Identifying new physics with photons at the LHC

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W. Ehrenfeld, A. Freitas, A. Landwehr, D. Wyler, arXiv:0904.1293

1. **New Physics with Photons**
2. **Analytical treatment of spin correlations**
3. **Monte-Carlo simulation**
4. **Conclusion**

New Physics with Photons

In **Gauge-mediated SUSY breaking** (GMSB) photons can originate from the decay $\tilde{\chi}_1^0 \to \gamma \tilde{G}$

Similar signature in **two Universal Extra Dimensions** (UED6) from $B_\mu^{(1,0)} \to \gamma\, B_H^{(1,0)}$

Ponton, Wang '06

Dobrescu, Kong, Mahbubani '07

UED6:

- $X^{(1,0)}$: lowest KK excitation
- Upon compactification, 6-componenet vector fields decompose into
  - 4-component KK vector fields $V_\mu^{(j,k)}$
  - One component being eaten to give mass to KK vectors
  - One physical **scalar** KK field $V_H^{(j,k)}$

New Physics with Photons

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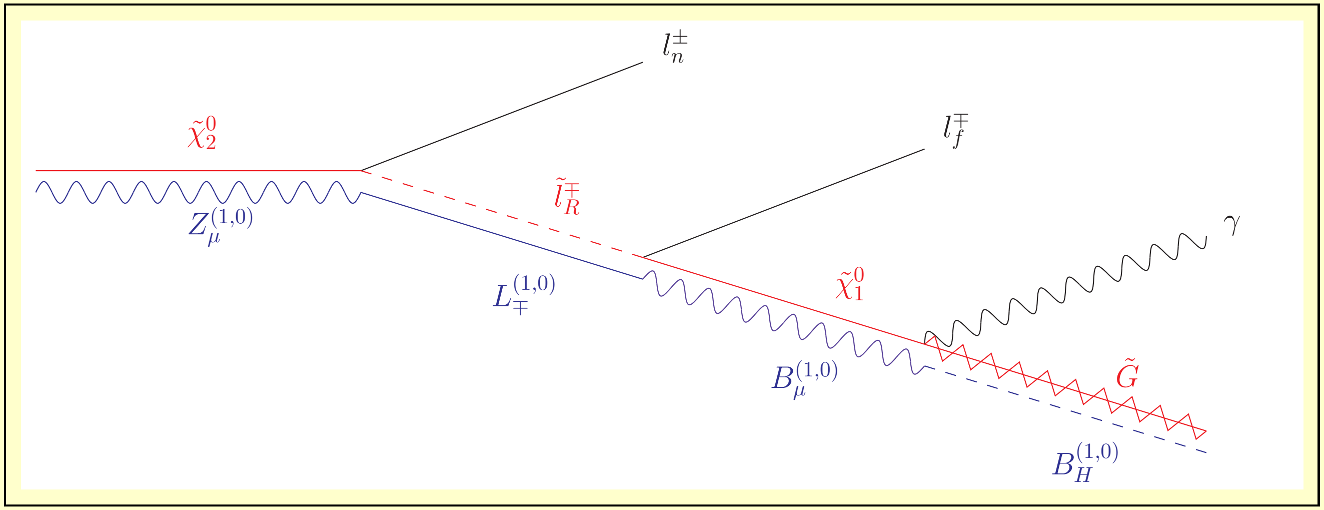
Typical decay chains:

$$\tilde{\chi}_2^0 \to l^\pm\, \tilde{l}_R^\mp \to l^+ l^-\, \tilde{\chi}_1^0 \to l^+ l^-\, \gamma\, \tilde{G}$$
$$Z_\mu^{(1,0)} \to l^\pm\, L_+^{(1,0)} \to l^+ l^-\, B_\mu^{(1,0)} \to l^+ l^-\, \gamma\, B_H^{(1,0)}$$



Mass spectra

G1a		U1	
Particle	Mass	Particle	Mass
$\tilde{g}$	747	$G_\mu^{(1,0)}$	696
$\tilde{u}_L$	986	$Q_+^{(1,0)}$	662
$\tilde{d}_L$	989		
$\tilde{u}_R$	942	$U_-^{(1,0)}$	608
$\tilde{d}_R$	939	$D_-^{(1,0)}$	606
$\tilde{\chi}_2^0$	224	$Z_\mu^{(1,0)}$	538
$\tilde{\chi}_1^0$	119	$B_\mu^{(1,0)}$	487
$\tilde{e}_L$	326	$L_+^{(1,0)}$	521
$\tilde{e}_R$	164	$E_-^{(1,0)}$	508
$\tilde{G}$	0	$B_H^{(1,0)}$	427

Minimal GMSB has hierarchical mass spectrum

UED6 **without UV operators** has more degenerate spectrum

But: Variations possible

Robust distinction only through spin analysis

Analytical treatment of spin correlations

Determine spin from distributions of visible decay products of

$$D \to l_n^{\pm} C \to l_n^{\pm} l_f^{\mp} B \to l_n^{\pm} l_f^{\mp} \gamma A$$

Barr '04
Smillie, Webber '05
Miller, Osland, Raklev '06

Can construct four invariant mass distributions

$$m_{n\gamma}^2 \equiv (p_{l_n} + p_\gamma)^2 = (m_{n\gamma}^{\text{max}})^2 \frac{1}{4}\left[2 - \left(1 - \frac{m_B^2}{m_C^2}\right)(1 - \cos\theta_{nf}^{(C)})\right](1 - \cos\theta_{n\gamma}^{(B)})$$

$$m_{f\gamma}^2 \equiv (p_{l_f} + p_\gamma)^2 = (m_{f\gamma}^{\text{max}})^2 \frac{1}{2}(1 - \cos\theta_{f\gamma}^{(B)})$$

$$m_{nf}^2 \equiv (p_{l_n} + p_{l_f})^2 = (m_{nf}^{\text{max}})^2 \frac{1}{2}(1 - \cos\theta_{nf}^{(C)})$$

$$m_{nf\gamma}^2 \equiv (p_{l_n} + p_{l_f} + p_\gamma)^2 = m_{n\gamma}^2 + m_{f\gamma}^2 + m_{f\gamma}^2$$

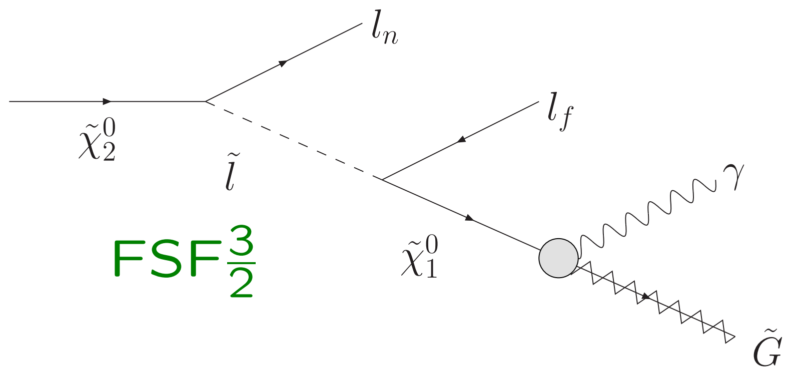
Cannot distinguish "near" lepton l_n and "far" lepton l_f experimentally

$\longrightarrow$ Use instead $\quad m_{h\gamma}^2 = \max\{m_{n\gamma}^2, m_{f\gamma}^2\} \quad m_{l\gamma}^2 = \min\{m_{n\gamma}^2, m_{f\gamma}^2\}$

Spin structures

GMSB:

FSF$\frac{3}{2}$



Visible spin correlations for **chiral** fermion vertices only   Wang, Yavin '07

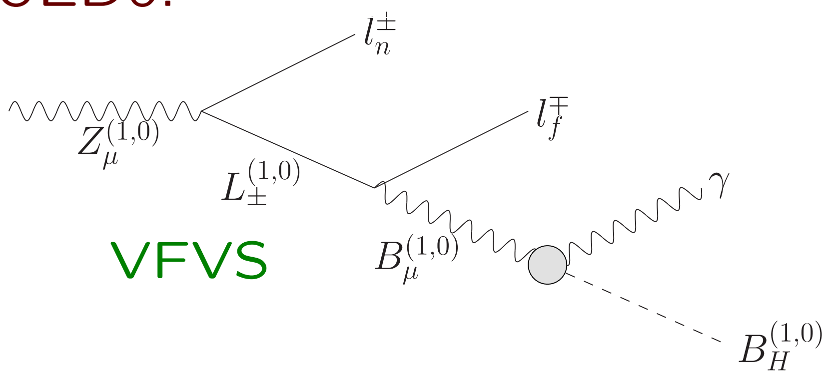
$\tilde{\chi}_1^0$-γ-$\tilde{G}$ vertex has the form

$[\not{p}_\gamma, \gamma_\mu]\, \gamma_\alpha$

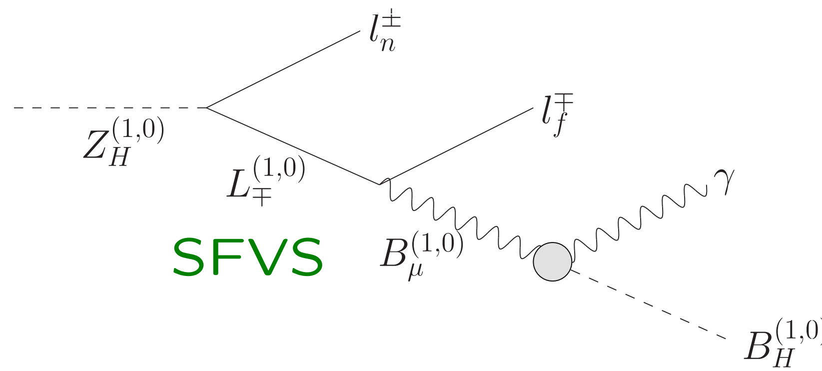
$\longrightarrow$ No spin effects for GMSB

UED6:

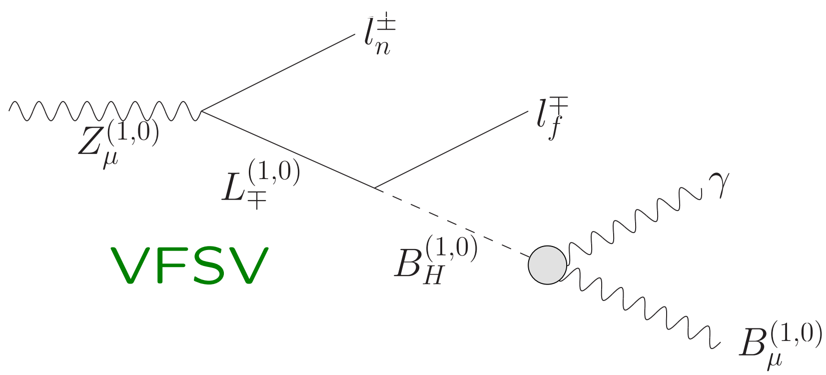
VFVS



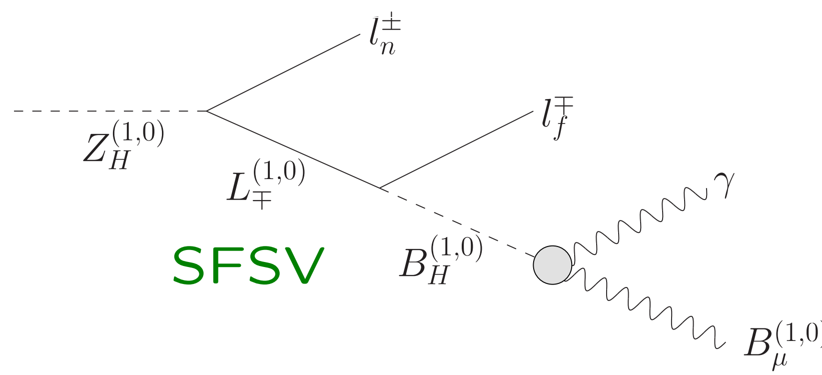
SFVS



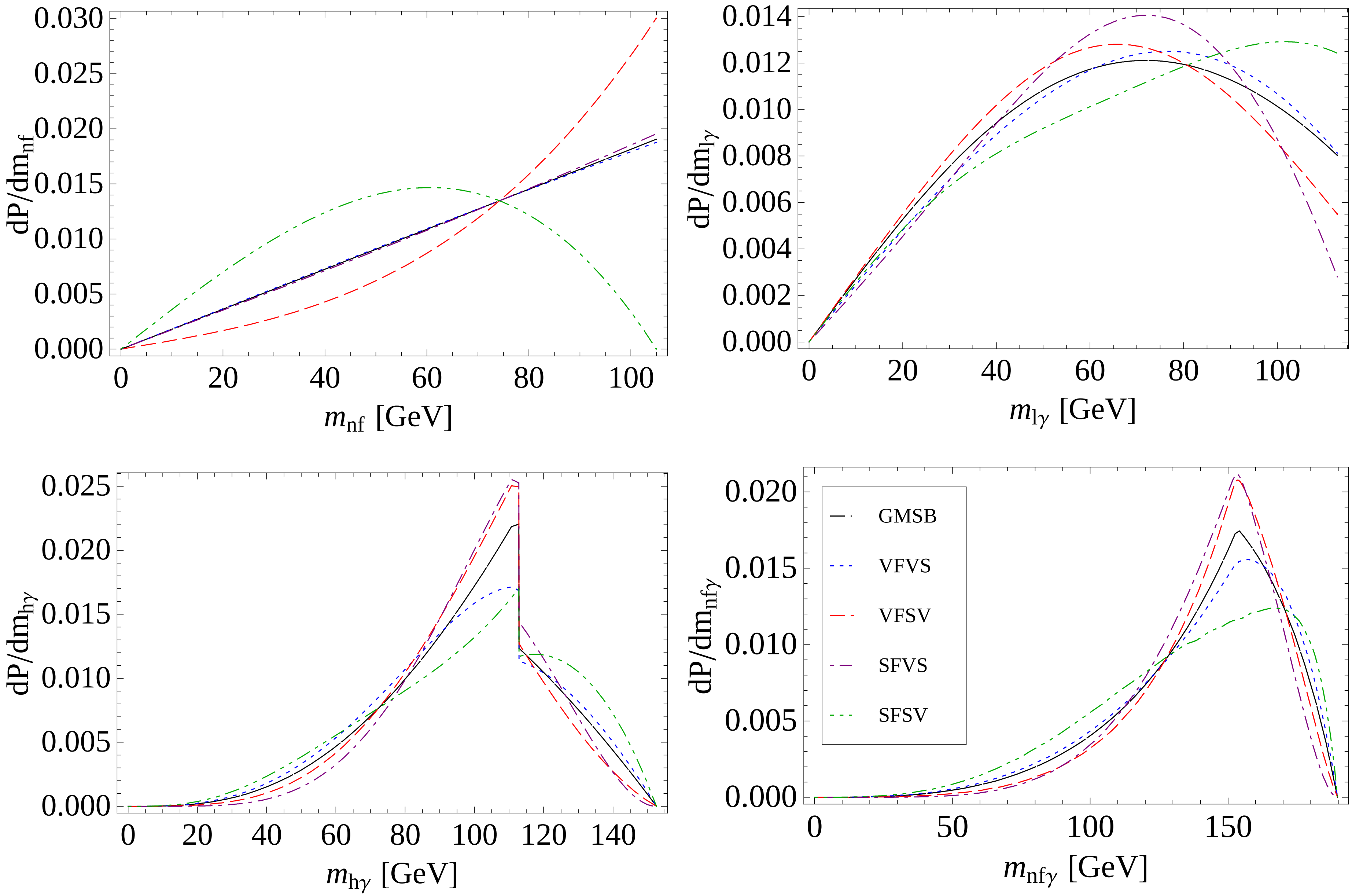
VFSV



SFSV

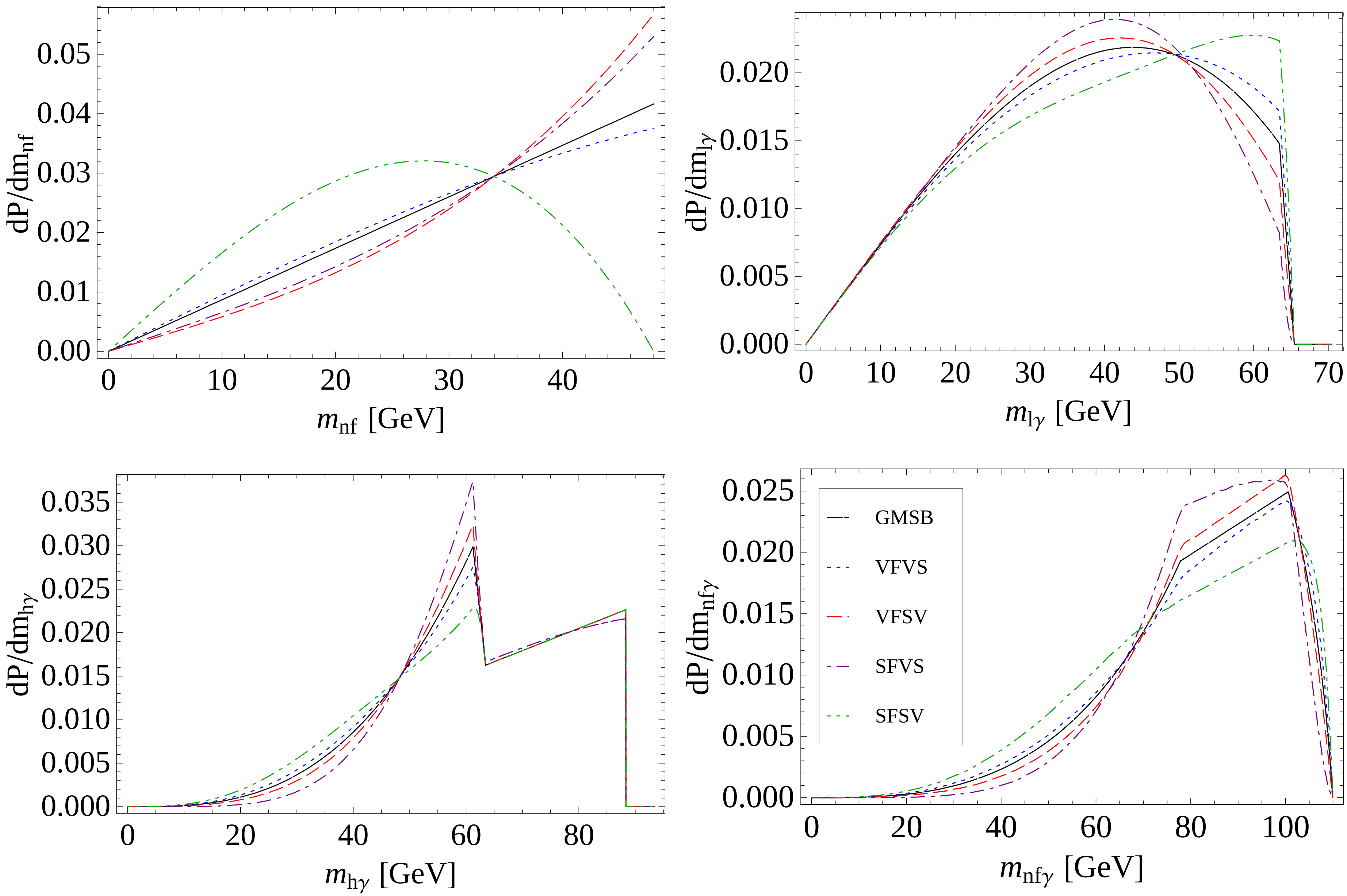


Results for scenario G1a



(Distributions are normalized to 1)

Results for scenario U1



(Distributions are normalized to 1)

Monte-Carlo simulation

- Event generation: CompHEP 4.4 + Pythia 6.4.12
- SUSY and KK particles are produced in pairs
  $\longrightarrow$ include second decay chain (with Pythia)
- Detector effects: AtlFast

- Cuts for SM reduction: Hinchliffe, Paige '99
  - 4 jets with $p_\top > 25$ GeV
  - $M_{\text{eff}} = \not{E}_\top + p_{\top,1} + p_{\top,2} + p_{\top,3} + p_{\top,4} > 400$ GeV
  - $\not{E}_\top > 0.1\, M_{\text{eff}}$
  - 2 photons with $p_\top > 20$ GeV
  - 2 electrons or muons with $p_\top > 20$ GeV

  $\longrightarrow$ Negligible SM background, 20% signal efficiency

Many event contain **two photons**

$\longrightarrow$ For computing distributions pick the one which gives smaller $m^2_{ll\gamma}$

Cross sections

Spin analysis depends only on **distribution shapes**, not **overall rate**

But rates are relevant for estimate of **statistical significance**

GMSB:

two sides of pair production

$$\sigma_{\text{G1a}} = \sigma_{\tilde{q}/\tilde{g}} \times 2 \times \text{BR}\left[\tilde{g} \to q\bar{q}\tilde{\chi}_2^0\right] \times \text{BR}\left[\tilde{\chi}_2^0 \to l^+l^-\tilde{\chi}_1^0\right] \times \text{BR}\left[\tilde{\chi}_1^0 \to \gamma\tilde{G}\right]$$
$$\simeq 1.2 \text{ pb}$$

UED6: Production cross sections are large

$\sigma_{Q_+^{(1,0)}Q_+^{(1,0)}} \sim 7$ pb $\sigma_{Q_+^{(1,0)}Q_-^{(1,0)}} \sim 18$ pb

$\sigma_{G_\mu^{(1,0)}G_\mu^{(1,0)}} \sim 10$ pb $\sigma_{G_\mu^{(1,0)}Q_+^{(1,0)}} \sim 24$ pb

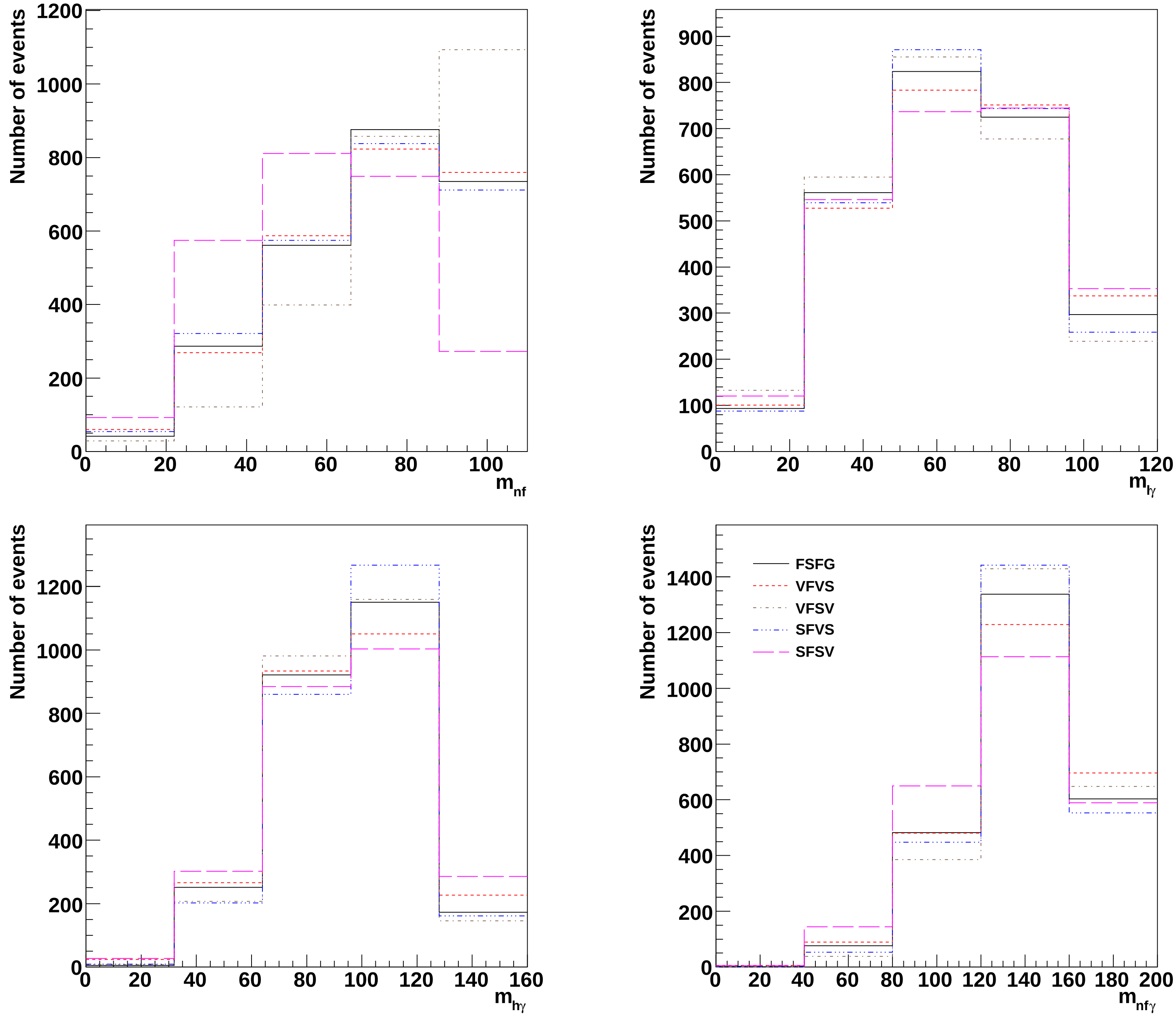
$\sigma_{G_\mu^{(1,0)}Q_-^{(1,0)}} \sim 26$ pb

Dobrescu, Kong, Mahbubani '07

But $\text{BR}\left[Z_\mu^{(1,0)} \to e^+e^-B_\mu^{(1,0)}\right] \approx 1.5\%$

$\longrightarrow \sigma_{\text{U1}} \simeq 0.12$ pb

Results

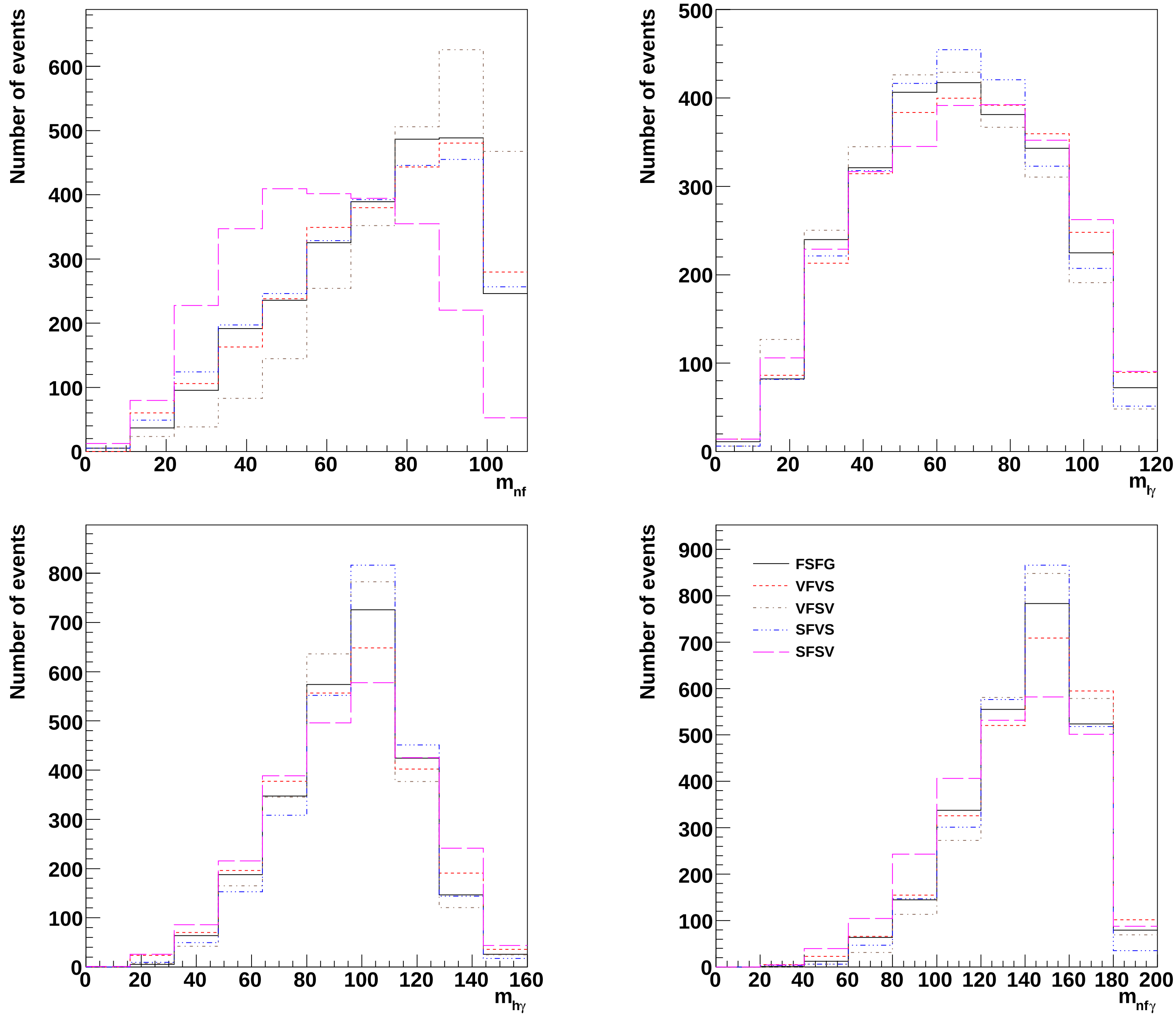


G1a

masses and cross sections

10 fb^{-1}

Results

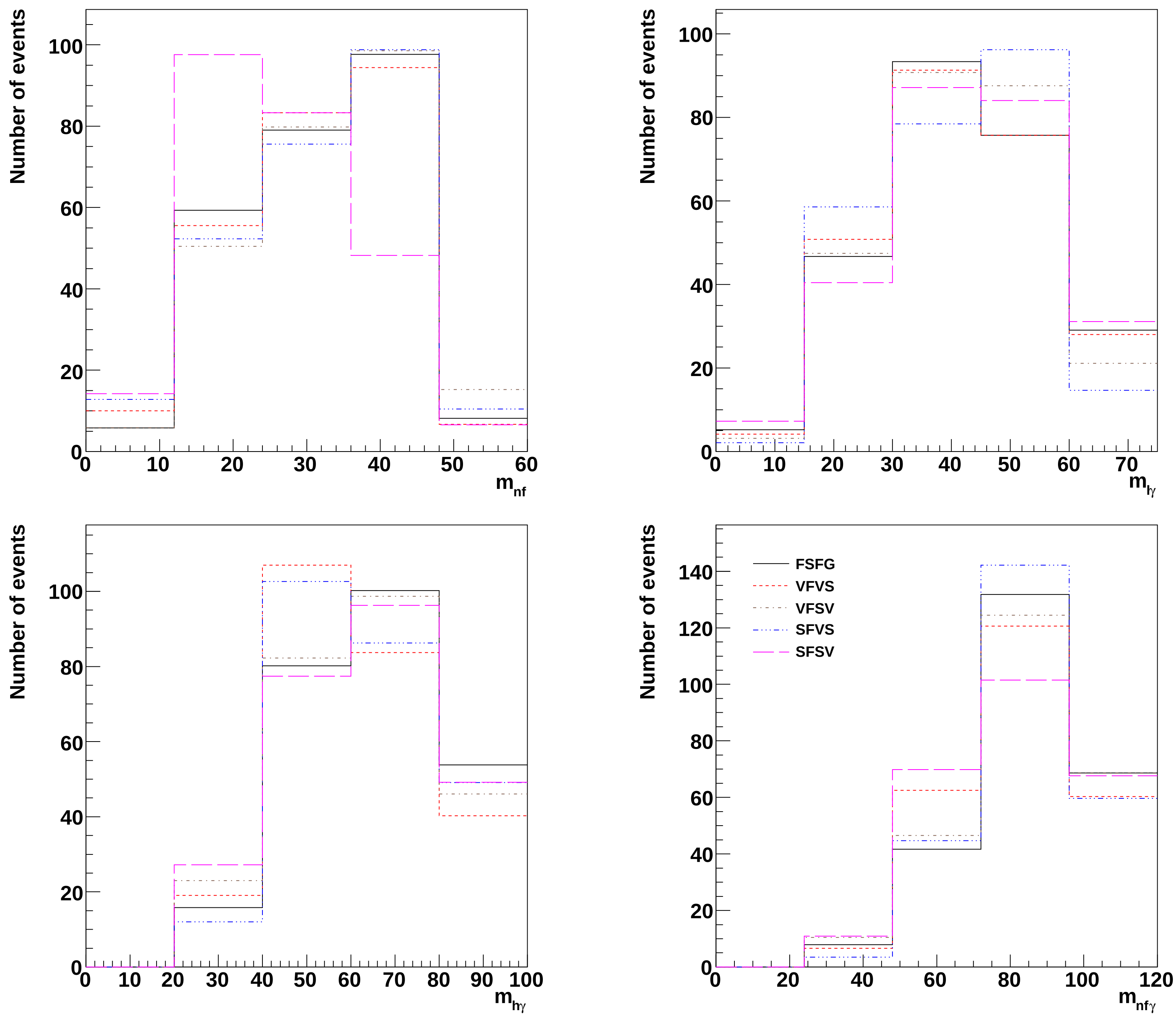


G1a

masses and cross sections

30 fb^{-1}

Results



U1

masses and cross sections

10 fb^{-1}

Conclusion

- GMSB and UED6 can be distinguished from spin correlations in decay chains
- χ^2 analysis with 10 fb^{-1}:

	GMSB	VFVS	VFSV	SFVS	SFSV
GMSB		0.000 ($m_{h\gamma}$)	0.000 (m_{nf})	0.006 ($m_{h\gamma}$)	0.000 (m_{nf})
VFVS	0.056 ($m_{h\gamma}$)		0.000 (m_{nf})	0.000 ($m_{h\gamma}$)	0.000 (m_{nf})
VFSV	0.577 (m_{nf})	0.155 ($m_{h\gamma}$)		0.000 (m_{nf})	0.000 (m_{nf})
SFVS	0.025 ($m_{l\gamma}$)	0.065 ($m_{l\gamma}$)	0.084 ($m_{h\gamma}$)		0.000 (m_{nf})
SFSV	0.000 (m_{nf})	0.000 (m_{nf})	0.000 (m_{nf})	0.000 (m_{nf})	

U1 masses and cross sec. G1a masses and cross sec.

(numbers are probability that two distributions originate from same underlying physics)