Spin Discriminination in Three-Body Decays

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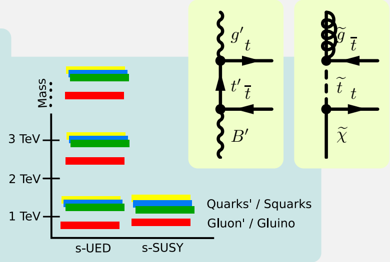
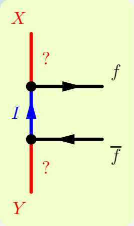
SUSY 2010, Bonn

What is our Work about?

- Same particle spectra in different models
- Determine spin to pin down underlying model
- Common example: UED vs. SUSY
- But: What about other spin assignments???



- Three body decay (conserved charge. . .)
- Intermediate heavy Particle → off-shell
- Undetectable child
- $X \to f\bar{f}Y$



Using a General Approach...

Writing down a general Lagrangian...

$$\mathcal{L}_{i,j,k}=X_i\bar{l}_f\widetilde{G}_i f+Y_i\bar{l}_f\widetilde{N}_i f+l_i\bar{f}\widetilde{T}_i f+l_iX_jY_k\widetilde{\Gamma}_{ijk}+h.c.$$

with generic couplings...

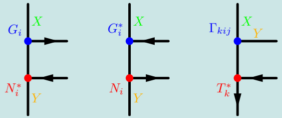
$\widetilde{G}_i$:	$G_s=(g(r,s)P_R+g(l,s)P_L)$;	$G_v=\gamma^\mu(g(r,v)P_R+g(l,v)P_L)$
$\widetilde{N}_i$:	$N_s=(n(r,s)P_R+n(l,s)P_L)$;	$N_v=\gamma^\mu(n(r,v)P_R+n(l,v)P_L)$
$\widetilde{T}_i$:	$T_s=(s(r)P_R+s(l)P_L)$;	$T_v=\gamma^\mu(v(r)P_R+v(l)P_L)$

We have three topologies:

Fermionic propagator (Top 1+ Top 2): $F_p=i\frac{\not{p}\ +m_l}{p^2-m_l^2}\propto\frac{1}{m_l}\propto\epsilon$;

Bosonic propagator (Top 3):

$W_{P,v}=-i\frac{(g^{\mu\nu}-p^\mu p^\nu/m_l^2)}{p^2-m_l^2}\propto\frac{1}{m_l^2}\propto\epsilon^2$; $W_{P,s}=i\frac{1}{p^2-m_l^2}\propto\frac{1}{m_l^2}\propto\epsilon^2$;

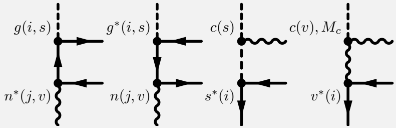


Approach:

- Calculate differential decay width $d\Gamma=d\,s\;d\,t|\mathcal{M}|^2$ where $s=(q_f+q_{\bar{f}})^2$, t invisible
- Expand in $1/m_l\propto\epsilon$
- Express decay width as polynomial in s:

$$d\Gamma=ds\;\;\text{PS}\cdot\epsilon^2\left(Z/s^2+A/s+B+C\cdot s+D\cdot s^2+E\cdot s^3+F\cdot s^4\right)$$

What are the characteristics of these coefficients? Example: $S \to f\bar{f}V$



$$d\Gamma = d\,s\ PS \cdot \epsilon^2 \left(Z/s^2 + \frac{A}{s} + B + C \cdot s + D \cdot s^2 + E \cdot s^3 + F \cdot s^4 \right)$$

$$B = \frac{64}{3\tau_Y^2} \left(g(r,s)^2 n(l,v)^2 + g(l,s)^2 n(r,v)^2 \right) \epsilon^2 (\tau_Y - 1)^2 \left(25\tau_Y^2 + 6\tau_Y + 1 \right) \quad +$$

$$C = \frac{128}{3\tau_Y^2} \left(g(r,s)^2 n(l,v)^2 + g(l,s)^2 n(r,v)^2 \right) \epsilon^2 (\tau_Y - 1)^2 \left(11\tau_Y^2 - 2\tau_Y - 1 \right) \quad \pm$$

$$D = \frac{64}{3\tau_Y^2} \left(g(r,s)^2 n(l,v)^2 + g(l,s)^2 n(r,v)^2 \right) \epsilon^2 (\tau_Y - 1)^4 \quad +$$

$$Z = A = E = F = 0$$

Ratios:
D/C: $\in [-1/2, 0]$
C/B: $\in [-2, 1/2]$
D/B: $\in [0, 1/25]$

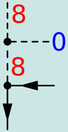
What does our Strategy look like?

'Faking' the order of ϵ^2:

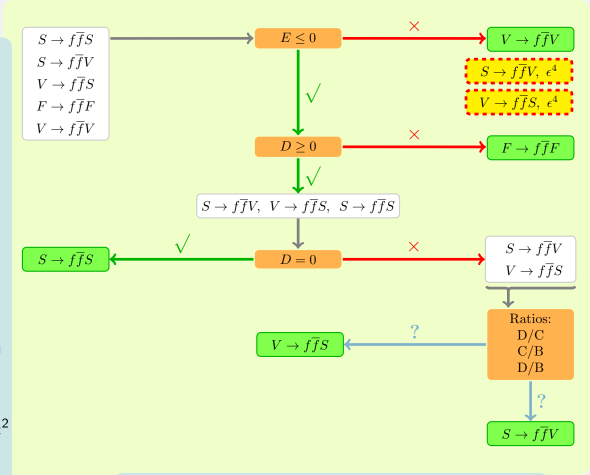
- If $g(r) = n(r) = 0$, ϵ^2 vanishes, and ϵ^4 'fakes' the leading order
- But: Decrease of absolute decay width with $1/M_l^4$!

ϵ^4	(S,S)	(S,V)	(V,S)	(V,V)
B	0	$\pm$	$\pm$	$\pm$
C	0	$\pm$	$\pm$	$\pm$
D	0	$\pm$	$\pm$	$\pm$
E	0	$+$	$+$	$+$
F	0	0	0	$+$

Changing the order in ϵ via energy dependent couplings:



- $M_c \propto M_l \propto 1/\epsilon \rightarrow \epsilon^4/\epsilon^2 = \epsilon^2$
- Only possible in two diagrams
- Additional contributions to coefficients
- No change for signs of coefficients



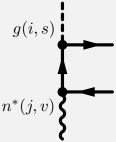
Fitting Problems:

- Low number of events $\rightarrow$ Noisy data
- Mass determination
- Fit procedure

Strategy in a not so Perfect World

Possible Models: $\{(S,S),(S,V),(V,S),(F,F),(V,V),(V,V)_4\}$

Possible Polynomials: $\mathcal{O}(s^1),\mathcal{O}(s^2),\mathcal{O}(s^3),\mathcal{O}(s^4)\quad(*)$



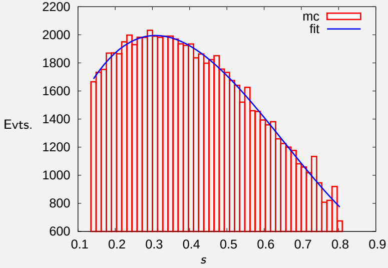
Integration by Partition:

$\sum_{i=1}^{n}\int_{-1+(i-1)\Delta\hat{s}}^{-1+i\Delta\hat{s}}\frac{d\Gamma}{d\hat{s}}d\hat{s}$

Fitting by Linear Least Squares and solving:

$(\hat{X})^T\hat{X}\cdot\vec{c}=(\hat{X})^T\vec{d}$

where $\vec{d}$: data, X: s values, $\vec{c}$: Coefficients



Masses:
$m_Y=(100\pm10)\ GeV$,
$(m_X-m_Y)=(900\pm20\ GeV)$, $m_l=3\ TeV$

- Implementation of generic model LAMA in O'Mega/Whizard
- Generate 100 random coupling sets for (S,S), (S,V), (V,S), (F,F), (V,V) for 10^4, 10^5, 10^6 events
- Fit them to $(*)$
- Apply strategy ⇊ and count the number of remaining models

1. $B\neq C\rightarrow$ remove (S,S)
2. $D>0\rightarrow$ remove (F,F); $D<0\rightarrow$ remove $(S,V),(V,S)$
3. C/B in (S,V) interval $\rightarrow$ if not remove (S,V)
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5. D/B in (S,V) interval $\rightarrow$ if not remove (S,V)
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10. if $F<0$ in $(V,V)_4$, $\rightarrow$ remove $(V,V)_4$
11. *Optional: Remove all models with* $\chi^2>3$
12. *Optional: Remove* $(V,V)/(V,V)_4$ *if* $E,F<0.001$ *respectively*

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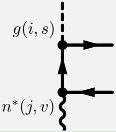

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	(S,S)	(S,V)	(V,S)	(F,F)	(V,V)	(V,V_4)
10^4 events:						
(S,S):	**97**	0	24	99	100	100
(S,V):	0	**100**	0	3	100	100
(V,S):	0	0	**100**	100	99	100
(F,F):	0	1	0	**100**	100	100
(V,V):	0	67	0	78	**100**	100
10^5 events:						
(S,S):	**99**	0	0	100	100	100
(S,V):	0	**95**	0	3	100	100
(V,S):	0	1	**99**	100	100	100
(F,F):	0	0	0	**100**	100	100
(V,V):	0	17	0	60	**100**	100
10^6 events:						
(S,S):	**96**	0	0	100	100	100
(S,V):	0	**87**	0	6	100	100
(V,S):	0	1	**99**	100	100	100
(F,F):	0	0	0	**100**	100	99
(V,V):	0	2	0	57	**100**	99

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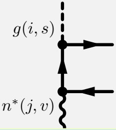

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	(S,S)	(S,V)	(V,S)	(F,F)	(V,V)	(V,V$_4$)
10^4 events:						
(S,S):	**97/97**	0/0	24/24	99/99	99/82	99/84
(S,V):	0/0	**96/100**	0/0	1/3	95/94	97/87
(V,S):	0/0	0/0	**100/100**	100/100	99/94	100/87
(F,F):	0/0	1/1	0/0	**100/100**	99/97	100/87
(V,V):	0/0	56/67	0/0	48/78	**98/96**	99/95
10^5 events:						
(S,S):	**99/99**	0/0	0/0	100/100	100/60	100/68
(S,V):	0/0	**94/95**	0/0	0/3	100/88	99/70
(V,S):	0/0	1/1	**99/99**	100/100	100/56	100/73
(F,F):	0/0	0/0	0/0	**100/100**	100/72	100/70
(V,V):	0/0	2/17	0/0	1/60	**99/97**	97/87
10^6 events:						
(S,S):	**96/96**	0/0	0/0	100/100	100/13	100/20
(S,V):	0/0	**87/87**	0/0	0/6	100/54	100/42
(V,S):	0/0	1/1	**99/99**	100/100	100/17	100/30
(F,F):	0/0	0/0	0/0	**100/100**	100/31	100/27
(V,V):	0/0	0/2	0/0	0/57	**100/100**	99/66

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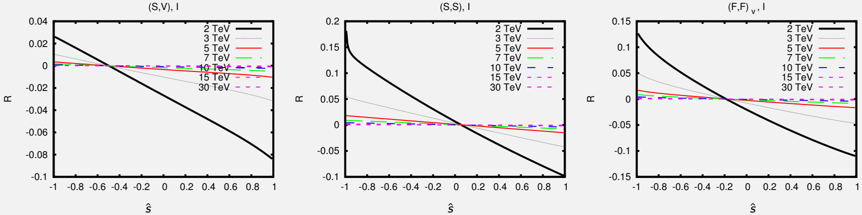
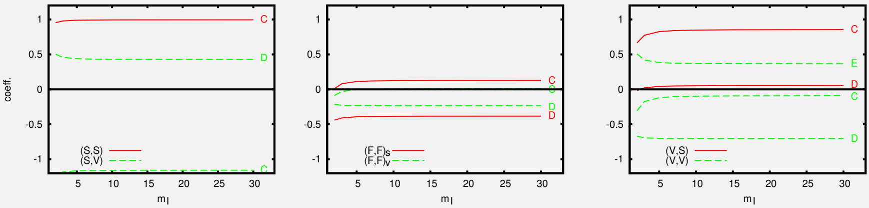
Which mass ranges are fine for m_l?



$R = \frac{d\,\Gamma_\epsilon - d\,\Gamma_H}{d\,\Gamma_H}$; Masses: $m_X = 1\ TeV,\ \ m_f = 0,\ \ m_Y = 100\ GeV$



Conclusions

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- Model independent approach for determination of spin in three-body decays
- Possibility to distinguish between decaying scalar, vector & fermion

Outlook:

- Improving strategy by using polarization information of SM fermions
- Determine spin of intermediate particle in fermion decays
- What if $m_l \sim m_X$?

Based on: arXiv:1005.3720 (JHEP)

Thank you for your Attention!