1502.02580 [hep-ex], Submitted to Phys.Rev.Lett

Introduction and motivations

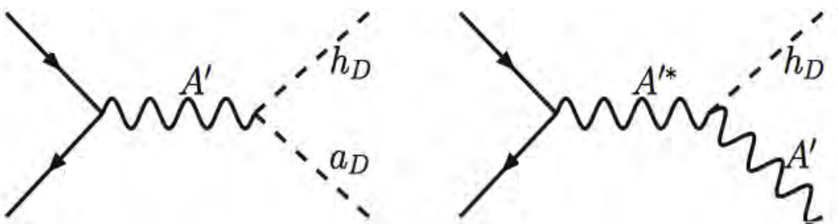
Long-lived

- Several new physics models include long-lived particles

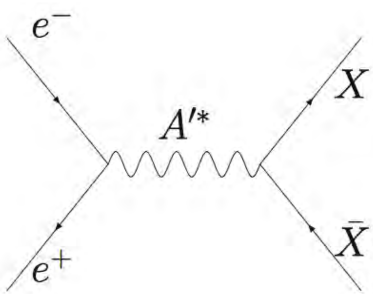
Vector portal

→ Produce a dark sector photon ***A'*** via kinetic mixing with the SM photon $\varepsilon F^{\mu\nu}F'_{\mu\nu}$

→ Decay into dark particles (long-lived if lightest)



Schuster, Toro, Yavin, 0910.1602

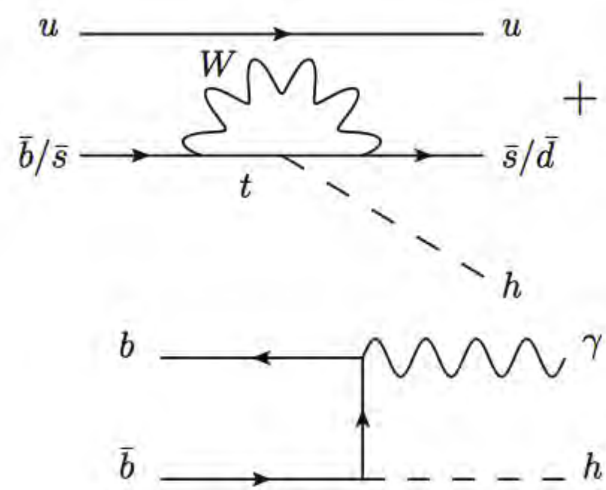


Essig, Schuster, Toro, 0903.3941

Higgs portal

→ Light scalar ***h*** mixes with the SM Higgs

→ Large coupling to heavy quarks (production and decay)

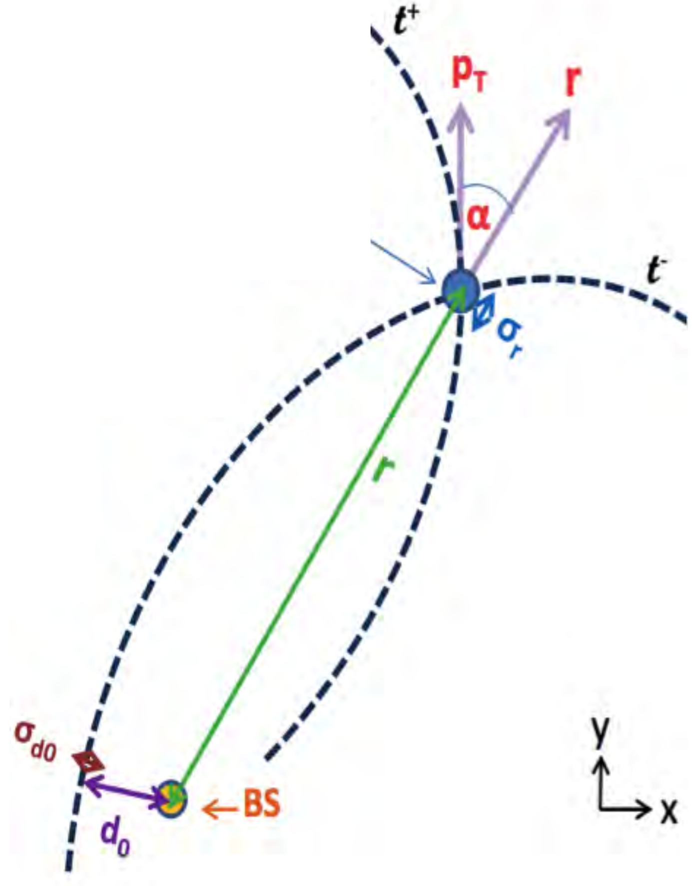


Clarke, Foot, Volkas , 1310.8042

- Searches exist for $m \ll$ GeV and m ~ multi GeV, not so much for m ~ GeV (well suited for B factories)
- No generic search exists using long lifetime as main signature

Analysis (I)

- Using the full Υ(2S), Υ(3S) and Υ(4S) samples (489 fb^{-1})
- Form vertex from track pairs, loosely selected as e^+e^-, $\mu^+\mu^-$, $e^\pm\mu^\mp$, $\pi^+\pi^-$, K^+K^-, $\pi^\pm K^\mp$ (full reconstruction)
- Require
  - Track $d_0 > 3\sigma_{d0}$
  - Vertex $\chi^2 < 10$
  - r >1 cm, $\sigma_r < 0.2$ cm
  - No hits before the vertex
  - $\alpha < 0.01$rad
- Veto K_S and Λ masses, reject vertices on beam-pipe and bulk detector elements
- Max. efficiency (47%) for $m \sim 1$GeV, cτ ~ 3cm
- Main background (bkg): random track crossing and detector interactions

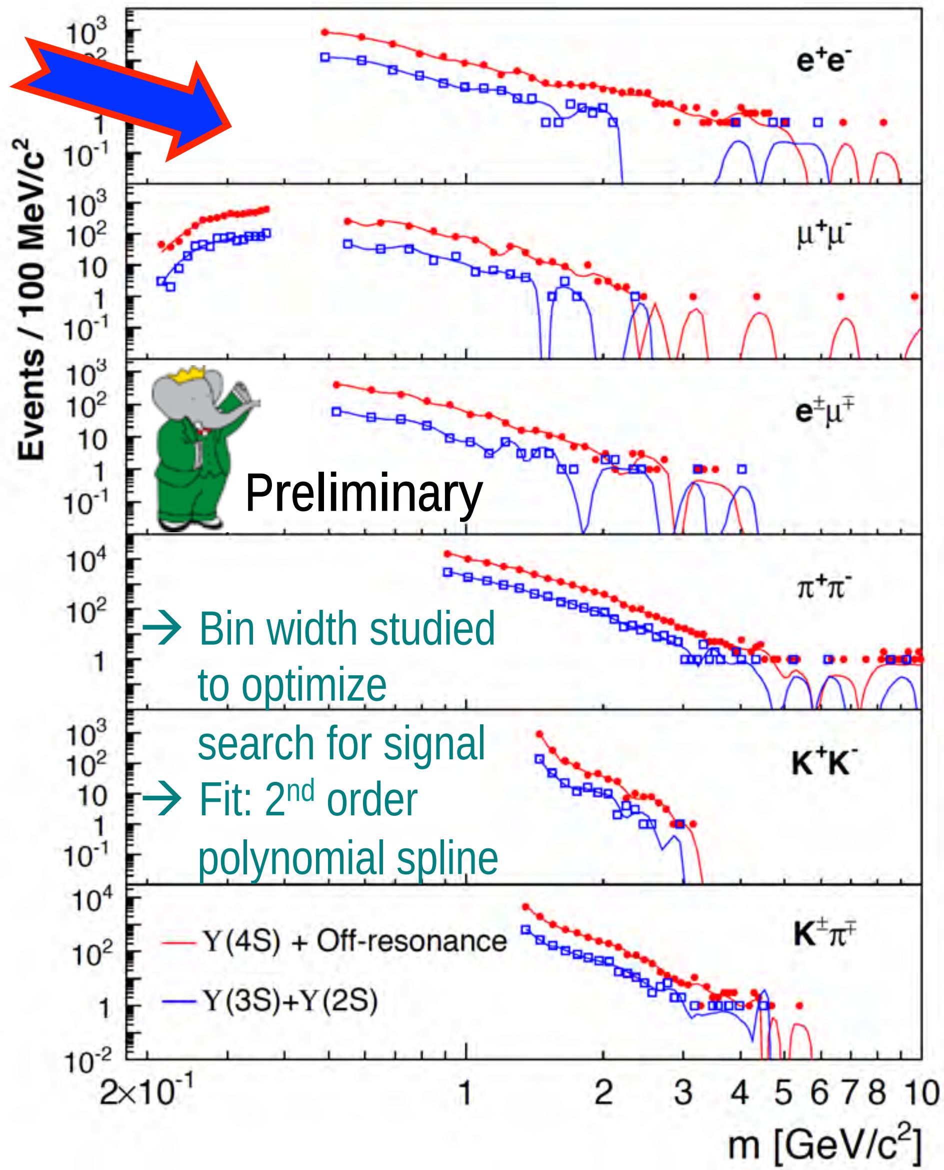


Analysis (II)

- First fit m distribution (data) assuming background only → background shape
- Scan for a signal mass peak on top of the background in steps of 2 MeV
- For each scan point, determine signal significance:

$$S = \mathrm{sign}[N(s)]\sqrt{2\log\left(\frac{L(s+b)}{L(b)}\right)}$$

↑ Ratio of maximum likelihood values for fits with signal+ background and background-only hypotheses

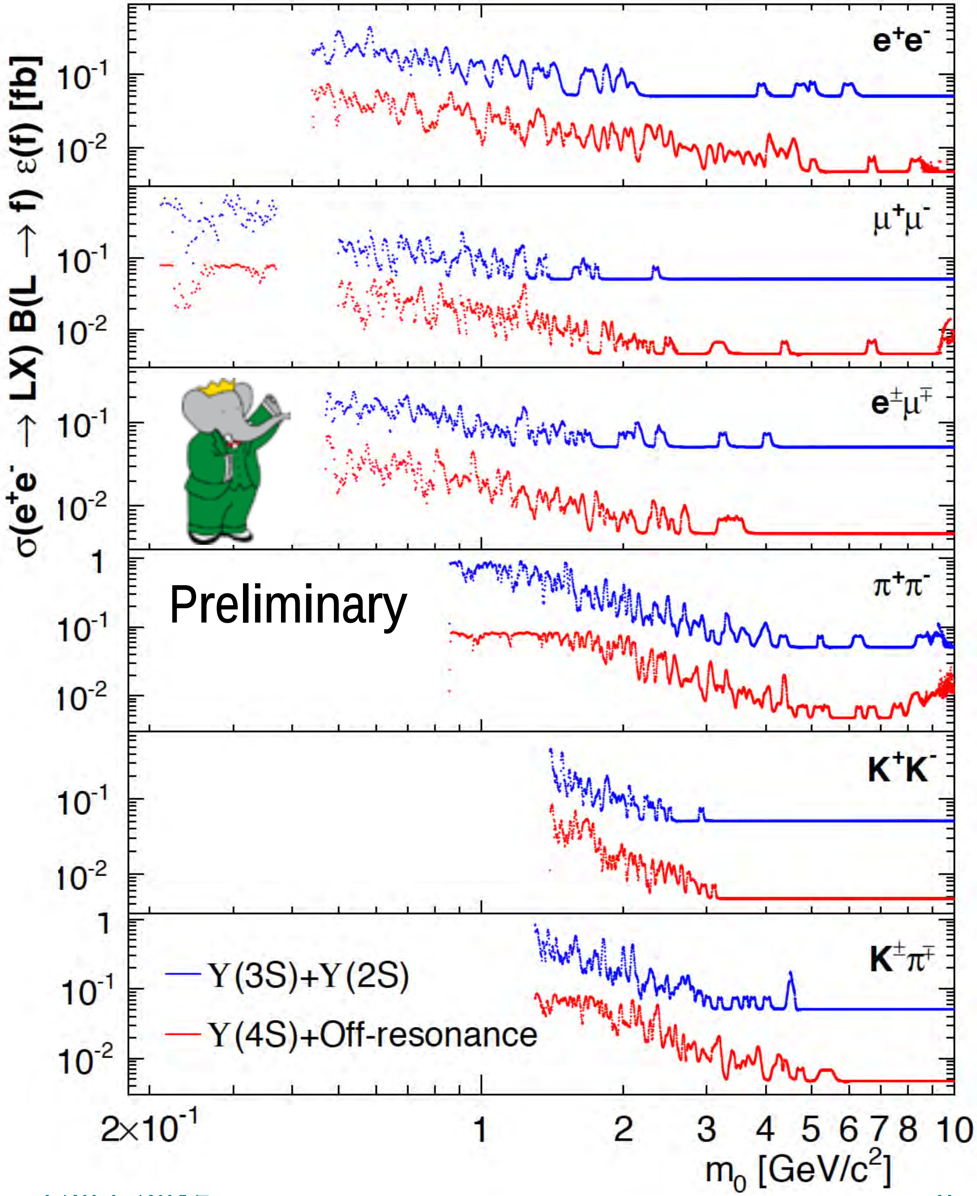


Results

Model-independent upper limits (90% CL) on σBε

Long-lived

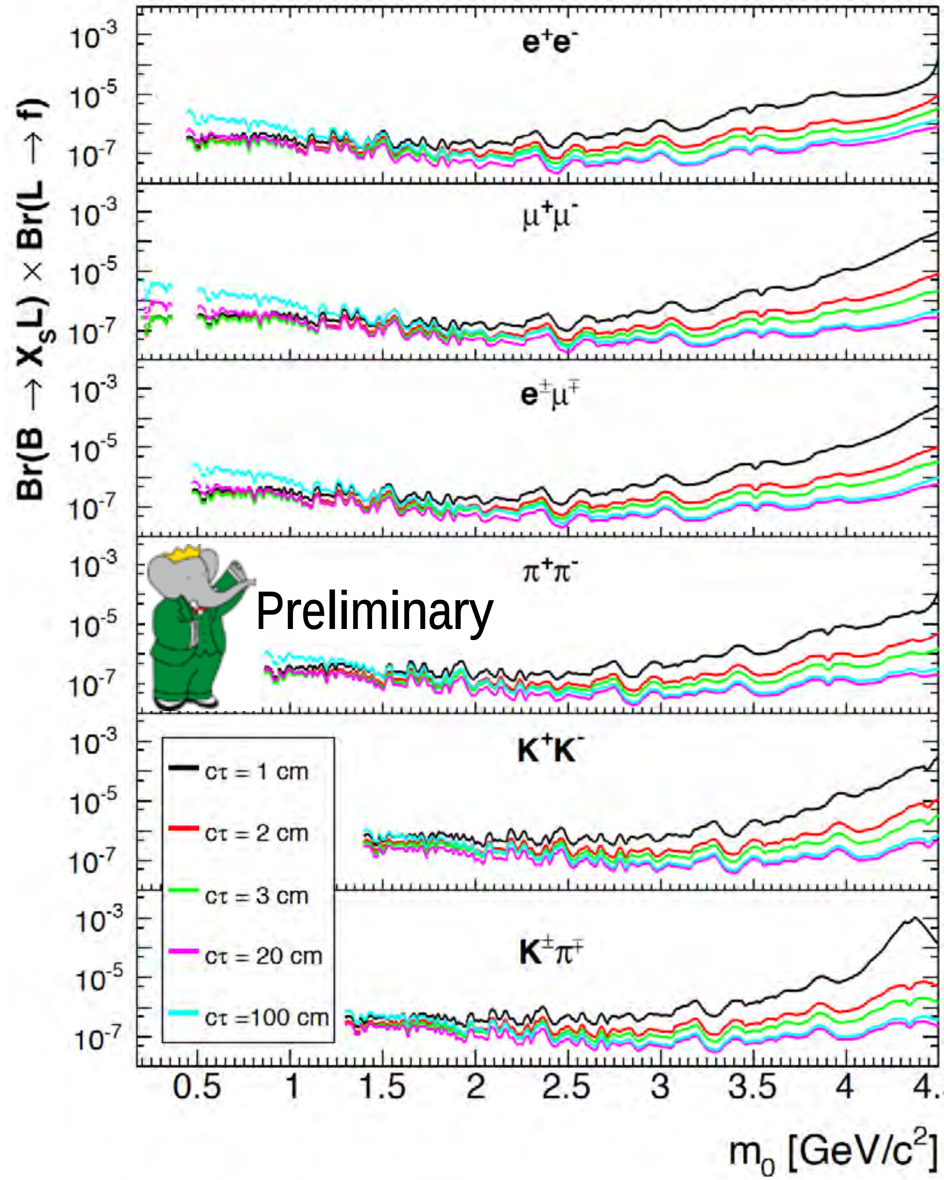
- Highest significance points:
  - $m_{\mu\mu}$ = 0.212 GeV; S=4.7
  - $m_{\mu\mu}$ = 1.24 GeV;   S=4.2
- Calculating look-elsewhere effect (toy MC) and considering resemblance to γ conversions, **there is no evidence for signal.**
- Supplementary material includes detailed efficiency tables as a function of mass, p_T and cτ to enable applying the results to any specific model.



Results

Higgs-portal upper limits for $B \rightarrow X_S L$

- Limits obtained for various L lifetimes hypotheses
- These limits exclude significant regions of the parameter space of the inflaton model from Bezrukov and Gobunov [JHEP 1307, 140 (2013)]



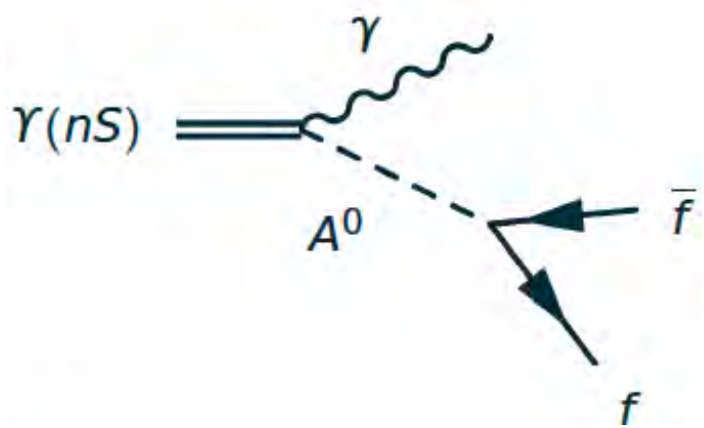
Light Higgs

Search for light Higgs resonance in radiative decays of the Y(1S) with a charm tag

arXiv:1502.06019 [hep-ex], Submitted to PRD-RC

Introduction and motivations

- Several new physics models predict a light CP-odd Higgs boson A^0
  - → e.g. non-minimal supersymmetry [Phys. Rep. 496, 1 (2010)]
  - → $A^0 = A_{MSSM} \cos\theta_A + A_{singlet} \sin\theta_A$
- Searches of light A^0 are possible in B factories via:



- Coupling of A^0 to fermion pairs:
  - up type: $\sim m_f \cos\theta_A / \tan\beta$
  - down type: $\sim m_f \cos\theta_A \tan\beta$
    - → $\tau^+\tau^-$ decays dominate for large tanβ (~20)
    - → $c\bar{c}$ decays dominate for small tanβ (~1)
- BaBar already provided limits on a variety of final states
- This analysis studies: $\mathcal{B}\left(\Upsilon(1S) \to \gamma A^0\right) \cdot \mathcal{B}\left(A^0 \to c\bar{c}\right)$

  With the decays $\Upsilon(2S) \to \pi^+\pi^- \Upsilon(1S)$, $\Upsilon(1S) \to \gamma A^0$, $A^0 \to c\bar{c}$

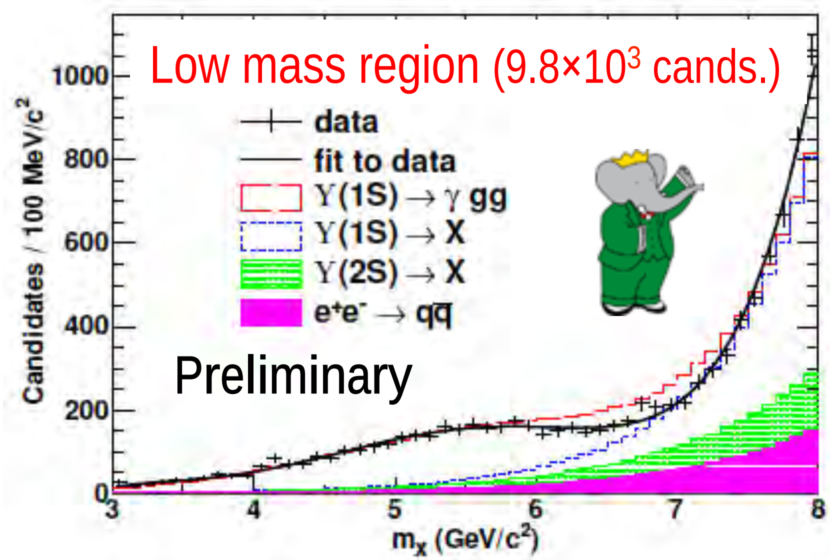
Pion tags give a cleaner Υ(1S) sample

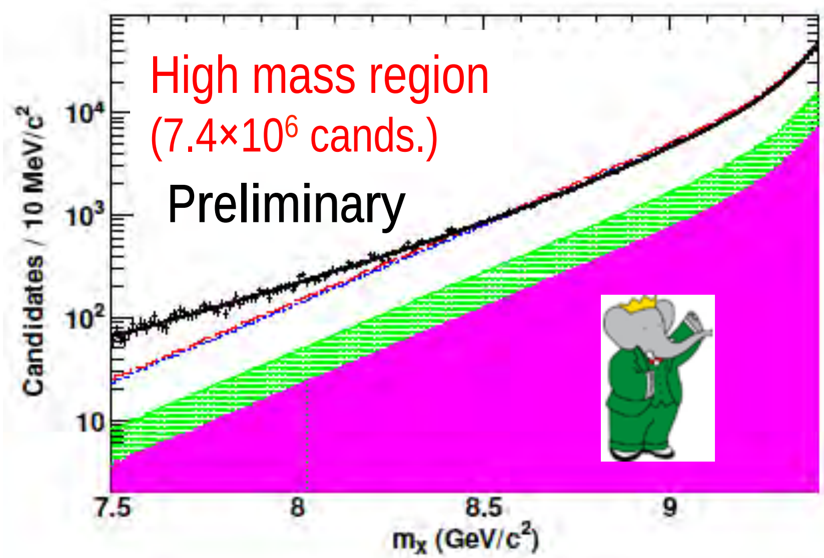
Analysis

- Sample:
  - (98.3±0.9)×10^6 Υ(2S)
  - (17.5±0.3)×10^6 Υ(2S) → $\pi^+\pi^-$ Υ(1S)
- Require events with γ, $\pi^+\pi^-$ and D$^{(*)}$ (in 5 decay chains)
- Get A^0 mass from:

$$m_X^2 = (P_{e^+e^-} - P_{\pi^+\pi^-} - P_\gamma)^2$$

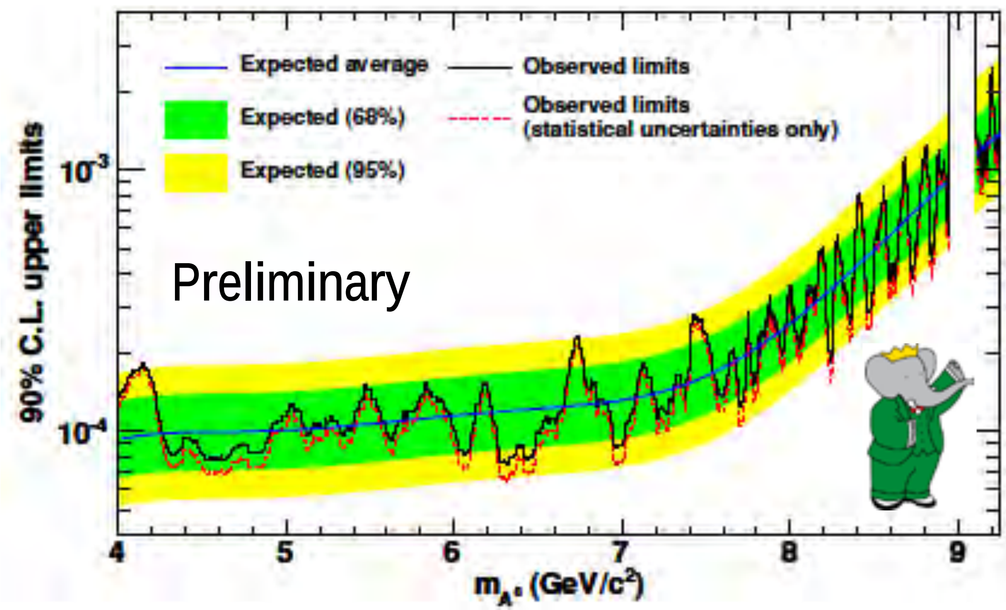
- Split mass spectrum in two regions:
  - m_X∊[4.00, 8.00] GeV/c^2 (hard γ, low bkg)
  - m_X∊[7.50, 9.25] GeV/c^2 (soft γ, high bkg)
- Use 10 Boosted Decision Tree classifiers (2 regions × 5 D$^{(*)}$ decays) for selection
- Search for signal by scan of m_X peaks on smooth bkg, every 10 (2) MeV in low (high) mass reg.
- Obtain Upper limits at 90% CL





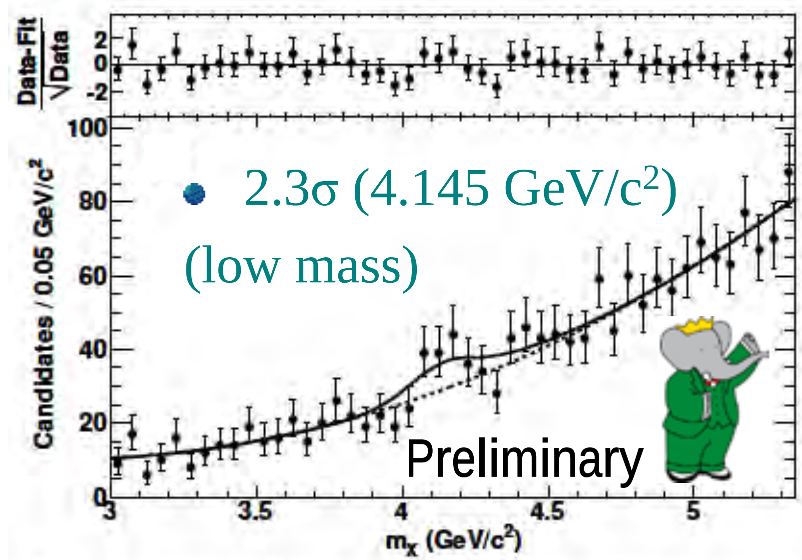
Results

- No significant signal observed
- Expected/observed upper limits at 90% CL on $\mathcal{B}\left(\Upsilon(1S) \to \gamma A^0\right) \cdot \mathcal{B}\left(A^0 \to c\bar{c}\right)$

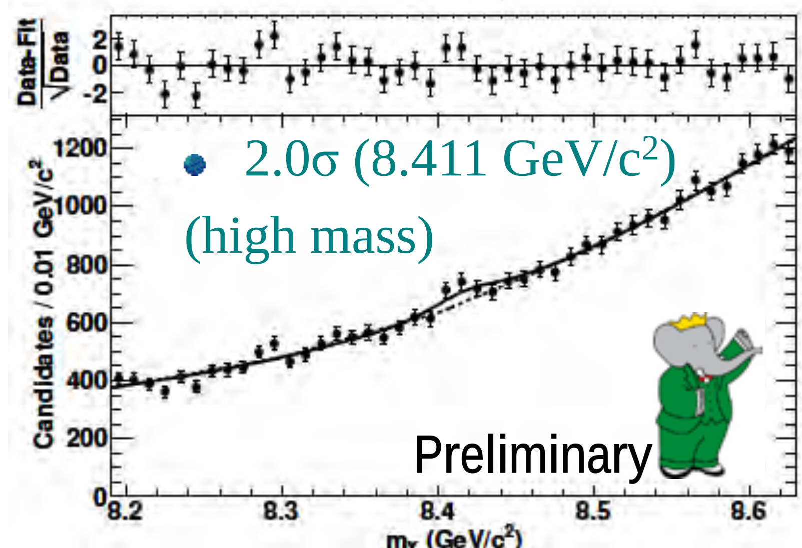


Range: 7.4×10^{-5} to 2.4×10^{-3}

- Highest local significances:



- 2.3σ (4.145 GeV/c^2) (low mass)



- 2.0σ (8.411 GeV/c^2) (high mass)

$A_{CP}(B^0)$

(In brief)

Study of CP Asymmetry in B^0 - $\bar{B}^0$ Mixing with Inclusive Dilepton events

PRL 114, 081801 (2015)

With the full Y(4S) sample (471×10^6 $B\bar{B}$ pairs)

Introduction and motivations

$A_{CP}(B^0)$

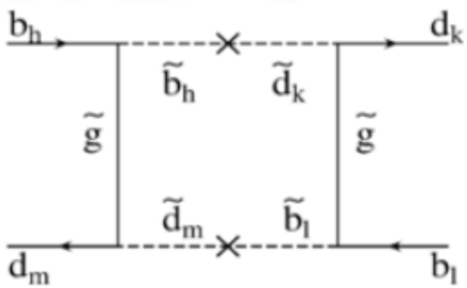
- CP violation in B^0 - $\overline{B}^0$ mixing allowed only at tiny level by the SM (~10^{-4})
- Time dependent CP (or T) asymmetry:

$$A_{CP} = \frac{\mathcal{P}(\overline{B}^0 \to B^0)(t) - \mathcal{P}(B^0 \to \overline{B}^0)(t)}{\mathcal{P}(\overline{B}^0 \to B^0)(t) + \mathcal{P}(B^0 \to \overline{B}^0)(t)} = \frac{1-|q/p|^4}{1+|q/p|^4} \simeq 2(1-|q/p|)$$

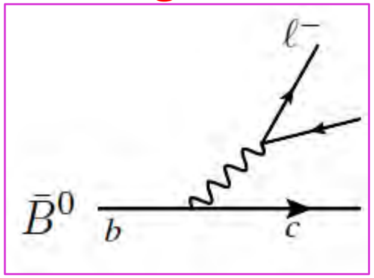
(the eigenstates of the neutral B system $|B_{L/H}\rangle = \frac{1}{\sqrt{p^2+q^2}}(p|B^0\rangle \pm q|\overline{B}^0\rangle)$)

- SM prediction is below the present experimental sensitivity
- The asymmetry could be altered by new physics effects

  ⇒ measurement of non-zero value would indicate the contribution of new physics



- This analysis exploits events with two charged leptons from semileptonic decays to probe oscillation probability. Both leptons have the same charge ⇒ mixing:
  - $\ell^+\ell^+$: $\overline{B}^0 \to B^0$ occurs
  - $\ell^-\ell^-$: $B^0 \to \overline{B}^0$ occurs
  - $\ell^+\ell^-$: no mixing



Analysis and results

$A_{CP}(B^0)$

- Use dilepton samples $\ell_1\ell_2$: (ee, eμ, μe, μμ) with same and opposite signs
- Perform a χ^2 fit of time-integrated signal yields:

detector efficiency charge asymmetries — effective mixing probability — $N(B^+B^-)/N(B^0\bar{B}^0)$

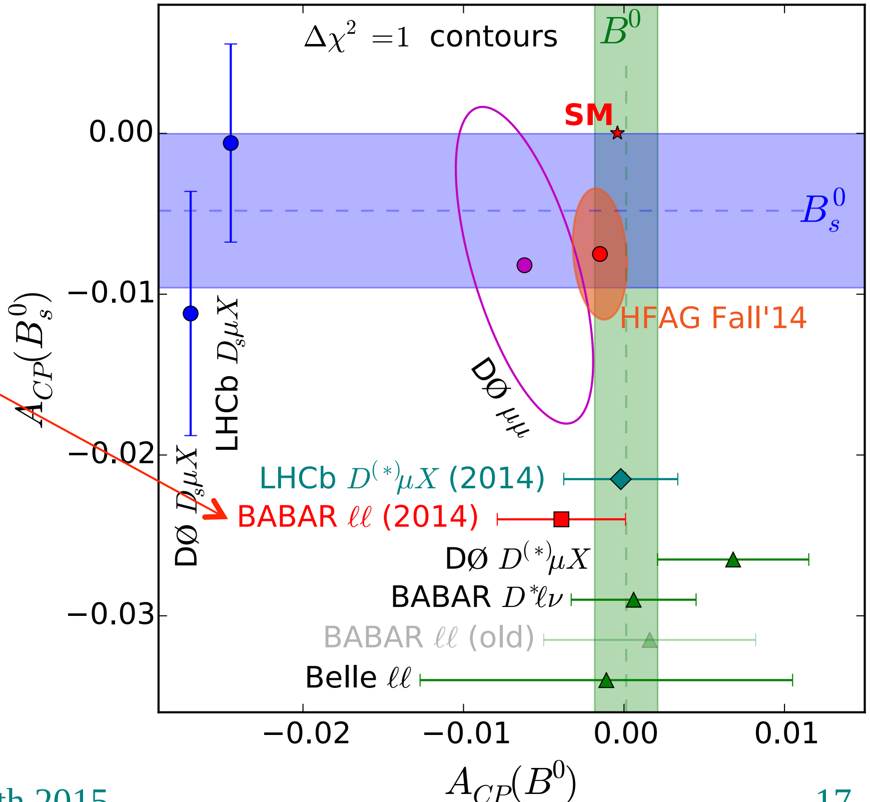
$$N^{\pm\pm}_{\ell_1\ell_2} = \frac{1}{2}N^0_{\ell_1\ell_2}(1 \pm a_{\ell_1} \pm a_{\ell_2} \pm A_{CP})\chi_d^{\ell_1\ell_2},$$

$$N^{\pm\mp}_{\ell_1\ell_2} = \frac{1}{2}N^0_{\ell_1\ell_2}(1 \pm a_{\ell_1} \mp a_{\ell_2})(1 - \chi_d^{\ell_1\ell_2} + r_B)$$

- Extract:

$$A_{CP} = (-3.9 \pm 3.5 \pm 1.9) \times 10^{-3}$$

- Result (one of the most precise) consistent with the Standard Model

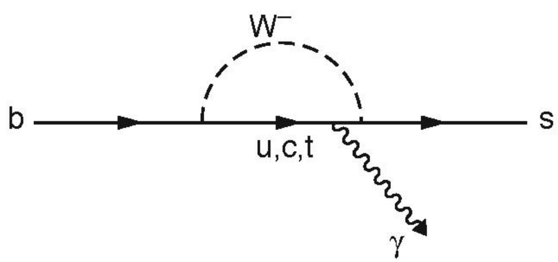


BF($B \to X_s \gamma$)

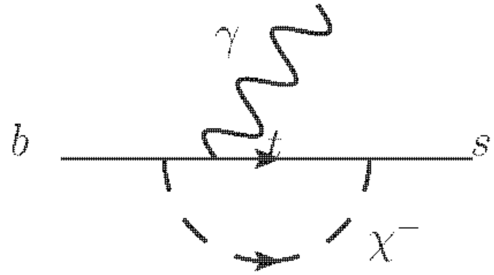
Measurement of the $\bar{B} \to X_s \gamma$ Branching Fraction with a sum of Exclusive Decays

PRD 91, 052004 (2015)

With the full Belle Υ(4S) sample (772×10^6 $B\bar{B}$ pairs)



SM process (FCNC)
→ Well described theoretically



Example for NP scenario
→ Probing such contributions

Analysis (I)

$B \to X_s \gamma$

- X_s = sum of **38** exclusive states

  $M_{X_s} \in [0.6, 2.8]$ GeV/c^2

  - 1 or 3 kaons, up to 1 K_S ($\to \pi^+\pi^-$)
  - up to 4 pions, up to 2 π^0
  - up to 1 η

  Represents ~70% of the inclusive in M_{X_s} range

  → inferring rates of K_L modes

Extrapolation of missing modes

Calibration of X_s hadronisation
→ Tune Pythia by data-MC comparisons
→ Assign systematics by varying the PYTHIA parameters and relative contributions from different modes

- $E^*_\gamma > 1.9$ GeV

- Backgrounds and their suppression:
  - Continuum $e^+e^- \to q\bar{q}$ ($q = u, d, s, c$)

    → suppressed using Neural Network (topological and kinematic variables)
  - Peaking background from $B \to D$ decays (e.g. $B \to D^{(*)}$ ($\to K\pi\pi$) ρ^+ ($\to \pi^+\pi^0$))

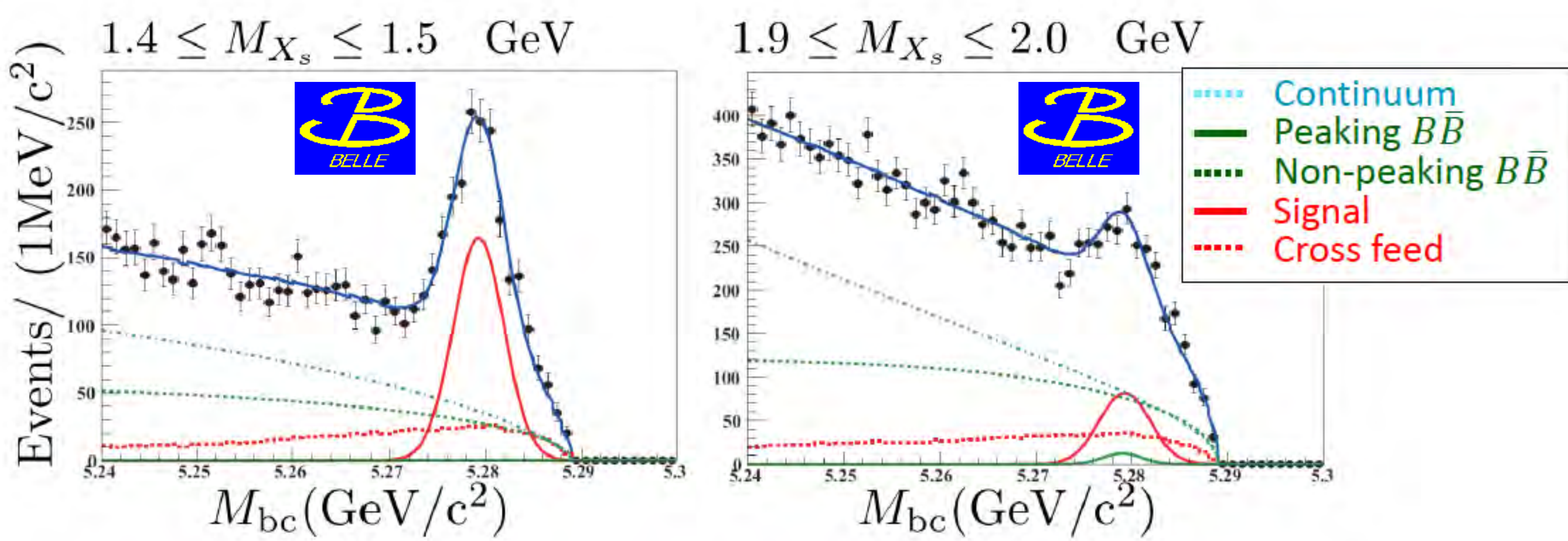
    → veto D mass

Analysis (II)

- Extraction of signal yields by maximum likelihood fit to M_{bc} in 19 M_{Xs} bins
  → to minimize dependence on photon spectrum

$$M_{bc} \equiv \sqrt{E_{\rm beam}^2 - |\vec{p}_B|^2}$$

Signal peaks at m_B



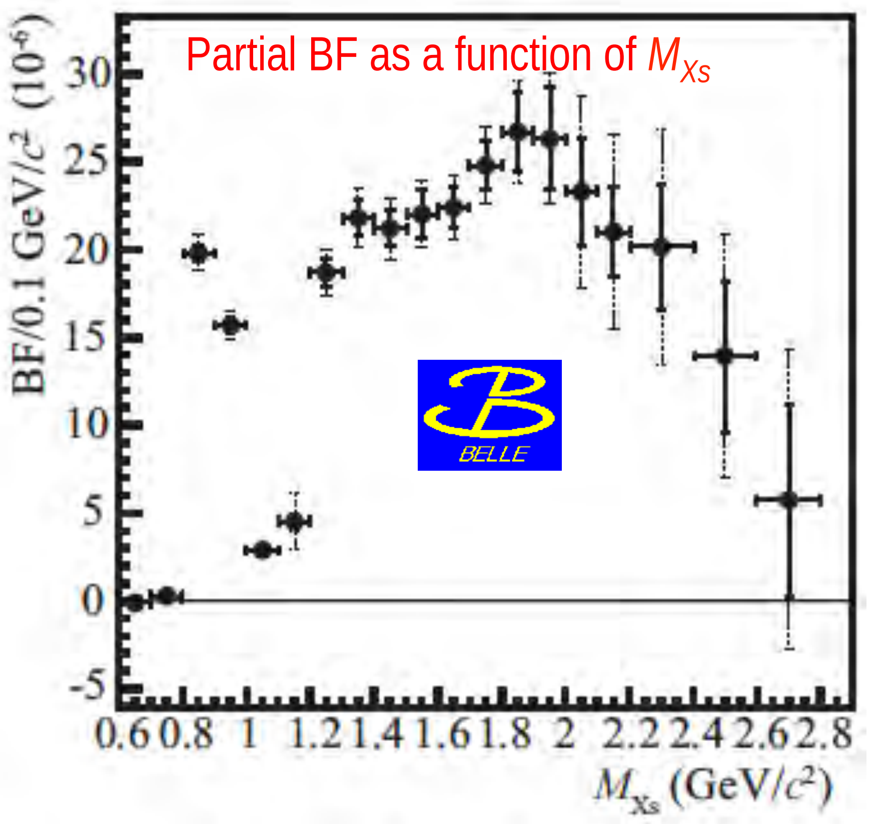
(Two sample bins)

Results (I)

With $M_{X_s} < 2.8$ GeV/c² ($E_\gamma > 1.9$ GeV)

$$\mathcal{B}(B \to X_s\gamma) = (3.51 \pm 0.17 \pm 0.33) \times 10^{-4}$$

- Consistent with the measurement from BaBar [Phys.Rev.D 86, 052012 (2012)]
- Best precision of sum-of-inclusives approach



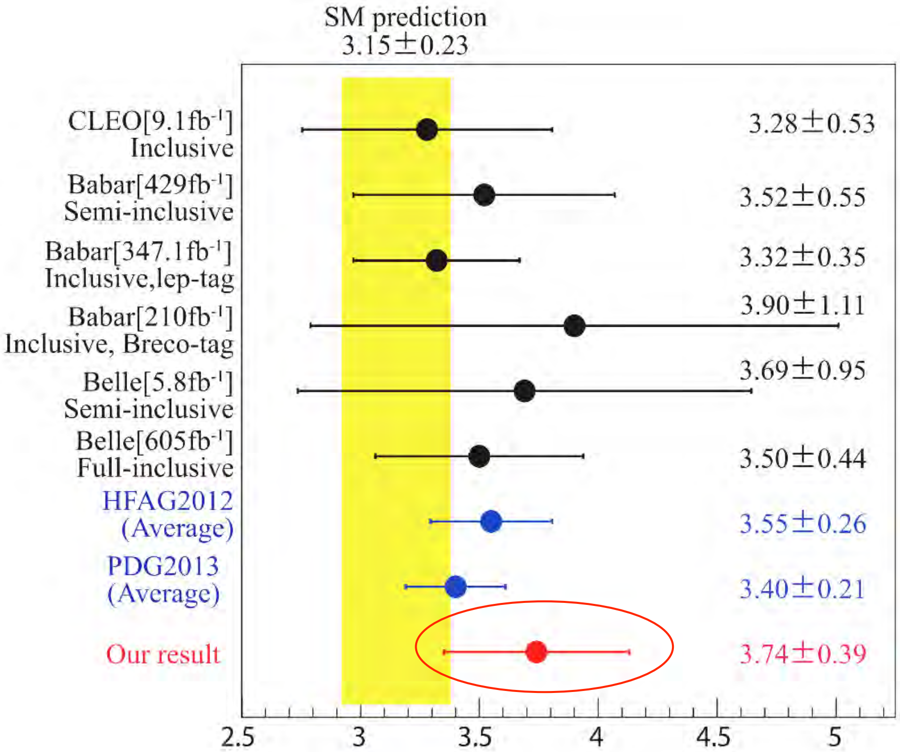
Results (II)

- Extrapolated BF to $E_\gamma > 1.6$ GeV to compare with the SM prediction

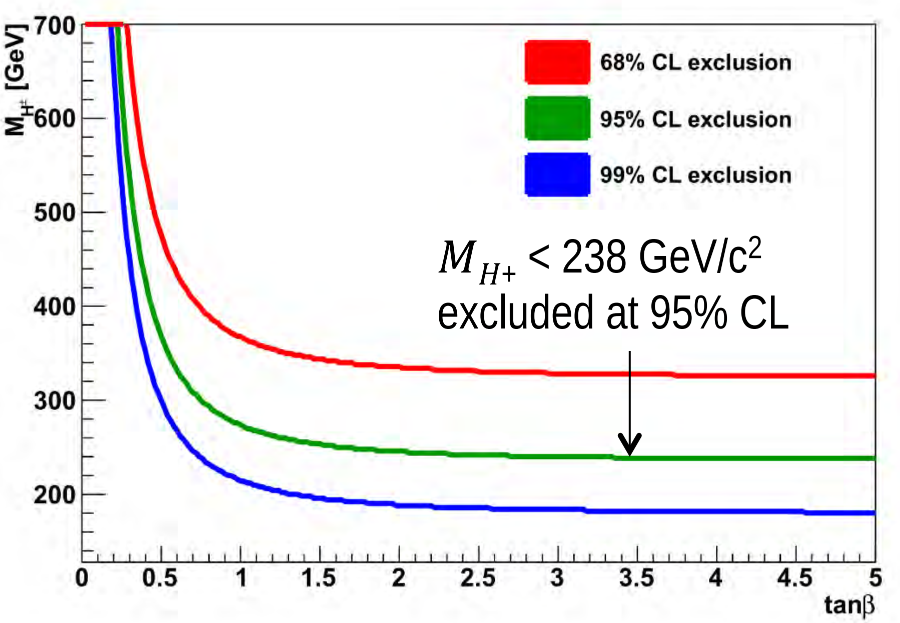
$$\mathcal{B}(B \to X_s\gamma) = (3.74 \pm 0.18 \pm 0.35) \times 10^{-4}\ (E_\gamma > 1.6\ \text{GeV})$$

- Consistent with the SM prediction [PRL 98, 022002 (2007)] within 1.3σ

$$\mathcal{B}(B \to X_s\gamma)_{SM} = (3.15 \pm 0.23) \times 10^{-4}\ \text{with NNLL}\ (E_\gamma > 1.6\ \text{GeV})$$



Constraint to M_{H^+} vs. tanβ only from this result



BF($B \to \tau\nu$)

Measurement of branching fraction of $B^+ \to \tau^+ \nu_\tau$ decays with the semileptonic tagging method and the full Belle data sample

arXiv:1409.5269 [hep-ex], Belle-CONF-1401

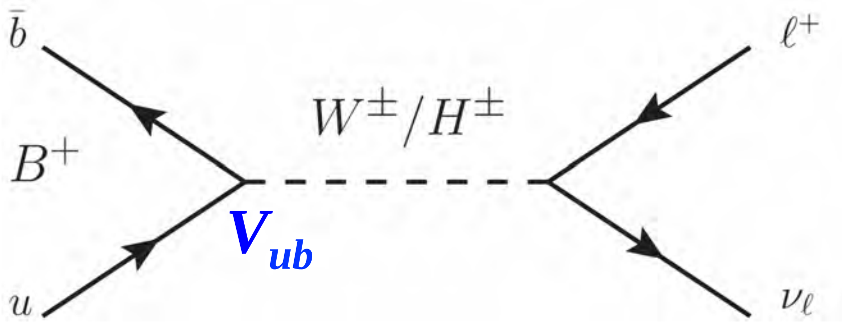
With the full Belle Y(4S) sample (772×10^6 $B\bar{B}$ pairs)

Introduction and motivations

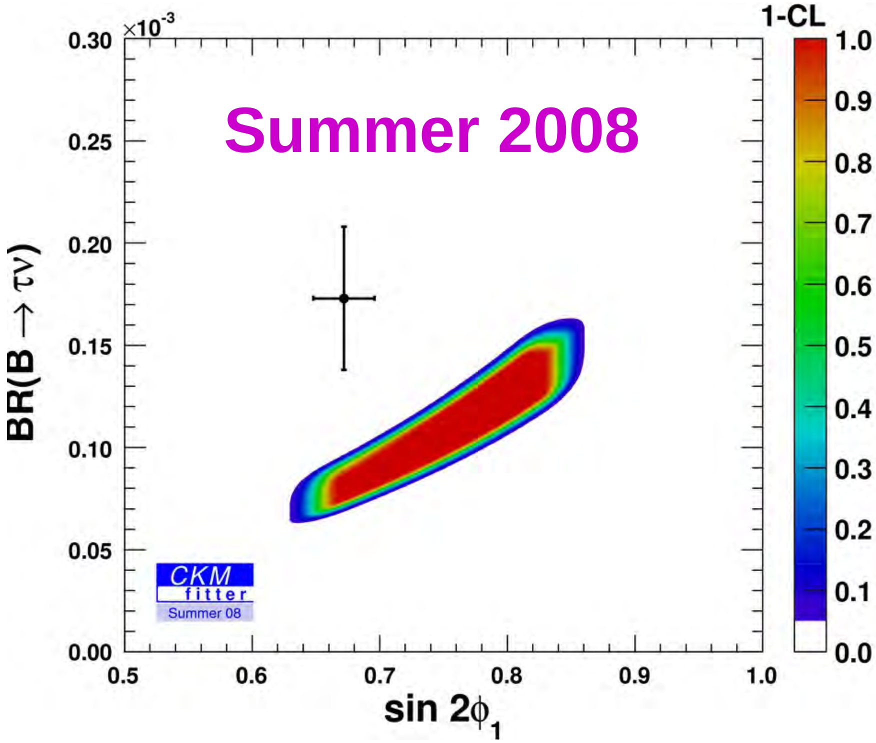
- In the SM:

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

- NP states such as charged Higgs bosons may interfere and alter the BF.



- In 2008 a tension appeared for V_{ub} from $B \to \tau\nu$ vs. CKM full triangle fit (excluding direct measurements of V_{ub}).
- This tension was eased, essentially by Belle's analysis with hadronic tagging [Phys.Rev.Lett. 110, 131801 (2010)]



Analysis

- Signal *B* decay often has only one track
  ⇒ Reconstruct the ***tag B*** from $B^{+} \to D^{(*)0} (e/\mu)^{+}\nu$ events (semileptonic tag)

- Improvement:
  - 20% more data, reprocessed
  - Better semileptonic tag (multivariate classifiers, more D decay channels)
  - Other technical advances (selection, tracking, background estimation)

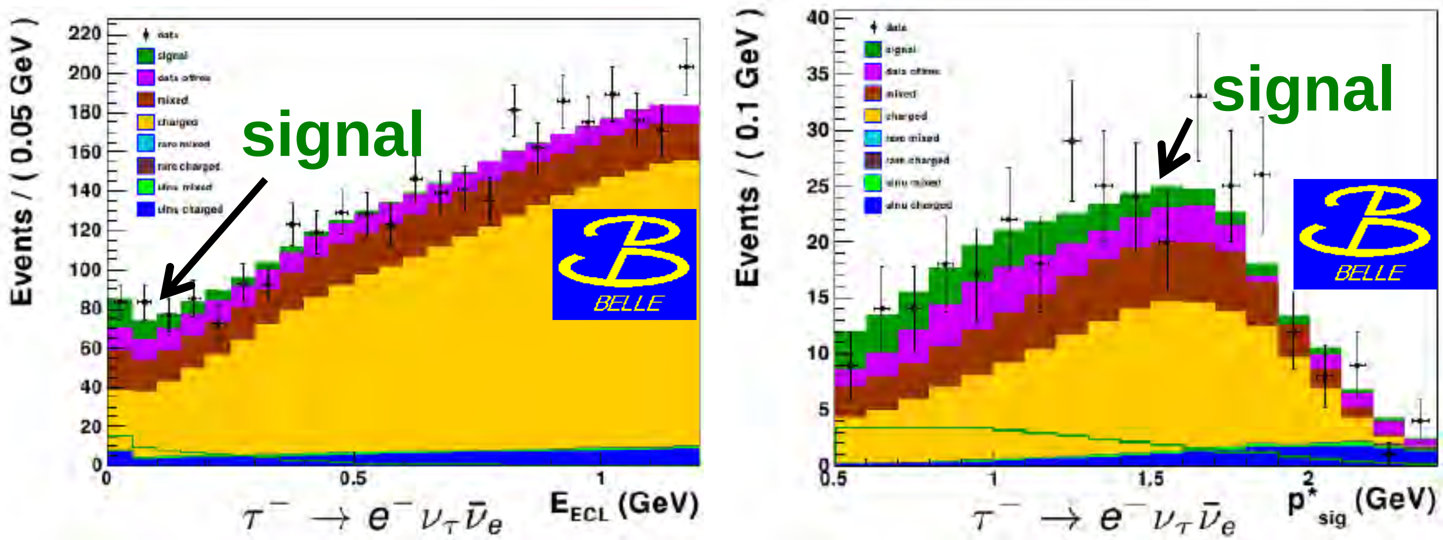
- τ reconstruction modes:
  - $\tau \to \mu\, \nu_\tau\, \nu_\mu$; $\tau \to e\, \nu_\tau\, \nu_e$; $\tau^- \to \pi^-\, \nu_\tau$; $\tau^- \to \rho^-\, \nu_\tau$ (new mode)

- Performing **fit** to extract yields in **two dimensions**:
  - $\mathbf{E_{ECL}}$ = extra energy in the ECL
    energy not associated to reconstructed B mesons → near zero for a signal event
  - $\mathbf{p^*_{sig}}$ = momentum of the signal side particle (μ, e, π, ρ) in the CM (new)

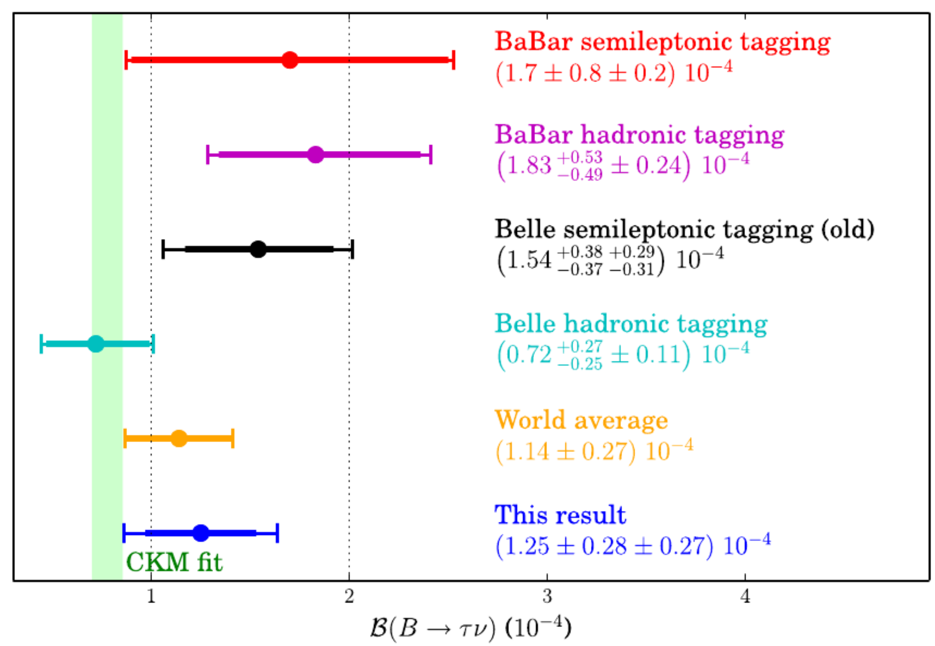
  PDFs taken as correlated (2 dimensional histograms) for $\tau \to \pi\, \nu_\tau$ and $\tau \to \rho\, \nu_\tau$

Results

Projections on fit variables (example for $\tau \to e\, \nu_\tau\, \nu_e$)



$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = (1.25 \pm 0.28 \pm 0.27) \times 10^{-4}$$



Reanalysis of B→τν basically eliminated the tensions between the UT fit and this BF

$B_s^0 \to \gamma\gamma$; $B_s^0 \to \phi\gamma$

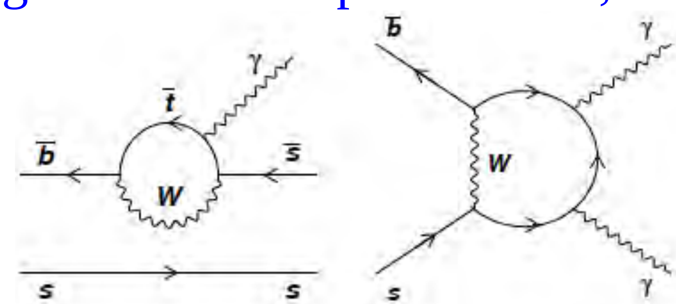
(In brief)

Search for $B_s^0 \to \gamma\gamma$ and a measurement of the branching fraction for $B_s^0 \to \phi\gamma$

arXiv:1411.7771 [hep-ex], Phys. Rev. D 91, 011101 (2015)

With the full Belle **Y(5S)** sample (121.4 fb^{-1})

- Proceed in SM through radiative loop transitions, sensitive to New Physics.

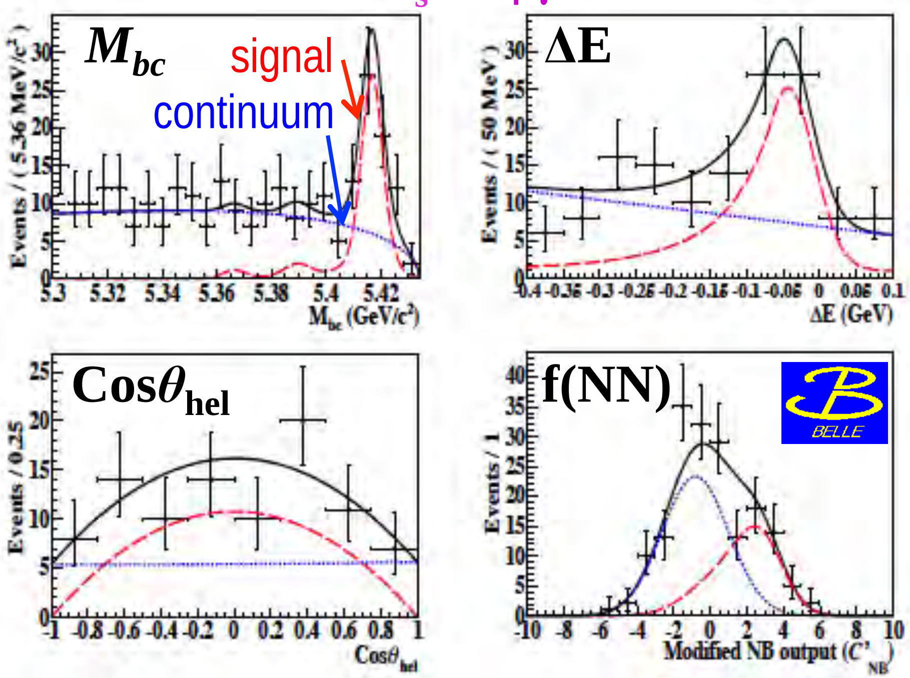


Analysis and results

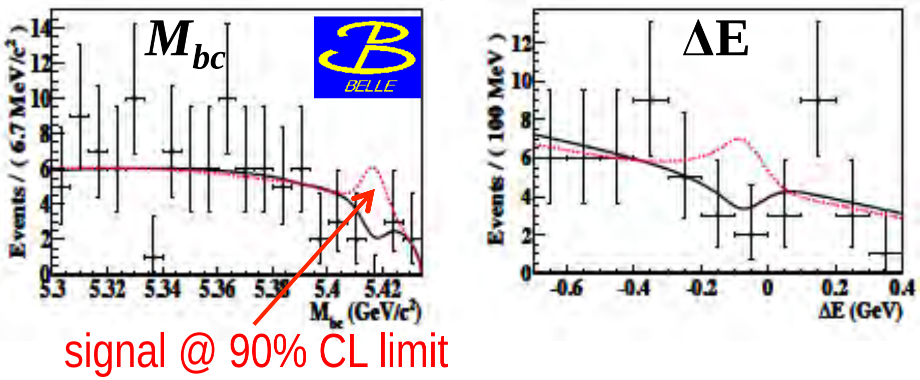
$B_s^0 \to \phi\gamma, \gamma\gamma$

- Multi dimensional maximum likelihood fit to extract signal yields

$B_s^0 \to \phi\gamma$



$B_s^0 \to \gamma\gamma$



- No significant signal observed
- Upper limit at 90% CL: 3.1×10^{-6}
- Significant improvement wrt current upper limit (previous Belle result)
- Getting closer to the SM prediction

- BF measured to be:

$$\mathcal{B}(B_s^0 \to \phi\gamma) = (3.6 \pm 0.5[\text{stat.}] \pm 0.3[\text{syst.}] \pm 0.6[f_s])\times10^{-5}$$

- Consistent with LHCb result: $(3.51\pm0.35\pm0.12)\times10^{-5}$ [Nucl. Phys. B 867, 1 (2013)]
- and with SM prediction: $(4.3\pm1.4)\times10^{-5}$ [Eur. Phys. C 55, 577 (2008)]

Summary and Conclusions

- B factories continue to produce exciting physics results, adding more information and using more sophisticated analysis techniques to probe new physics effects
- All measurements presented here agree with the Standard Model predictions and provide constraints in the parameter space of NP models.
- Larger samples are needed to tell whether or not there could be indications for NP. The analyses shown here have interesting perspectives with more data.

Belle II

Due for first physics at 2017–2018

LHCb

Run-II is just about to start