Relating B_s Mixing and $B_s \to \mu^+\mu^-$ with New Physics – An Update

E. Golowich, J. Hewett, S. Pakvasa,
A.A. Petrov, G. Yeghiyan
(GHPPY hereafter)

1] [PR D83 (2011) 114017]
2] [arXiv: 1102.0009v.2 [hep-ph]]

DPF-2011 (8/8/11-8/13/11)
Brown University Providence RI

Outline and Notation

Outline

1] Review status of $B_s \to \mu^+\mu^-$.

2] Update of B_s Mixing in the SM.

3] GHPPY approach to $B_s \to \mu^+\mu^-$ and NP.

Some Abbreviations

1] SM = Standard Model

2] NP = New Physics

3] RPV = R-parity Violating

4] FCNC = Flavor-changing Neutral Current

SM Theory for $B_s \to \mu^+\mu^-$

Two approaches*:

I] 'Raw': $Br^{(I)} = \frac{1}{8\pi^5}\frac{M_{B_s}}{\Gamma_{B_s}}(G_F^2 M_W^2 m_\mu f_{B_s} |V_{ts}^* V_{tb}| \eta_Y Y)^2$

II] 'ΔM': $Br^{(II)} = \frac{3}{4\pi^3}\frac{\Delta M_{B_s}^{(expt)}}{\Gamma_{B_s}}\frac{(G_F M_W m_\mu \eta_Y Y)^2}{\hat{\eta}\hat{B}S_0}$

Comparison:

For Method I, $(3.29 \pm 0.46) \times 10^{-9}$

& Method II, $(3.33 \pm 0.21) \times 10^{-9}$

GHPPY use Method II (smaller uncertainty)**

*Buras PL B566 (2003) 115.

**Buras, Carlucci, Gori, Isidori JHEP 1010:009 (2010) get Br = $(3.2 \pm 0.2) \times 10^{-9}$

Recent Interest in B_s Physics

Stimulated by NP possibilities in:

1] (CDF, D0): Study of time dependence in
$B_s \rightarrow \psi + \varphi$.

Coverage in ICHEP-2010 and EPS-2011.

2] (D0): Like-sign dimuon asymmetry
$A_{sl}^b = (N^{++} - N^{--})/ (N^{++} + N^{--})$.

Update in arXiv:1106.638v1[hep-ex]

3] (CDF, D0, LHCb, CMS): Studies of $B_s \rightarrow \mu^+\mu^-$.

Discussed next

About $Br[B_s \to \mu^+\mu^-]$

Theory:

$Br^{(SM)} = (3.3 \pm 0.2)\cdot 10^{-9}$ (GHPPY value)

Experiment:

$Br^{(PDG)} < 4.7\cdot 10^{-8}$ CL = 90% (PDG Live)

$Br^{(CDF)} = (1.8^{+1.1}_{-0.9})\times 10^{-8}$ (arXiv:1107.2304v1[hep-ex])

and the preliminary LHCb/CMS (≡ LHC) bounds

$Br^{(LHC)} < 0.9\cdot 10^{-8}$ CL = 90% (Wilkinson: EPS 2011)

$Br^{(LHC)} < 1.1\cdot 10^{-8}$ CL = 95% (Wilkinson: EPS 2011)

Thoughts:

'NP Window': $Br^{(LHC)}/ Br^{(SM)} = 1.1/0.33 \sim 3.3$

'Win-win' Situation? Getting near

1] Either confirming SM prediction

2] Or encountering NP.

B_s Mixing at in the SM at NLO

Experiment:

$\Delta M_{Bs}^{(Expt)} = (117.0 \pm 0.8)\times 10^{-13}$ GeV Tiny uncertainty!

Theory:

$$\Delta M_{B_s}^{(SM)} = \frac{(G_F M_W |V_{ts}^* V_{tb}|)^2}{6\pi^2} M_{B_s} f_{B_s}^2 \hat{B}_{B_s} \eta_{B_s} S_0(\bar{x}_t)$$

Upon using PDG Eq. (11.27) $|V_{ts}| = 0.0403^{+0.0011}_{-0.0007}$

$$\Delta M_{B_s} = (125.2^{+13.8}_{-12.7}) \times 10^{-13}\,\text{GeV}$$

Compare: PDG Eq. (11.13) $|V_{ts}| = 0.0387 \pm 0.0021$

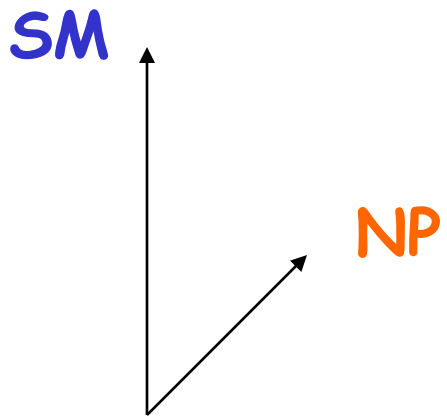
$$\Delta M_{B_s} = (115.4 \pm 16.7) \times 10^{-13}\,\text{GeV}$$

GHPPY use boxed result (smaller uncertainty).

Note: Only Pre-EPS 2011 inputs used.

What if there is NP in B_s-mixing?

Assume $\Delta M_{Bs}^{(Expt)} = \Delta M_{Bs}^{(SM)} + \Delta M_{Bs}^{(NP)}$ with relative phase unknown:



If so, $\Delta M_{Bs}^{(NP)} = \boxed{(-8.2^{+13.8}_{-12.7}) \times 10^{-13}\,\text{GeV}}$

with 1σ range $\Delta M_{Bs}^{(NP)} = (-20.9 \rightarrow +5.6) \times 10^{-13}$ GeV.

To constrain NP parameters, GHPPY adopt

$$|\Delta M_{Bs}^{(NP)}| \leq 20.9 \times 10^{-13}\ \text{GeV}.$$

Possibilities for New Physics?

The LHC era is underway, with many NP 'extras' possible:

- Extra gauge bosons
  (LR models, etc)
- Extra scalars
  (Multi-Higgs models, etc)
- Extra fermions
  (Little Higgs, etc)
- Extra dimensions
  (Universal extra dimensions, etc)
- Extra global symmetries
  (SUSY, etc)

List of GHPPY NP Models

Strategy

NP models can have many parameters. We find paths which relate ΔM_{Bs} to $B_s \rightarrow \mu^+\mu^-$.

NP List

Additional Neutral Vector Boson Z'

Family ('Horizontal') Symmetry

RPV SUSY

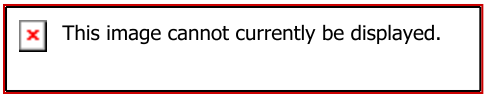
Fourth Quark Generation

FCNC Higgs

Saved for a Forthcoming Paper

RPC ('Ordinary') SUSY

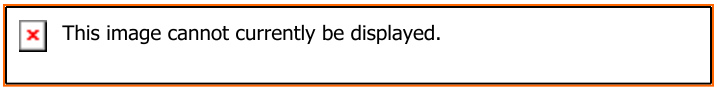
RG Factor (at LO) for NP Amplitude

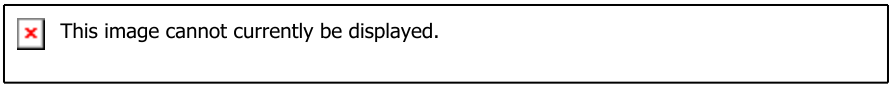
Ex: Assume NP involves 

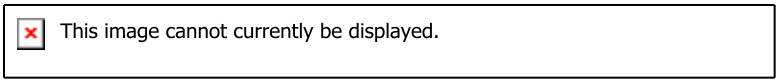
Two scales: $M >> m_b$

Have $C_1(M) = S_0$ Need $C_1(m_b)$

Integrate RG equation

Get 

with 

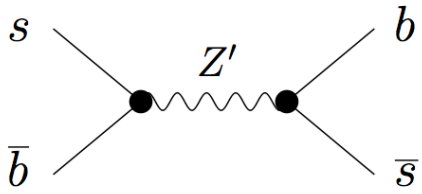
and 

Vector Boson Z'

Two Input Parameters: $g^2_{Z' s\bar{b}}$ and $M^2_{Z'}$

B_s Mass Difference:

$$\Delta M^{(Z')}_{B_s} \propto \frac{g^2_{Z' s\bar{b}}}{M^2_{Z'}}$$



Branching Ratio:

$$Br^{(Z')}_{B_s \to \mu+\mu-} \propto \frac{g^2_{Z' s\bar{b}}}{M^2_{Z'}} \frac{M^2_Z}{M^2_Z}$$

Bound:

This image cannot currently be displayed.

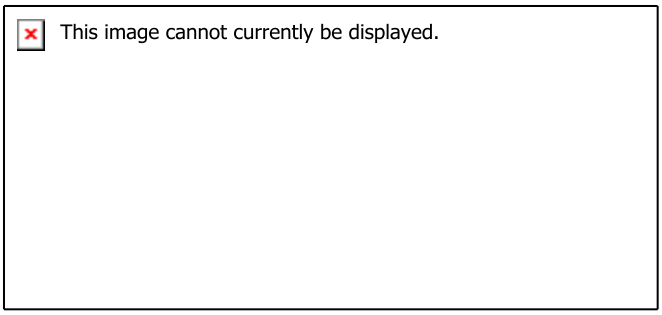
Conclude: Below SM value if $M_{Z'} > 0.3$ TeV.

Family ('Horizontal') Symmetries

What are they? Symmetries to relate the various quark and/or (lepton) families.
E.g., see Wilczek, Zee, PRL 42 (1979) 421.

Motivation? Understanding (still needed) of fermion masses and mixing matrices.

Why 'Horizontal'? Just look:



What's new? Gauge bosons (massive since the symmetry is spontaneously broken).

Is this still of interest? Sure, e.g. studying FCNC and CPV patterns in Family Symmetries.*

*See Lalak, Pokorski and Ross, JHEP 1008:129 (2010) .

Family Symmetry (cont.)

In GHPPY, start with seven input parameters (!!). But a long history of study has reduced this to just two (as in the Z' model). Find:

Relate Mixing and Decay Branching Ratio:

$$\mathrm{Br}^{(FS)}_{B_S \to \mu^+\mu^-} \propto |\Delta M^{(FS)}_{B_S}|^2$$

Bound on Branching Ratio:

$$\mathrm{Br}^{(FS)}_{B_S \to \mu^+\mu^-} \leq 0.9 \times 10^{-12}$$

Conclude: Far below SM value!

R-parity Violating SUSY

$R_{\rm P}$ VIOLATING SUSY

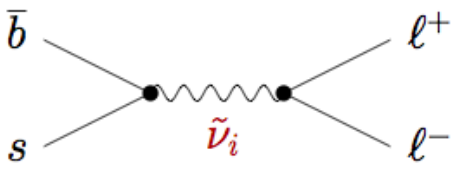
Introduce RPV Interaction $\mathcal{W}_{\not R}$

$$R_{\rm P} \;=\; (-)^{3(B-L)+2S} \;=\; \begin{cases} +1 & \text{(particle)} \\ -1 & \text{(sparticle)} \end{cases}$$

$$W_{\not R} = \tfrac{1}{2}\lambda_{ijk} L_i L_j E_k^{(c)} + \lambda'_{ijk} L_i Q_j D_k^{(c)} + \tfrac{1}{2}\lambda''_{ijk} U_i^{(c)} D_j^{(c)} D_k^{(c)} \quad .$$

Q = isodoublet quark, L = isodoublet lepton, *etc*
and i,j,k are generation labels.

Example: $B_s \to \mu^+\mu^-$

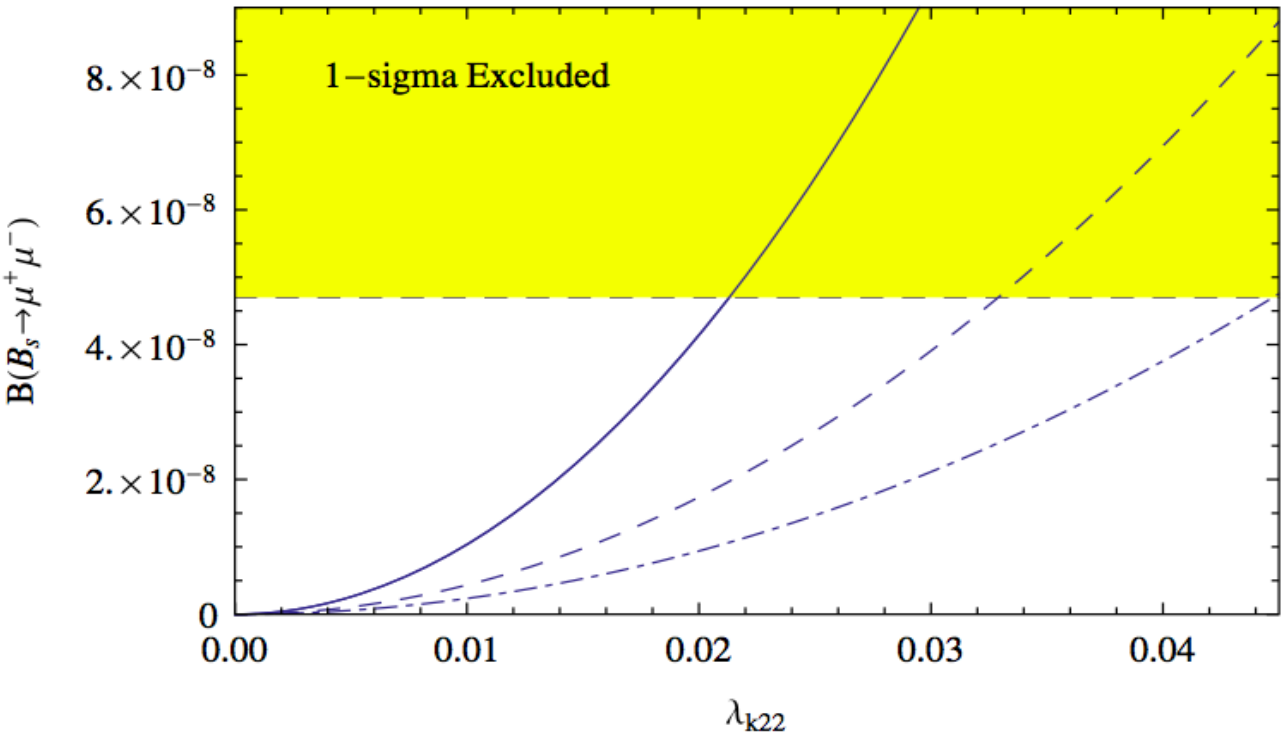


Non-electromagnetic process!

Mediated by sneutrino

RPV SUSY (cont.)

Plot: $B_s \to \mu^+\mu^-$ branching fraction as a function of the RPV leptonic coupling λ_{k22} and parametrized with sneutrino mass increasing from solid to dash to dash-dot lines.



See also Kundu, Saha, PRD 70 (2004) 096002; Dreiner, Kramer, O'Leary, PRD 75 (2007) 114016.

Fourth Quark Generation

What's new? Extra fermions, the quarks t' & b'.

Motivation? No existing proof limiting number of families to just three. So why not try four.

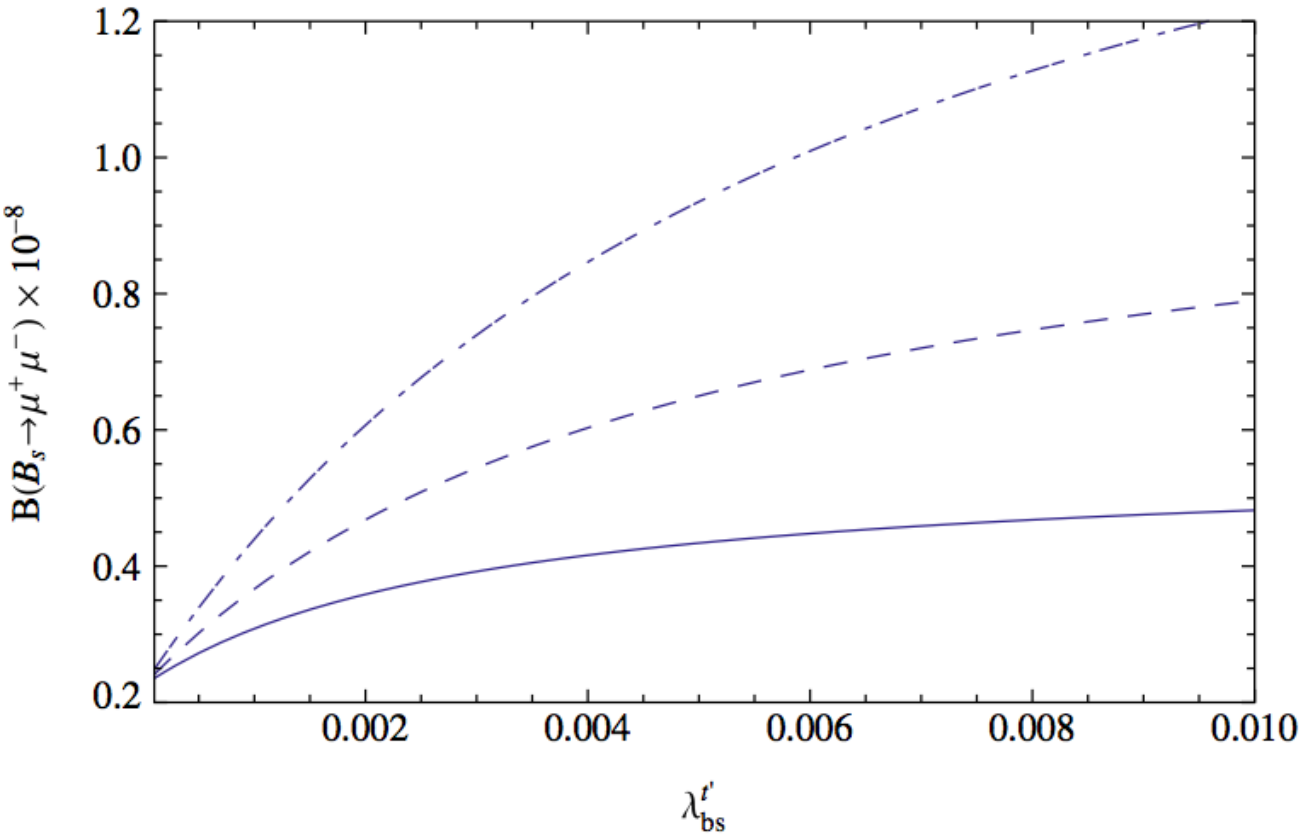
Already ruled out? Still viable, although certainly constrained by direct searches, by CKM unitarity and by EW precision data (oblique parameters S,T,U).

Is there recent literature? Actually, lots of papers, especially regarding a fourth generation and Higgs boson physics. But also on flavor physics.*

*See Soni, Alok, Giri, Mohanta, and Nandi, PRD (2010) 033009.

Fourth Generation (cont)

Plot: $B_s \rightarrow \mu^+\mu^-$ branching fraction as a function of the CKM parameter $\lambda_{bs}^{t'}$ with t' mass increasing from lower to upper curves.



FCNC Higgs Bosons

What's new? Extra scalars in the form of two or more Higgs doublets .

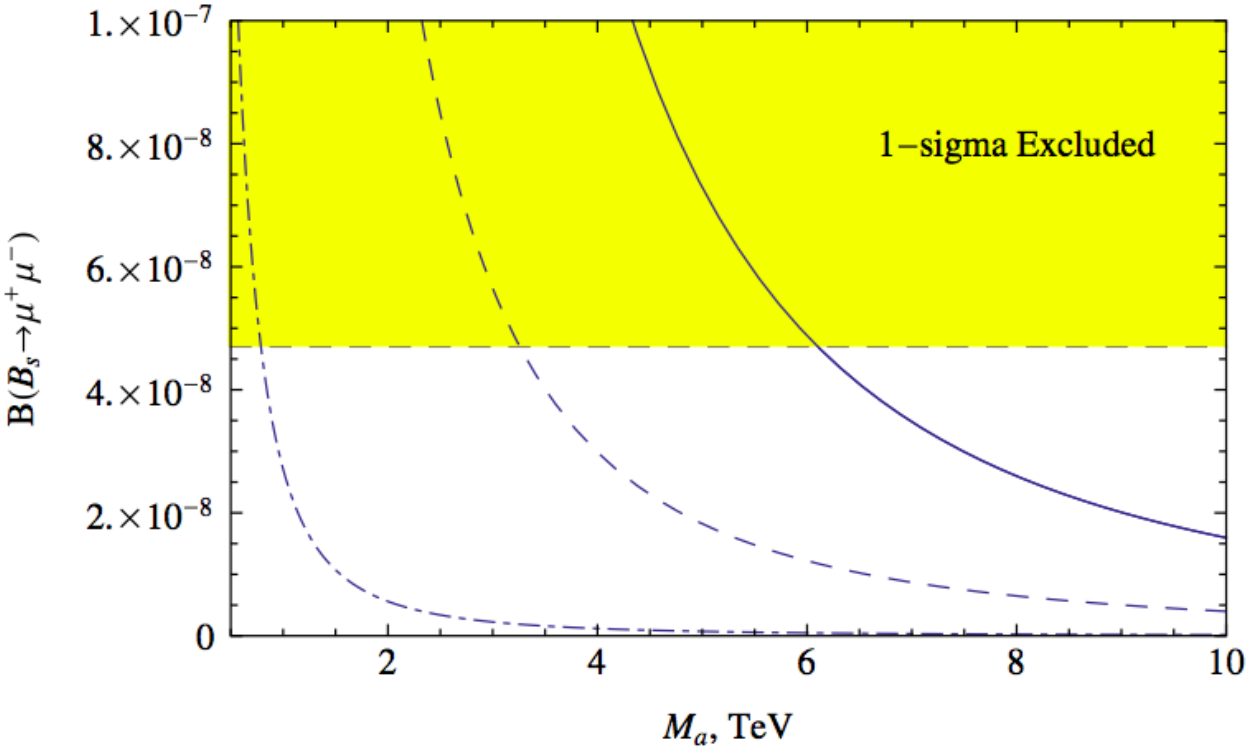
Motivation? No proof limiting number of Higgs doublets. Indeed, **two** Higgs doublets occur in models of supersymmetry.
Encounter $H_{1,2}$, A^0, $H^{\pm}$.

Already ruled out? No – just limits. PDG lists
$M(H_2) > M(H_1) > 92.9$ GeV,
$M(A^0) > 93.4$ GeV (tan β > 0.4),
$M(H^{\pm}) > 79.3$ GeV.

Is there recent literature? Continuing stream of papers. For a recent entry of interest to flavor physics, see:
Buras, Carlucci, Gori, Isidori JHEP 1010:009 (2010) .

FCNC Higgs (cont.)

Plot: $B_s \rightarrow \mu^+\mu^-$ branching fraction versus pseudoscalar Higgs mass M_a parameterized by coupling [Thi s :] decreasing from top lines to bottom.



Concluding Remarks

Update of GHPPY SM Evaluations:

1] B_s Mixing:

$$\Delta M_{Bs}^{(SM)} = (125.2^{+13.8}_{-12.7}) \times 10^{-13}\,\mathrm{GeV}$$

$$\Delta M_{Bs}^{(Expt)} = (117.0 \pm 0.8) \times 10^{-13}\,\mathrm{GeV}$$

Theory uncertainty is about 16 times the larger due to uncertainty in $f_{B_s}^2 \hat{B}_{B_s} V_{ts}^{*2}$. This large uncertainty hinders studies of additive NP terms.

2] $B_s \to \mu^+\mu^-$:

Use $\Delta M_{Bs}^{(Expt)}$ as input to reduce uncertainty,

$Br^{(SM)} = (3.3 \pm 0.2) \cdot 10^{-9}$ (GHPPY value)

with dominant uncertainty from $\hat{B}_{B_s}$ and half as much from top-mass m_t.

Concluding Remarks (cont.)

What about NP?

3] EPS 2011:

Up-to-date LHC direct search data presented. One Is left asking – 'Where is the NP'? Fortunately, improved data set soon at hand. For theory overview see 'Flavour theory' by Neubert.

4] GHPPY approach to $B_s \to \mu^+\mu^-$:

Use $\Delta M_{Bs}^{(Expt)} = \Delta M_{Bs}^{(SM)} + \Delta M_{Bs}^{(NP)}$ to bound $\Delta M_{Bs}^{(NP)}$ and thence to constrain NP parameters.
Five NP models studied – another on the way.
Feel free to adopt GHPPY to your own NP models.
But realize – various assumptions required to overcome abundance of NP parameters.

Final note: For $D^0 \to \mu^+\mu^-$, SM component is tiny!
Can seek NP signal there.

Two Issues for the Speaker

1] GHPPY use only pre EPS 2011 inputs, so their predictions will change as inputs are improved.

	GHPPY	EPS 2011
m_t:	173.1 ± 1.3	173.3 ± 0.9
$a_s(M_z)$:	0.1184 ± 0.0007	0.1183 ± 0.0010

Not too bad for these, but graphs need fixing.

2] Maybe use $\Delta\Gamma_{Bs}^{(Expt)}$ as well as $\Delta M_{Bs}^{(Expt)}$?

Try 'mass difference' $\mathcal{D}M_{Bs} \equiv \Delta\Gamma_{Bs}^{(Expt)} R^{(SM)}$
where $R^{(SM)} \equiv \Delta M_{Bs}^{(SM)}/\Delta\Gamma_{Bs}^{(SM)}$

Currently* $R^{(SM)} = (50.3 \pm 14.3) \times 10^{-4}$ (28%)

Better than $R^{(Expt)} = (34.9 \pm 20.0) \times 10^{-4}$ (57%)

But GHPPY $\Delta M_{Bs}^{(SM)}$ has uncertainty 10.4%.

*Lenz and Nierste arXiv:1102.4274 [hep-ph]