Some thoughts on spin determination

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What we would like to know

- Assumption: LHC found signals for new particles, missing energy
- Question: Is it SUSY, UED etc. or something nobody has thought of
- First hints from: cross sections and mass (differences)
- What about the spin ?

Many scenarios predict dominant 2-body decays

- spin investigated e.g. in
  C. Athanasiou et al., JHEP **08** (2006) 055; J.M. Smillie EPJC **51** (2007) 933

But what about 3-body decays $X \to f\bar{f}Y$, e.g. SUSY in focus point region, split SUSY

- in general complicated due to interference effects
- but in case of (very) heavy intermediate particles expand in $\epsilon = m_X/m_I$

Three body decays

- Generic formula for $X, Y \in \{S, V, F\}$

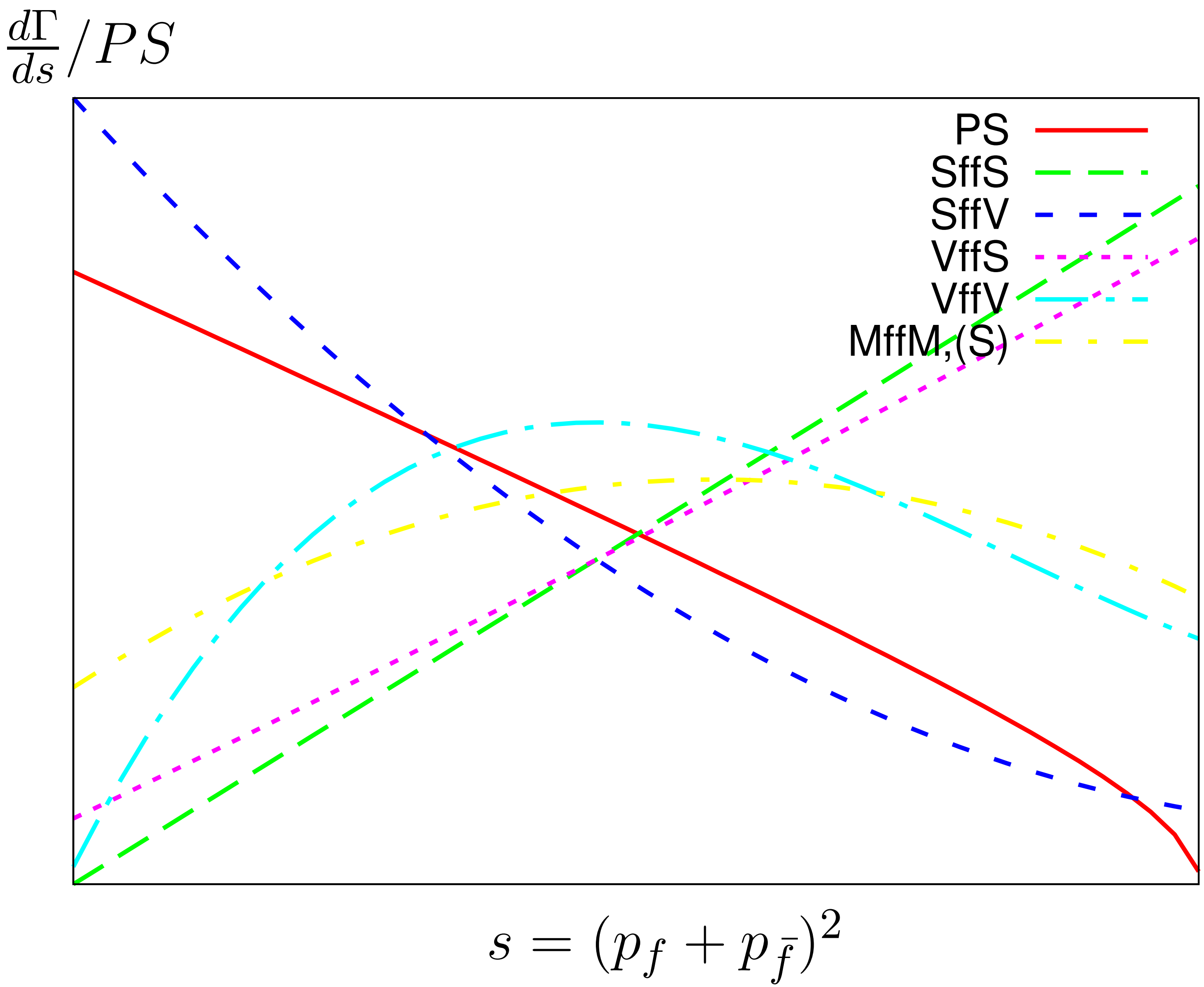
$$\Gamma(X \to f\bar{f}Y) \quad = \quad \frac{PS}{256\pi^3 \hat{s}} \left(\frac{Z}{\hat{s}} + A + B\hat{s} + C\hat{s}^2 + D\hat{s}^3 + E\hat{s}^4 + F\hat{s}^5 \right)$$

- $A, \ldots F, Z$ functions of $\epsilon, m_Y, m_X, g_i, m_f$
  expansion, e.g. $B = \sum_{k=2}^{4} B_k \epsilon^k$
- PS . . . phase space factor; $\hat{s} = f[(p_f + p_{\bar{f}})^2] \in [-1, 1]$
- only for $V \to f\bar{f}V$: $F, Z \neq 0$
- for $m_f = 0$

$$\Gamma(X \to f\bar{f}Y) \quad = \quad \frac{PS}{256\pi^3 \hat{s}} \left(B\hat{s} + C\hat{s}^2 + D\hat{s}^3 + E\hat{s}^4 + F\hat{s}^5 \right)$$

$F = O(\epsilon^4)$

Distributions for $X \to f\bar{f}Y$



all couplings are the same, all intermediate masses are equal

Coefficients for $m_f = 0$

some of the coefficients are either 0 or have a definite sign

	$S \to f\bar{f}S$			$S \to f\bar{f}V$			$V \to f\bar{f}S$		$V \to f\bar{f}V$		$F \to f\bar{f}F$
ϵ^2	unc.	c	1+2	unc.	c	1+2	unc.	c/1+2	unc.	c/1+2	ϵ^4
B_i	$\pm$	$\pm$	$+$	$+$	$+$	$+$	$+$	$+$	$+$	$+$	$\pm$
C_i	$\pm$	$\pm$	$+$	$\pm$	$\pm$	$\pm$	$+$	$+$	$\pm$	$\pm$	$\pm$
D_i	0	0	0	$+$	$+$	$+$	$+$	$+$	$\pm$	$\pm$	$-$
E_i	0	0	0	0	0	0	0	0	$+$	$+$	0

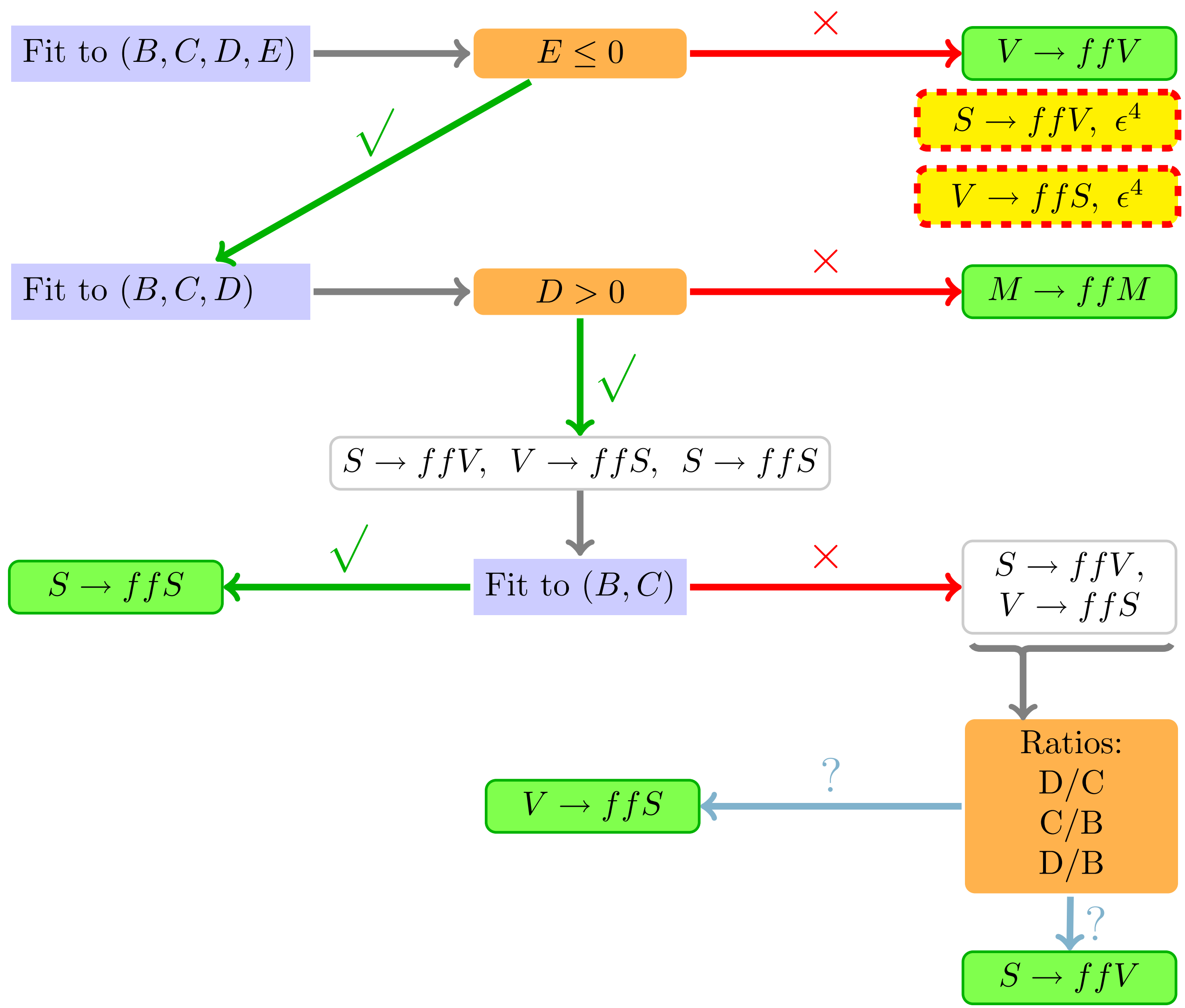
in addition

$$S \to f\bar{f}V: \quad D/C \in [-\tfrac{1}{2}, 0]$$
$$V \to f\bar{f}S: \quad D/C \in [0, \tfrac{1}{22}]$$

$$S \to f\bar{f}V: \quad C/B \in [-2, \tfrac{1}{2}]$$
$$V \to f\bar{f}S: \quad C/B \in [\tfrac{1}{2}, \tfrac{22}{25}]$$

$$S \to f\bar{f}V: \quad D/B \in [0, 1]$$
$$V \to f\bar{f}S: \quad D/B \in [0, \tfrac{1}{25}]$$

Strategy


Fit to (B, C, D, E)
$E \leq 0$
$V \to ffV$
$S \to ffV,\ \epsilon^4$
$V \to ffS,\ \epsilon^4$
Fit to (B, C, D)
$D > 0$
$M \to ffM$
$S \to ffV,\ \ V \to ffS,\ \ S \to ffS$
$S \to ffS$
Fit to (B, C)
$S \to ffV,$
$V \to ffS$
Ratios:
D/C
C/B
D/B
$V \to ffS$
?
?
$S \to ffV$

First results for $S \to f\bar{f}V$, I

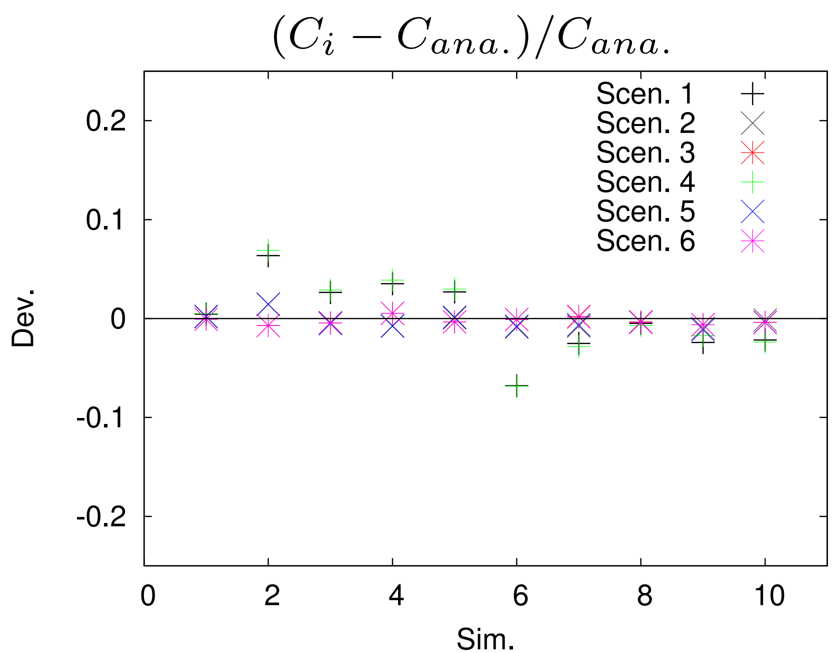
χ^2 :

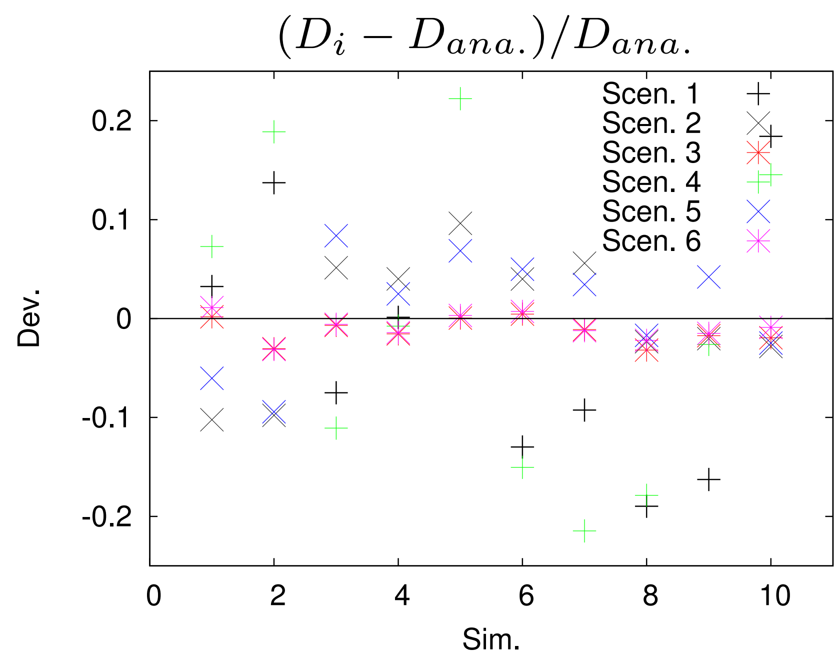
#bins	10			50		
#events	10k	100k	1000k	10k	100k	1000k
Scen.	1	2	3	4	5	6
(BC)	44	207	2082	30	23	237
(BCD)	1.28	1.63	1.17	1.12	1.11	0.93
(BCDE)	2.99	1.77	0.97	1.85	1.13	0.89
(BCDEF)	1.65	1.33	1.07	1.25	1.05	0.90

Scen.	1	2	3	4	5	6	Analytic
D/C	-0.372	-0.370	-0.375	-0.375	-0.367	-0.374	-0.372
C/B	-1.177	-1.181	-1.181	-1.175	-1.182	-1.181	-1.178
D/B	0.439	0.437	0.443	0.440	0.433	0.442	0.438

ratios for the (BCD) fit

First results for $S \to f\bar{f}V$, II





Things to be investigated

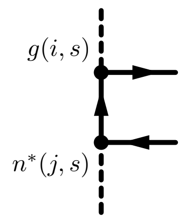
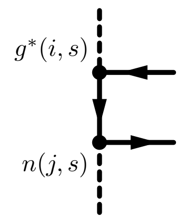
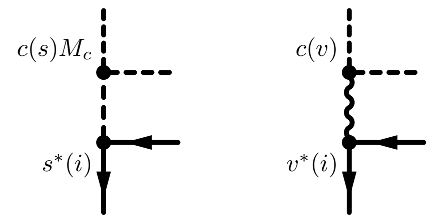
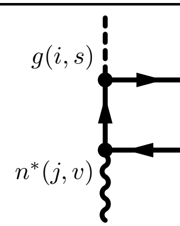
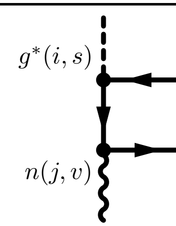
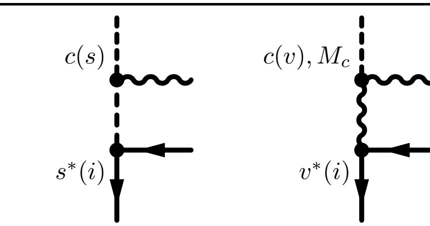
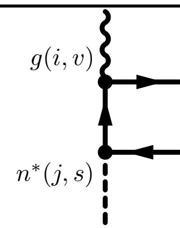
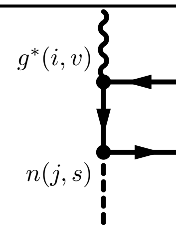
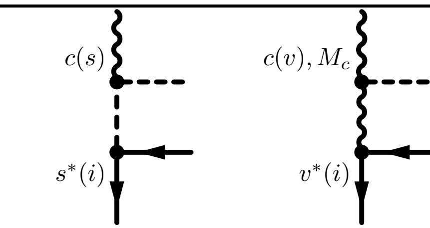
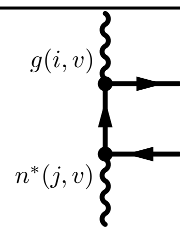
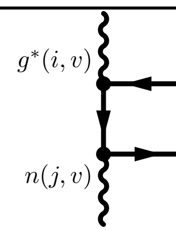
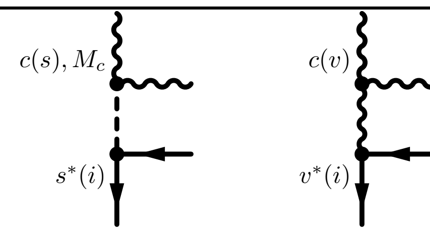
Known issues

- is indeed $m_X \ll m_I \rightarrow$ hint: small width
- how well can the decay chain be isolated
  pair production + subsequent decay, e.g. $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$
- radiative corrections will change things (how much?)
- what can be done for larger ϵ

Questions:

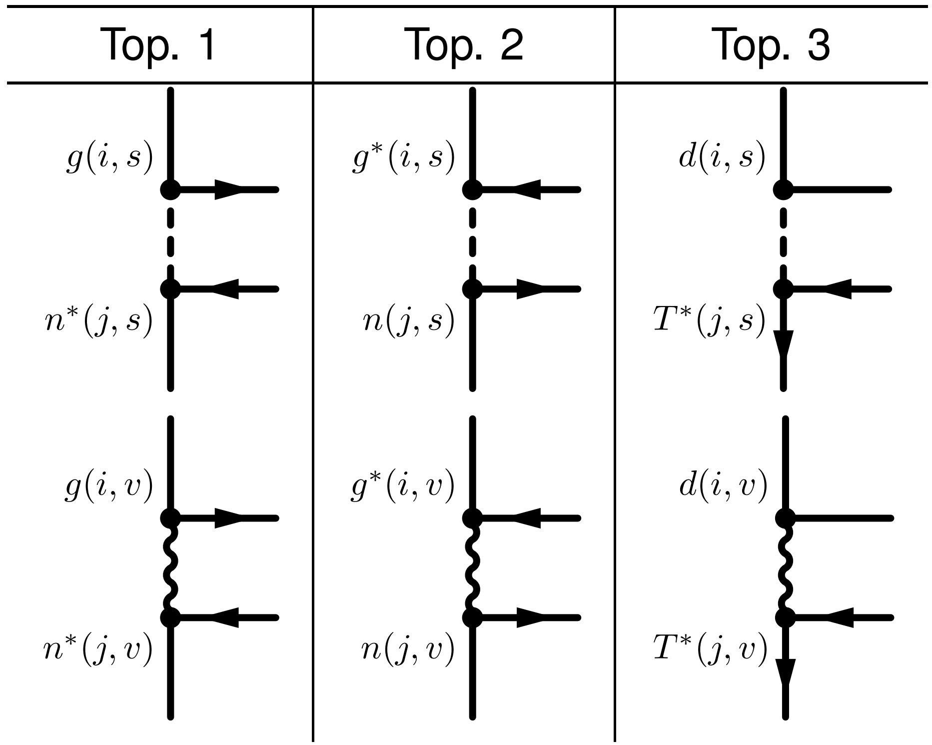
- how well can one measure such differential distributions?
- binning ?

Contributions I

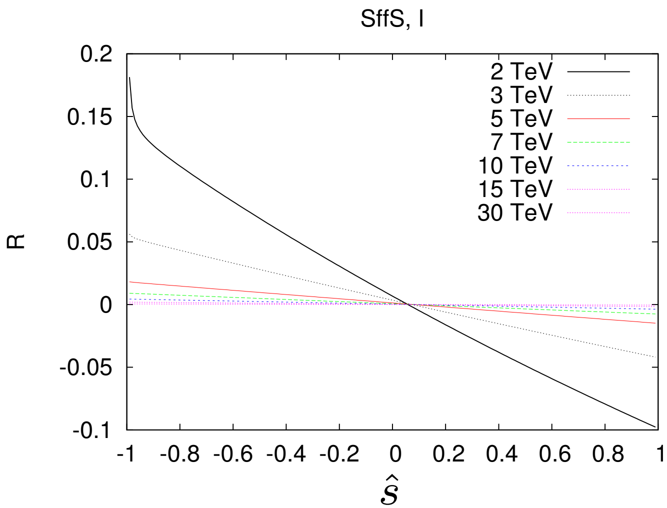
Decay	Top. 1	Top. 2	Top. 3(s/v)
$S \to f\bar{f}S$			
$S \to f\bar{f}V$			
$V \to f\bar{f}S$			
$V \to f\bar{f}V$			

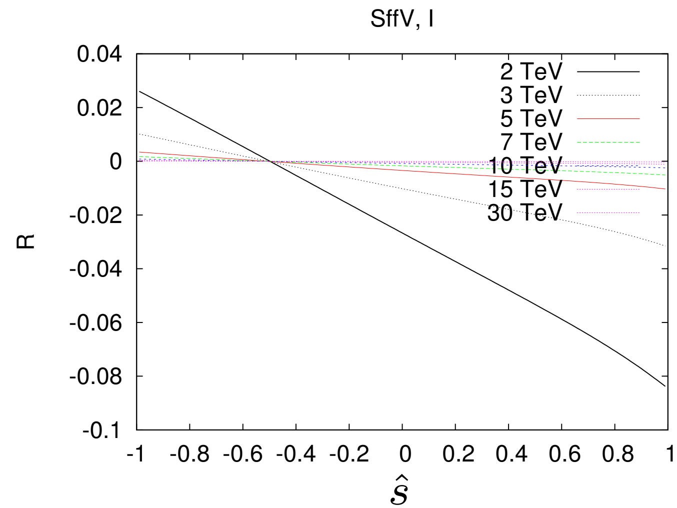
Contributions II

$$F \to f\bar{f}F$$

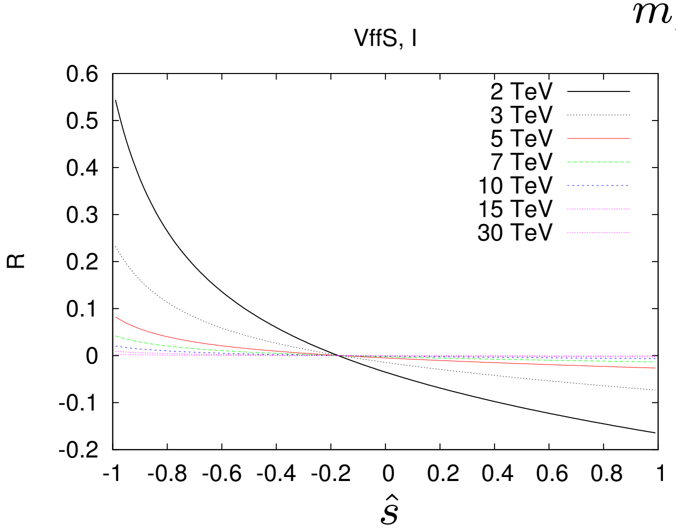


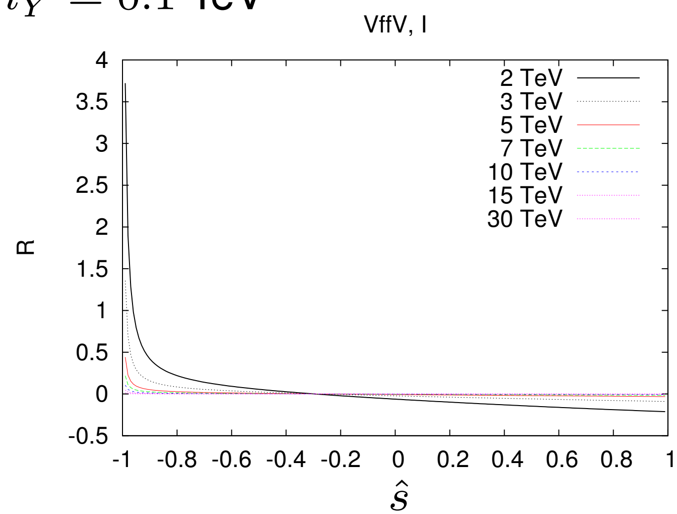
How large can ϵ be?





$m_X = 1$ TeV, $m_Y = 0.1$ TeV





$$R = \frac{\frac{1}{\Gamma_i}\frac{d\Gamma_i}{d\hat{s}} - \frac{1}{\Gamma_\infty}\frac{d\Gamma_\infty}{d\hat{s}}}{\frac{1}{\Gamma_\infty}\frac{d\Gamma_\infty}{d\hat{s}}}$$