The Forward-Backward Top Asymmetry in a Singlet Extension of the MSSM

Alejandro de la Puente

University of Notre Dame

PHENO 2012 Symposium

University of Pittsburgh

Based on JHEP 1202 (2012) 016 [arXiv:1111.4488 [hep-ph]]

A more natural solution to the LHP

S-MSSM:

A. Delgado, C. Kolda, J.P. Olson, A.P, Phys.Rev.Lett. 105 (2010) 091802

A. Delgado, C. Kolda, A.P, arXiv:1111.4008 [hep-ph] (to appear in Phys. Lett. B)

$$W = W_{Yukawa} + (\mu + \lambda S)H_u H_d + \frac{1}{2}\mu_s S^2$$

A more natural solution to the LHP

S-MSSM:

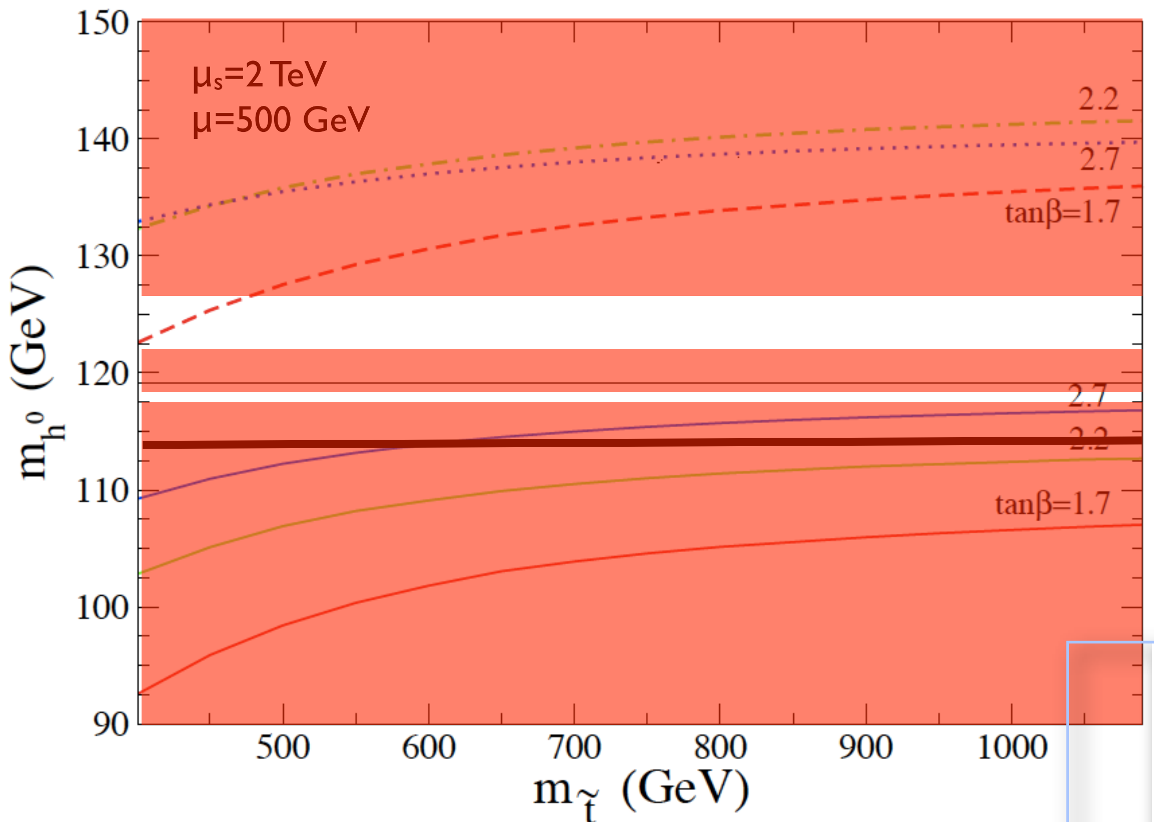
$$W = W_{Yukawa} + (\mu + \lambda S) H_u H_d + \frac{1}{2}\mu_s S^2$$

The scalar potential of the S-MSSM

$$\begin{aligned} V &= (\mu^2 + m_{H_u}^2)|H_u|^2 + (\mu^2 + m_{H_d}^2)|H_d|^2 + (m_s^2 + \mu_s^2)|S|^2 + (B_s S^2 + h.c.) \\ &+ [(\lambda \mu_s S^\dagger + B_\mu + A_\lambda \lambda S) H_u H_d + \lambda \mu S^\dagger (|H_u|^2 + |H_d|^2) + h.c.] \\ &+ \lambda^2 (H_u H_d)(H_u H_d)^\dagger + \lambda^2 |S|^2 (|H_u|^2 + |H_d|^2) \\ &+ \frac{1}{8}(g^2 + g'^2)(|H_u|^2 - |H_d|^2)^2 + \frac{1}{2} g^2 |H_u^\dagger H_d|^2 \end{aligned}$$

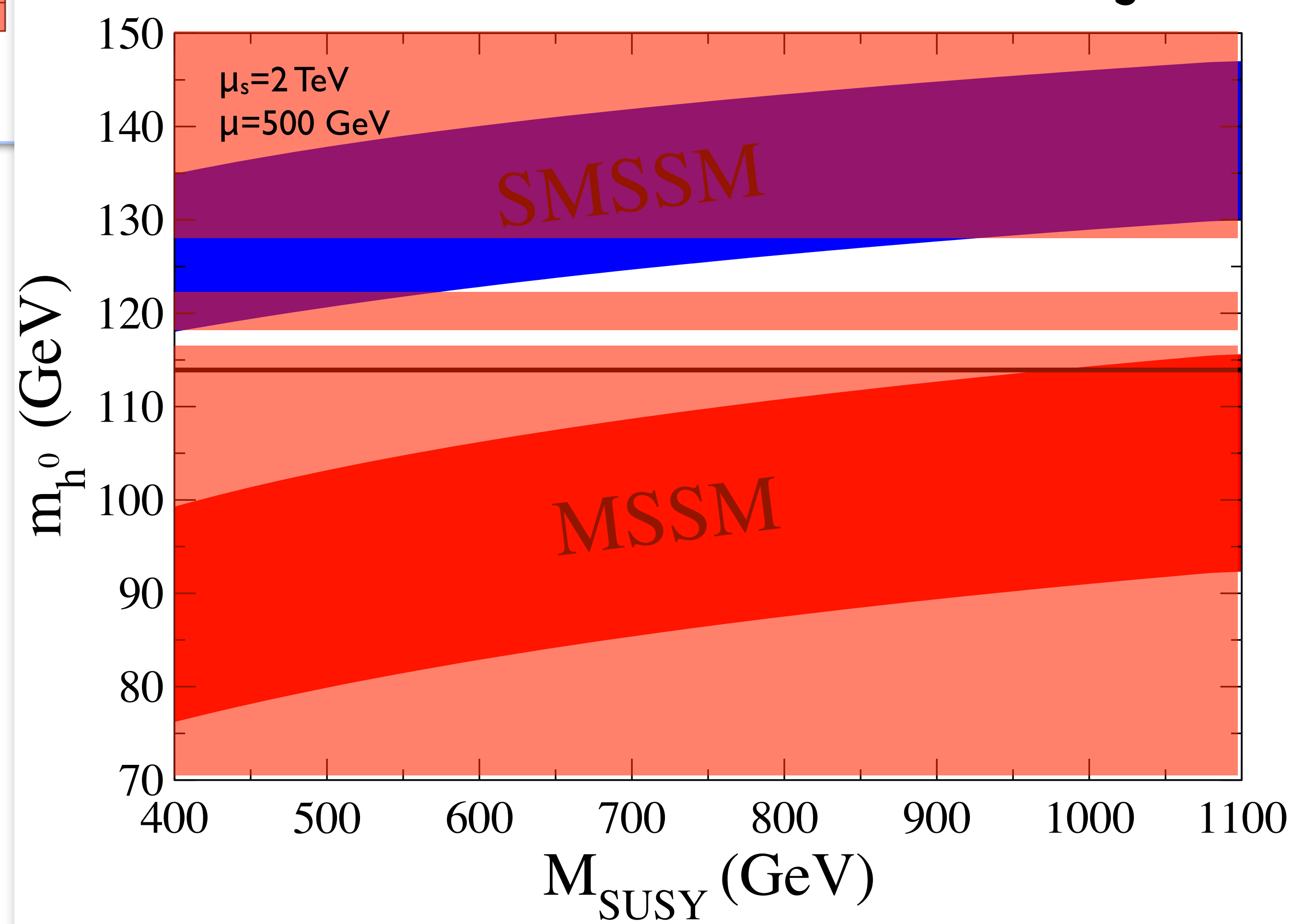
In a nutshell...

Small μ_s limit:



$$A_t = \sqrt{6} m_{\tilde{t}}$$
$$M_1 = \frac{1}{6} m_{\tilde{t}}$$
$$M_2 = \frac{1}{3} m_{\tilde{t}}$$
$$M_3 = m_{\tilde{t}}$$
$$A_\lambda = -m_{\tilde{t}}$$

Large μ_s limit:



$$\mu_s = 20 \text{ GeV}$$
$$A_\lambda = 280 \text{ GeV}$$
$$\mu = 0 \text{ GeV}$$
$$B_\mu = 0 \text{ GeV}^2$$

The Forward-Backward Top Asymmetry within the context of the S-MSSM

A.P, JHEP 1202 (2012) 016

CDF and DØ have reported a new measurement of the inclusive forward-backward top asymmetry

$$
\begin{aligned}
A^{t\bar{t}}_{FB} &= 0.158 \pm 0.072 \pm 0.017 \text{ (CDF with 5.3 fb}^{-1}\text{)},\\
A^{t\bar{t}}_{FB} &= 0.196 \pm 0.060^{+0.018}_{-0.026} \text{ (DØ with 5.4 fb}^{-1}\text{)}.
\end{aligned}
$$

The Forward-Backward Top Asymmetry within the context of the S-MSSM

CDF and DØ have reported a new measurement of the inclusive forward-backward top asymmetry

$$A_{FB}^{t\bar{t}} = 0.158 \pm 0.072 \pm 0.017 \text{ (CDF with 5.3 fb}^{-1}\text{)},$$
$$A_{FB}^{t\bar{t}} = 0.196 \pm 0.060^{+0.018}_{-0.026} \text{ (DØ with 5.4 fb}^{-1}\text{)}.$$

The S-MSSM is extended by dimension-five operators in the superpotential in order to study their contributions to the asymmetry

A simple extension is given by:

$$W = W_{\mathrm{S-MSSM}} + \frac{\Lambda_{ij}}{M}\hat{S}\hat{H}_u\hat{u}_i^c\hat{Q}_j - \frac{\Sigma_{ij}}{M}\hat{S}\hat{H}_d\hat{d}_i^c\hat{Q}_j .$$

- **Allow for t-channel contributions to $q\bar{q}$ scattering mediated by Higgs particles.**
- **Scale M dictates where these operators arise.**

A simple extension is given by:

$$W = W_{\mathrm{S-MSSM}} + \frac{\Lambda_{ij}}{M}\hat{S}\hat{H}_u\hat{u}^c_i\hat{Q}_j - \frac{\Sigma_{ij}}{M}\hat{S}\hat{H}_d\hat{d}^c_i\hat{Q}_j.$$

- **Assume a fermion basis where SM up-type Yukawa couplings are diagonal.**
- **Consider**

$$\Lambda = \begin{pmatrix} 0 & 0 & \Lambda_{13} \\ 0 & 0 & 0 \\ \Lambda_{31} & 0 & 0 \end{pmatrix} .$$

- **We assume that $\Sigma_{ij} \sim 0$ since compared to Λ effects, corrections arising from Σ are suppressed.**

For scalars/pseudoscalars, Lagrangian given by:

$$\mathcal{L}_{u,t} \supset \sum_i \left(F^i_{R,H} H_i - i F^i_{R,A} A_i\right) \bar{u}_L t_R + \left(F^i_{L,H} H_i + i F^i_{L,A} A_i\right) \bar{u}_R t_L + h.c.$$

where

$$\begin{aligned} F^i_{R,(H,A)} &= \frac{\Lambda_{31}}{\sqrt{2}M}\left(v \sin\beta \; O^{(H,A)}_{i,S} + v_s \; O^{(H,A)}_{i,H_u}\right), \\ F^i_{L,(H,A)} &= \frac{\Lambda_{13}}{\sqrt{2}M}\left(v \sin\beta \; O^{(H,A)}_{i,S} + v_s \; O^{(H,A)}_{i,H_u}\right) \end{aligned}$$

Additionally, for charged scalars:

$$\mathcal{L}_{d,t} \supset -\frac{v_s}{M} \Lambda_{31} \cos\beta \; \bar{d}_L t_R H^- + h.c$$

Asymmetry

Define the total NP contribution to the differential cross section by:

$$M^{NP}_{total} = M^{NP} + M^{SM\ LO,\ NP}_{INT}$$

Then, the asymmetry can be defined by:

$$A^{total}_{FB} = A^{NP}_{FB} \cdot R + A^{SM}_{FB} \cdot (1 - R)$$

where

$$\begin{aligned} A^{NP}_{FB} &= \frac{\sigma^{NP}_F - \sigma^{NP}_B}{\sigma^{NP}_F + \sigma^{NP}_B}, \\ A^{SM}_{FB} &= \frac{\sigma^{SM}_F - \sigma^{SM}_B}{\sigma^{SM}_F + \sigma^{SM}_B}, \\ R &= \frac{\sigma^{NP}_{total}}{\sigma^{SM}_{total} + \sigma^{NP}_{total}}. \end{aligned}$$

Constraints I

- **u-t mass mixing:**

$$M_U^2 = \begin{pmatrix} \left(\Lambda_{13}\ \frac{v_s v_u}{M}\right)^2 & \left(\Lambda_{13}\ \frac{v_s v_u}{M}\right) m_{t,0} \\ \left(\Lambda_{13}\ \frac{v_s v_u}{M}\right) m_{t,0} & \left(\Lambda_{31}\ \frac{v_s v_u}{M}\right)^2 + m_{t,0}^2 \end{pmatrix}$$

Imposing that $m_u \leq 3.1\ \mathrm{MeV}$ constrains the product $\Lambda_{13} \cdot \Lambda_{31}$

- **Meson-mixing ($K^0 - \bar{K}^0$):**

$$\frac{1}{32\pi^2}\left(\frac{\mathrm{TeV}}{m_{H^\pm}}\right)^2 \sum_i F(x_i)\left(V^\dagger \Lambda'\right)_{1i}^2 \left(V^\dagger \Lambda'\right)_{2i}^{*2} < 10^{-6}$$

$$\Lambda' = \frac{v_s}{2M}\Lambda \cos\beta$$

- **New top decay channels:**

$$\Gamma\left(t \to \phi_i u\right) = \frac{m_t}{32\pi}\left(1 - \frac{m_{\phi_i}^2}{m_t^2}\right)^2 \left(F_L^{i2} + F_R^{i2}\right)$$

Impose that $\Gamma_{total} \leq 7.6\ \mathrm{GeV}$

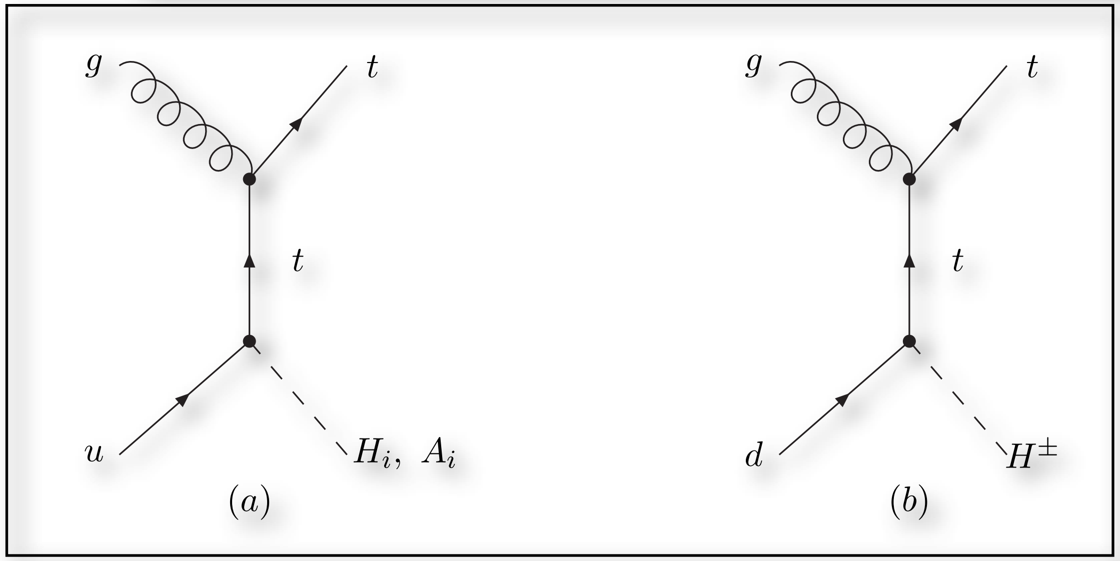
Constraints II (Collider)

- **Same sign-top production:**

$$g_{tt} \propto (\Lambda_{13}\Lambda_{31})^2$$

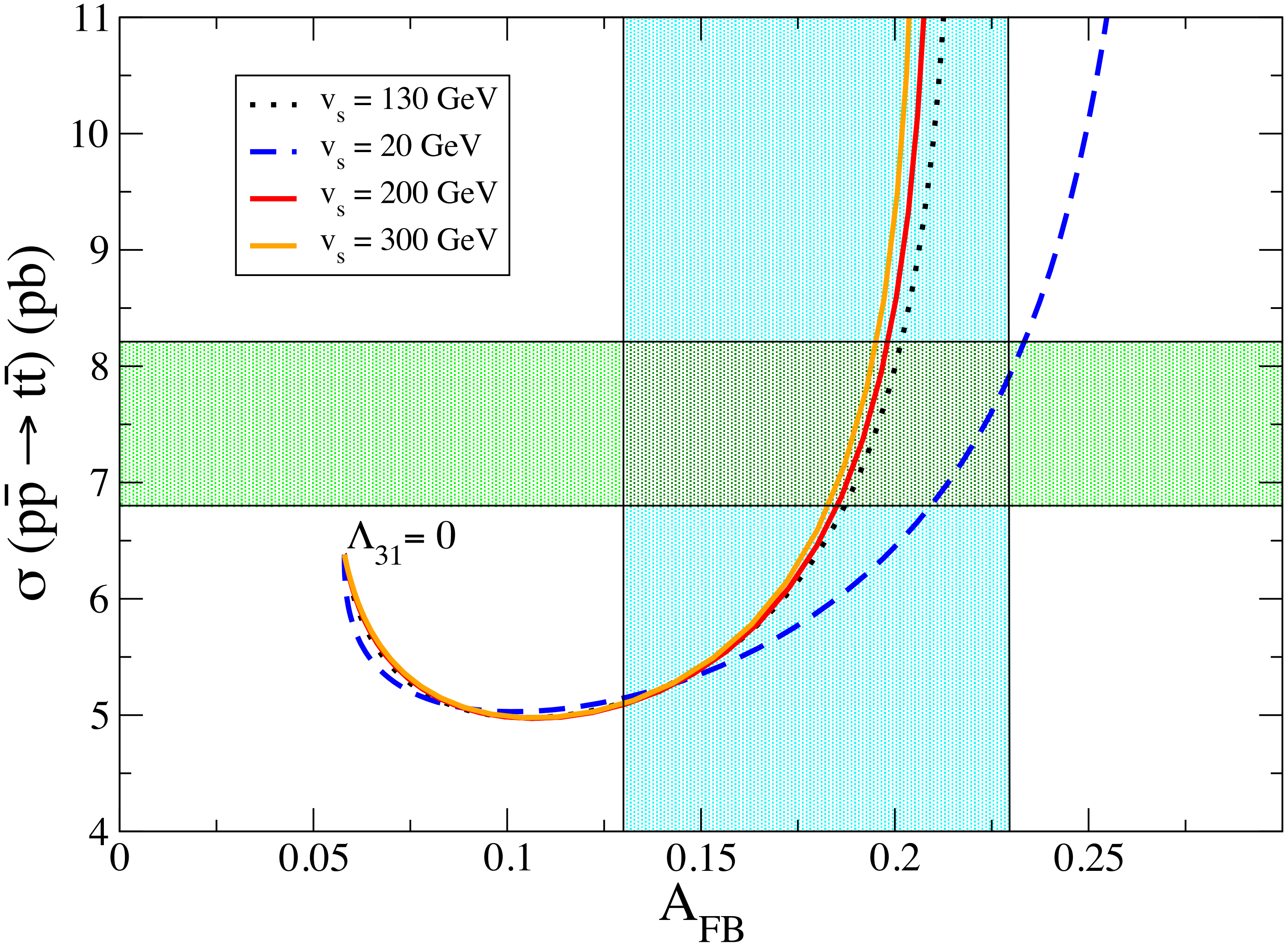
- **Single-top production: Recent DØ measurement:**

$$\sigma\left(p\bar{p} \to tqb + X\right) = 2.90 \pm 0.59 \text{ pb}$$



- Suppression of (b) by making either Λ_{13} or Λ_{31} small.
- Suppression of (a) a bit more trickier...
  - Due to complexity of final states direct comparison with DØ measurement difficult to make

Small μ_s limit:



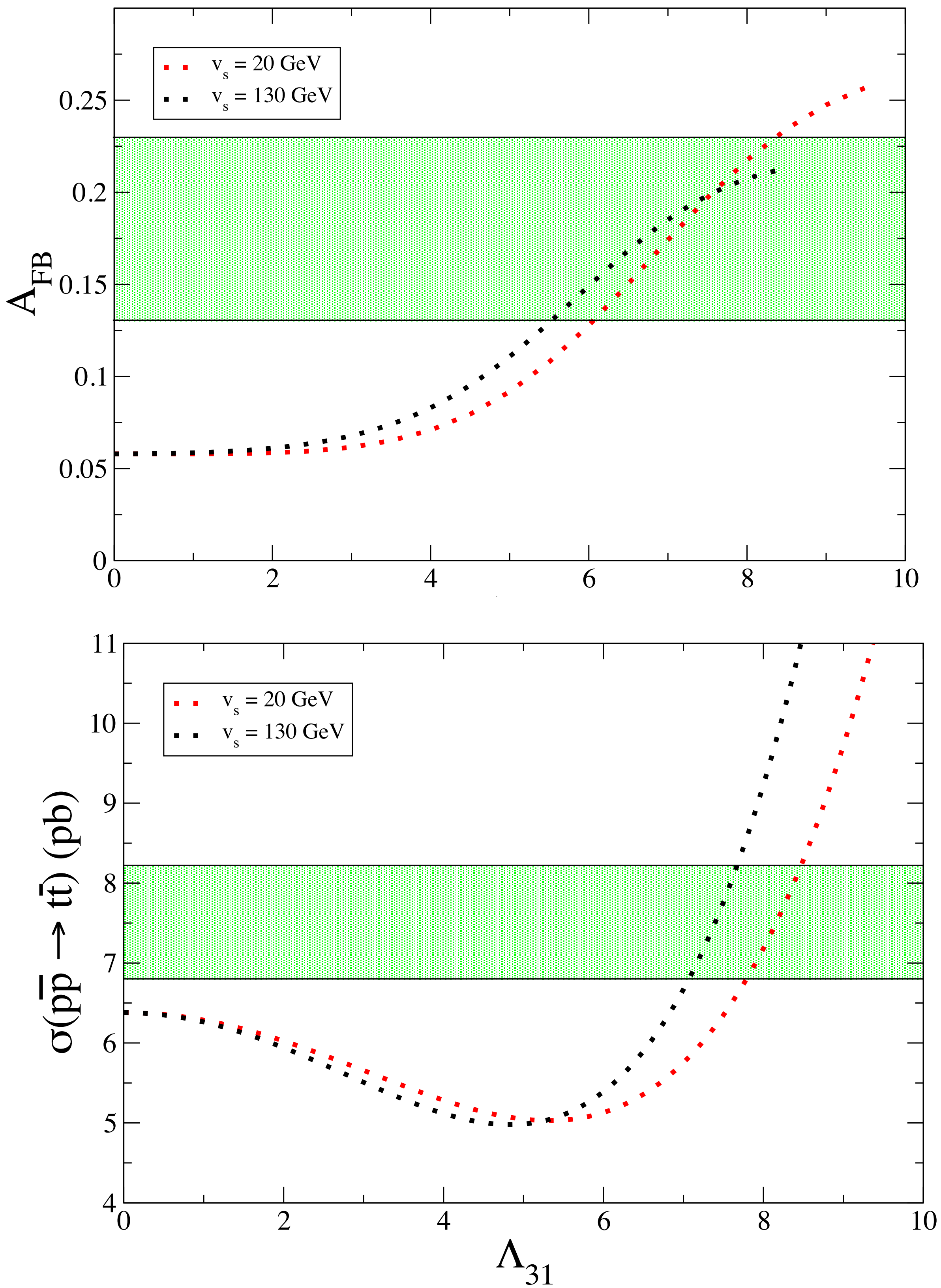
For all curves

$\mu_s = 20 \text{ GeV and } \mu, B_\mu = 0$

except for small v_s

where $\mu, \sqrt{B_\mu} = 180, 500 \text{ GeV}$

Small μ_s limit:



For all curves

$$\mu_s = 20 \text{ GeV and } \mu, B_\mu = 0$$

except for small v_s

where $\mu, \sqrt{B_\mu} = 0, 500 \text{ GeV}$

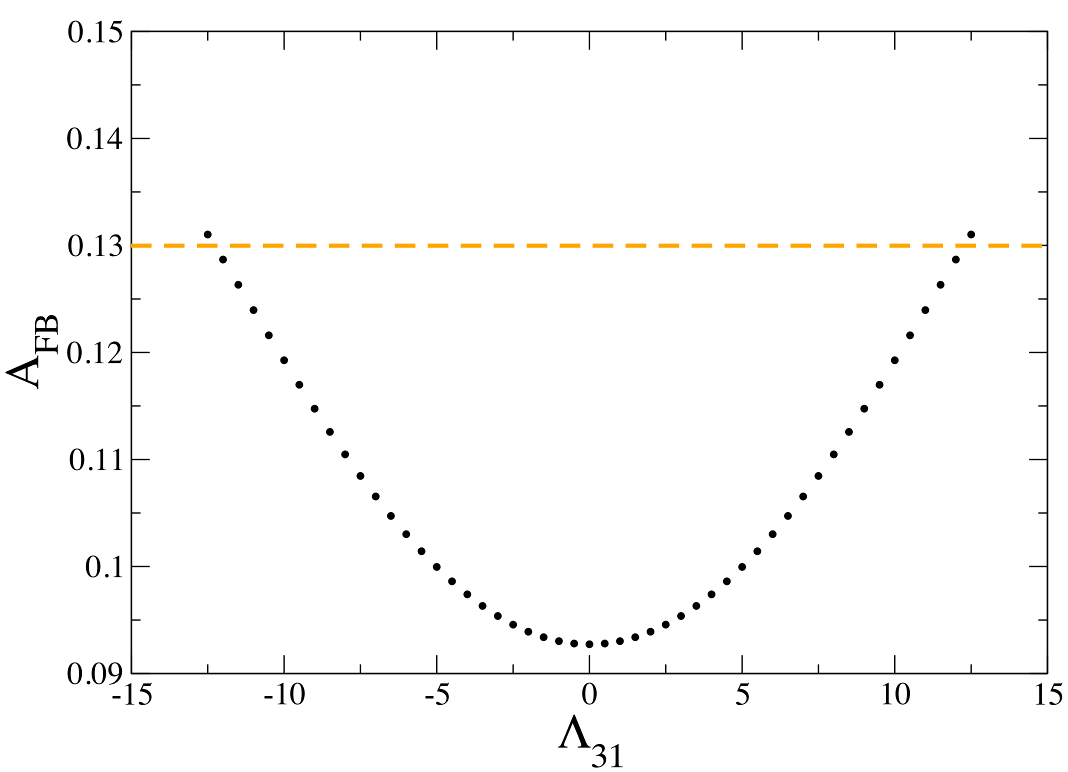
Large μ_s limit:

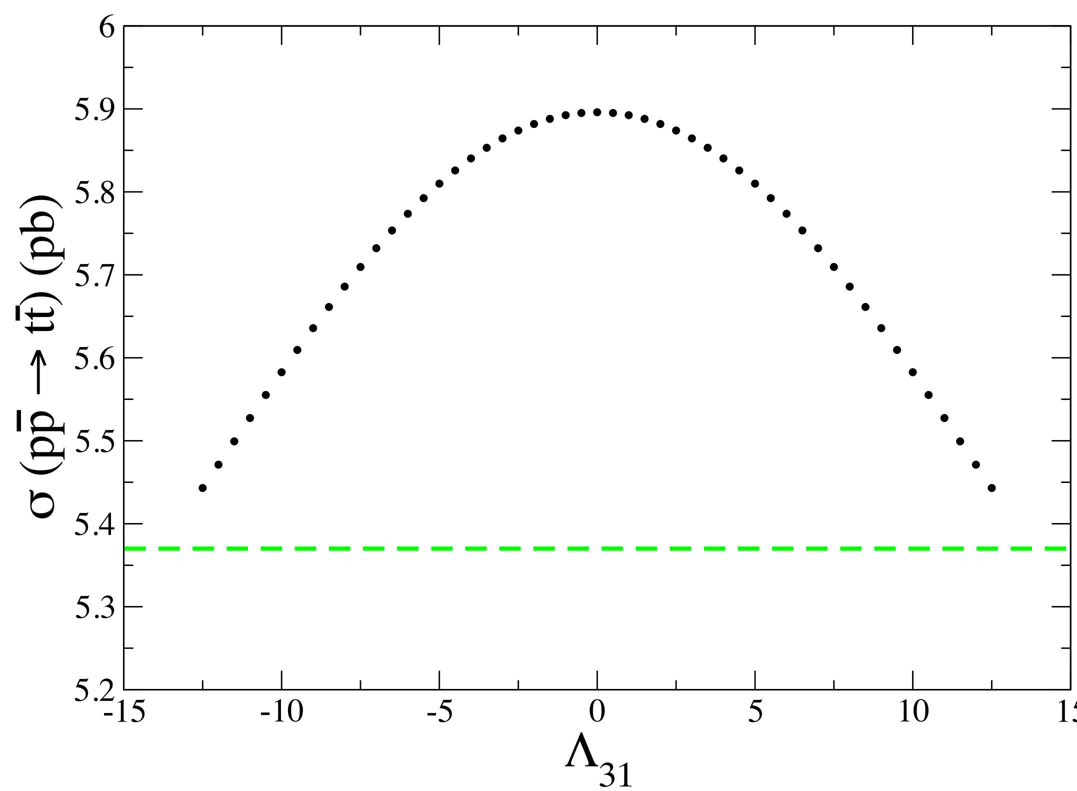
Singlet decouples and only light scalar is SM-like Higgs.

Coupling to up and top quarks proportional to

$$\frac{(\Lambda_{13,31})\, v \sin\beta}{M} O^H_{1,S}$$

$\mu_s = 1.5$ TeV, $\mu = 500$ GeV, $A_\lambda = -1.$ TeV and $\sqrt{B_\mu} = 500$ GeV





Large tension between minimizing negative interference contributions to the cross section and obtaining a large asymmetry

Conclusions:

- S-MSSM provides a natural solution to the LHP.
- Can be extended to address recent results from Colliders.

- In this work we address the large forward-backward top asymmetry reported by CDF and DØ.
- Small μ_s more promising with Λ couplings below 4π and regions where effective approach holds.
- Large μ_s, needs both $\Lambda_{13}, \Lambda_{31}$. Constraints can be easily satisfied since v_s is small. But... Cross section too small