SPheno 3.3.0: extensions including flavour, CP-phases and models beyond the MSSM

oro [1] an F tau [2]

Inst tut für or t s s un Astrop s , n v rs tät ür urg
D ür urg G r an

Abstract

s r r nt t ns ons of t progra SPheno n u ng avour asp ts, C p as s, -par t v o at on an ow n rg o s rva s In as of avour ng a ass s of sup rs tr part s a a u at n u ng t o p t avour stru tur an a poss C p as s at t -oop v g v ta s on p nt s saw o s, ow n rg o s rva s an t orr spon ng t ns on of t Y s Hou s A or or ov r, w o nt on t poss t s to n u t ns ons n SPheno

Program Summary

Program title no
Program Obtainable from: `http://projects.hepforge.org/spheno/`
Programming language
Computers for which the program has been designed

1. Introduction

In ts org na v rs on SPheno a n sgn to a at t sp tru n t n g t ng an ts u to g n rat on ng or C v o at on [ ] or ov r, t two- an t r - o a s of t Y part s as w as of t H ggs osons an a u at as w as t pro u t on rat s of t s part s n e^+e^- ann at on o ts f s wrtt n n FORTRAN

progra as n t n to n u avour asp ts, C v o at on an -par t v o at on or ov r, r nt var ants of t s saw an s av n p nt In t s pap r w s r t orr spon ng ang s an p ntat ons D ta s on t a gor t s us an foun n t org na anua [ ] or ov r, w g v n t app n s t fau t va u s for var ous ags as w as t rror o ng

2. Extensions with MSSM particle content at the electroweak scale and conserved R-parity

SPheno as n t n to n u avour an C v o at ng p as s us ng t HA onv nt ons [ ] for t g n ra For t s purpos t o p t avour stru tur s n u ng C p as s av n p nt n t GEs at t - oop v us ng t for u as g v n n [ ] av t n t for u as of [ ] for t - oop ass s to a ount for t avour stru tur s, g w a u at t - oop orr t 6×6 ass atr s for squar s an arg ptons an t - oop orr t $\times$ ass atr for sn utr nos [, 6] or ov r, w ta nto a ount a poss p as s n t a u at on of a ass atr s at t - oop v ut for on pt on w o not ons r t oop n u ng tw n t s a ar an ps u os a ar H ggs osons For t - oop orr t ons to t H ggs-s tor w us t for u as of r f [–] In t orr spon ng for u as g n rat on ng s n g t an t us, t ar p nt su t at w ta t t r g n rat on ass para t rs n t sup r-CK ass s for t squar s an n t sup r- ass s for t s ptons as nput, w r for t pr s n t on of t two as s w r f r to r f [ ] s approa g v s r a r su ts prov n t ng tw n n an r g n rat on s f r ons s s a n t sup r-CK ass How v r, for a arg ng tw n t s two g n rat ons, w s av r str t B-p s s ata, s g [ ], t s approa n u an a t ona t or t a un rta nt a ng t sa approa for t - oop a u at on an u t p ng t orr spon ng r n s α_s w g t as a roug st at an un rta nt of up to G u to n g t ng avour ng n t -oop a u at on n as of a arg ng

A o par son for t H ggs ass s tw n t r su ts of t s o an t sp tru g n rators SOFTSUSY [ ], SuSpect [ ] an t progra FeynHiggs [ ] an foun n r f [6], w r a so an st at of t a v a ura s for var ous s nar os an foun In r f [6] avour ng as not n ons r How v r, w av , t at t r su ts o ta n n r f [6] ar qua tat v un ang , w n o par ng SPheno w t FeynHiggs after turn ng on avour ng or ov r, w a n w output o s w s rv as nput for t progra HiggsBounds [,] to a u at t n at a for n at tr – v In t s as t fo ow ng a o s ar portant [–]

$$\tilde{t}_1 \rightarrow c\,\tilde{\chi}^0_{1,2} \qquad (\ )$$

$$\tilde{t}_1 \rightarrow W^+\,b\,\tilde{\chi}^0_1,\ H^+\,b\,\tilde{\chi}^0_1 \qquad (5)$$

$$\tilde{t}_1 \rightarrow b\,\nu_i\,\tilde{l}^+_j,\ b\,l^+_i\,\tilde{\nu}_k\,. \qquad (6)$$

In as of G B o s s nar os st w r t arg s ptons ar n t to g t st sup rs tr part s ( ) an t grav t no $\tilde{G}$ s t In t s as t s ptons a a or ng to

$$\tilde{l}_i \rightarrow l_j\,\tilde{G} \qquad (\ )$$

t r n w r a so t for u as for t tr - v w t s an foun In t pr s nt v rs on on t g uon QCD orr t ons for t a s nto quar s [,] av n p nt a s nto t gg na stat av n p nt us ng t ow st or r for u a as g v n n [6] r for , t nu rs prov SPheno av to ta n w t ar an for r n ana s s ot r progra s, su as HDECAY [6], FeynHiggs [, 6] or HFOLD [6] s ou us

av t at t r su ts of t rout n s agr w t t output of HIZA D [6] us ng t too o pa ag [6] or ov r, s v ra of t nu r a r su ts a s av n ross- t aut ors of t progra SDECAY [, 66] as w as a ross- of var ous r su ts o ta n n [6 −] av n p rfor In a t on t s t of ow n rg o s rva s as n t n as s r n s t on

t n t s v ra o ass s ar p nt

- H g s a o s G A, G B, A B
- A G A s nar o w r a soft Y r a ng para t rs ar g v n fr at t G s a w s t r n usua v a t on t on $g_1(M_{\mathrm{GUT}}) = g_2(M_{\mathrm{GUT}})$ How v r, t s s a an s t to a va u us ng ntr n o SPhenoInput, s s t on 6 In a t on on sp fr t on-s ass of t ps u os a ar an t sup rpot nt a para t r μ at t trow a s a Bot poss t s a ow for t p ntat on of non-un v rsa H ggs ass para t rs w p ng t s f r ons un v rsa as propos an s uss g n [−]
- A para t rs sp at t trow a s a Q_{EWSB} w t a us r sp va u for Q_{EWSB}

In a as s t s assu t at t r qu r nput s g v n v a t HA onv nt on [,]

In a t ons v ra ass s of n utr no ass o s av n n u w t a t ona stat s at g n rg s a s For t ata an ng w t n t HA for at w as now o part of a pu proposa [6] an w ar s uss n ta n s n u o s ar

- A s saw I o w t r nt ass s for t r g t- an n utr nos orr spon ng par- t ont nt an os n s tt ng t ntr of t o MODSEL as s r n s t on para t rs ar s t us ng t o s MNURNURIN an YNURLHUIN, s s t ons an , r sp t v s ng t s t r su ts of [,] av n o ta n
- wo var ants of s saw II o av n p nt H r on an t r oos a pa r of $SU( )$ tr p ts or a pa r of $SU( )$ -p ts to g n rat n utr no ass s rst v rs on us s t for u as [ ] n u ng t orr t ons pr s nt n [ ] an - oop GEs for t gaug oup ngs an gaug no ass para t rs as us n [ ] s var ant s fast r f on us s - oop GEs ut ss a urat n part u ar for ow s saw s a s [ ]

  In as of a pa r of $SU( )$ -p ts a s on var ant as n p nt us ng t o p t - oop GEs an orr spon ng t r s o orr t ons at t s saw s a as s r n [ ] In ot as s t o s M15IN (M15T15TBIN), YHD15THDIN, YHU15TBHUIN an Y15IN (YL15TLIN) av to us to transf r t ata, s s t ons ( ), , an ( ) o s n par nt s ar to us n as of $SU( )$ tr p ts on
- A s saw III o w t t r $SU( )$ att r -p ts us ng t o p t - oop GEs an or- r spon ng t r s o orr t ons at t s saw s a as s r n [ ] o s M24IN an Y24IN an us to s t t para t rs, s s t ons an
- A n a $SU( )$ o as s r n [ ] orr spon ng part ont nt an os n s tt ng t ntr of t o MODSEL as s r n s t on para t rs ar s t us ng t o s MNURNURIN an YNURLHUIN, s s t ons an , r sp t v a t ona $SU( )$ para t rs an s t t n ng t o MINPAR as s r n s t on

Not , t at n t s o s t part ont nt at t trow a s a s t sa as n t usua an t at t r n s ar on u to t o va uat on of t para t rs

In as of s saw t p II an t p III o s a t ona arg part s ar nt grat out at t s saw s a (s) s r su ts n ang s of t ta- o nts for t gaug oup ngs an gaug no

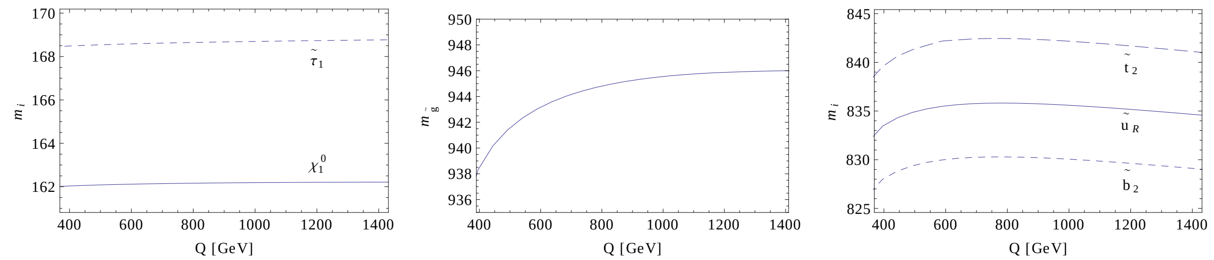

Figure 1: Residual scale dependence of various SUSY masses as a function of the renormalisation scale Q for $M_{1/2}$ = 400 GeV, m_0 = 90 GeV, A_0=0, tan = 10, > 0. The lines correspond to the masses of $\tilde\chi_1^0$ (full line, left plot), $\tilde\tau_1$ (dashed line, left plot), ˜, (full line, middle plot), $\tilde b_2$ (dashed line, right plot), $\tilde u_R$ (full line, right plot) and $\tilde t_2$ (long dashed line, right plot).

ass para t rs w w av n u at t - oop v or ov r, w av ta n nto a ount t orr spon ng t r s o ts at 1- oop v for gaug oup ngs an gaug no ass para t rs ut s ng t for u as g v n n [5, 6] How v r, w av n g t t orr spon ng t r s o orr t ons to t s f r on ass para t rs w ar proport ona to t a t ona Yu awa oup ngs squar s orr t ons ar n g n ra s a as t s oup ngs ar s a for s saw s a s ow 1 ^{14} G How v r, t g t o portant n as t at t r s a arg ass sp tt ng tw n f r ons an s a ars of t orr spon ng s saw u t p t, s g] w r t s as n nv st gat for t as of s saw t p I B s t s un rta nt s t r a n ng t or t a un rta nt s ar t sa as n t usua s nar os w t out a t ona stat s ow t G s a an t st fro n g t ng g r or r n ot , t GEs an t for u as for t ass a u at on As an st at for t orr spon ng t or t a un rta nt n u on an stu t r s ua p n n on t r nor a sat ons a w r t Y sp tru s a u at r fau t t s a $Q_{EWSB} = \sqrt{m_{\tilde t_1} m_{\tilde t_2}}$ s us ar ng t s a tw n $Q_{EWSB}/$ an Q_{EWSB} w fin t ass s of arg nos, n utra nos an s ptons var w t n a f w p r- w r t var at ons of t strong nt ra t ng part s ar a out a fa tor two arg r t an t on s w t trow a nt ra t ons on g u no s ows t arg st var at on of up to p r- nt as an a so s n n figur w r w s ow t s a p n n of t ass s of var ous part s ta ng] as an a p s fin ngs ar n p n nt of t s saw s a o s us , w s as to un rstan , aus on ou ons r a non-un v rsa o at t G s a w t ust part ont nt ow t G s a a ng to t sa ass s as for t un v rsa o s w t t a t ona s saw part s In r f] t - oop GEs av n pr s nt an n] t a ng - oop orr t ons to ass s of g u no, arg nos an n utra nos ar pr s nt B o par ng t r at v s fts g v n t r w t t s a p n n s uss a ov w fin on s s t at t ar of t sa or r of agn tu s n at s t at stu ng t s a p n n g v s n t orr t asur of t t or t a un rta nt

3. R-parity violation

Curr nt t nar o s p nt , t n ng t sup rpot nt a t t r s

$$W_{R\!\!\!/} = \epsilon_i \widehat{L}_i \widehat{H}_u \qquad ( )$$

an t orr spon ng soft Y r a ng t r s att r n u va uu p tat on va u s v_i for t sn utr nos In t s ass of o s n utr no p s s an p a n u to t ng of n utra nos w t n utr nos an oop ontr ut ons orr spon ng ta s an foun n ,] or ov r, R-par t v o at on a s to a ng tw n -part s an Y part s n utra nos w t n utr nos, arg nos w t t arg ptons, s ptons w t t arg H ggs, t r a part of t sn utr nos w t h^0 an H^0, an t ag nar part of t sn utr nos w t A^0 orr spon ng a s an wr tt n n a o pa t for f on t n s t n utra no n rang to $i = 1, \ldots,$, t arg no n ar $i = 1, \ldots, 5$ an t s pton n $i = 1, \ldots,$ an t orr spon ng stat s ar not ow S_i^+ n utra s a ars S_i^0 an ps u os a ars P_j^0 av n rang s $i = 1, \ldots, 5$ an $j = 1, \ldots,$, r sp t v In a as s ass or r ng s un rstoo For a p , t two- o a s of t n utra nos r a now

$$\tilde\chi^0_i \to Z^0\,\tilde\chi^0_j,\; W^\pm\,\tilde\chi^\mp_k \qquad (5\ )$$
$$\tilde\chi^0_i \to S^0_k\,\tilde\chi^0_j\;,\; P^0_k\,\tilde\chi^0_j\;,\; S^\pm_l\,\tilde\chi^\mp_k \qquad (5)$$
$$\tilde\chi^0_i \to q_k\tilde q^*_j,\; \bar q_k\tilde q_j \qquad (5\ )$$
$$\tilde\chi^+_k \to Z^0\,\tilde\chi^+_s,\; W^+\,\tilde\chi^0_j \qquad (53)$$
$$\tilde\chi^+_k \to S^0_k\,\tilde\chi^+_s,\; P^0_k\,\tilde\chi^+_s,\; S^+_l\,\tilde\chi^0_j \qquad (5\ )$$
$$\tilde\chi^+_k \to q_i\tilde q'_j \qquad (55)$$

In t s wa on an as ta ov r t a s st n s t on to t -par t v o at ng as D ta s uss ons of R-par t v o at ng a s n t n ar o n u ng for u as for var ous oup ngs an foun n r fs [6] sa para t rs g v ng r s to n utr no ass s a so a to t a of t an , t us t r ar orr at ons tw n t a prop rt s an n utr no p s s [6 8] For t n ar o on as two opt ons

- us w t n HA t o s EXTPAR, RVSNVEVIN an RVKAPPAIN to sp f t o para t rs at t trow a s a
- us on of t g s a o s GA, G B or A B to a u at t -par t ons rv ng para t rs at t trow a s a -par t para t rs ar t n a at t s s a us ng on of t two poss t s
  - a t us ng t o s RVSNVEVIN an RVKAPPAIN
  - us t ag of t o SPhenoInput as s r n s t on 5 6 to a u at t ϵ_i an t sn utr no va uu p tat ons va u s v_i su , t at n utr no p s s s r sp t orr spon ng n utr no ata an sp n o NeutrinoBoundsIn, s s t on 5 5

In t s ass of o s t ass atr s ar a u at at tr - v pt for t n utr no/n utra no ass atr w r qu r s t n us on of t fu - oop ontr ut ons or ov r, a poss -par t v o at ng a o s ar a u at

4. Low energy observables

In t s s t on w su ar t a n r f r n s fro w t for u as for t orr spon ng p ntat on av n ta n or ov r w g v p ntat on sp ta s w n v r n ssar For t o nt t ow n rg o s rva s ar on a u at n as of ons rv -par t

. . B physics observab es

fo ow ng o s rva s ar a u at n SPheno $BR(b \to s\gamma)$, $BR(b \to s\mu^+\mu^-)$, $BR(b \to s\sum_i \nu_i\nu_i)$, $BR(B^0_d \to l^+l^-)$, an $BR(B^0_s \to l^+l^-)$ $(l = e,\mu,\tau)$ $BR(B_u \to \tau^+\nu)$, $\Delta M_{B^0_s}$ an $\Delta M_{B^0_d}$ For t a u at on of t son o nts w us runn ng oup ngs an Y ass s w ar n g n ra vo v at t s a $Q = 6$ G for two r asons ( ) t s os to t runn ng as of t top quar w g v s t t arg st - ontr ut on to t s o s rva s ( ) For $BR(b \to s\gamma)$ w us t for u a of r f [ ] w r t orr spon ng o nts av to g v n at t s s a For t a u at on of t son o nts an t orr spon ng o s rva s w av us

- $BR(b \to s\gamma)$ [–], t va u g v n s for $E_\gamma \geq 6$ G an $m_c/m_b = \ .3$
- $BR(b \to s\mu^+\mu^-)$ [– 3]
- $BR(b \to s\sum_i \nu_i\nu_i)$ [,]
- $BR(B^0_s \to l^+l^-)$, $BR(B^0_d \to l^+l^-)$ $(l = e,\mu,\tau)$ [, , , 5]
- $BR(B_u \to \tau^+\nu)$ [6]

Table 1: Parameters used in the calculation of the B-physics observables. The masses and life times are taken from the PDG [108] whereas the decay constants and hadronic parameters are taken from ref. [109] including the update given in [110].

$\tau_{B^0} = 1.5$[illegible] ps	$\tau_{B_s^0} = 1.5$[illegible]6 ps	$\tau_{B_u^+} = 1.6$[illegible] ps	$\tau_{B_c^+} =$ [illegible] ps
$f_B =$ [illegible]	$f_B\sqrt{B_{B_d}} =$ [illegible]6 [illegible]	$f_{B_s} =$ [illegible]	$f_{B_s}\sqrt{B_{B_s}} =$ [illegible]
$M_{B^0} = 5.$[illegible]6 G[illegible]	$M_{B_s^0} = 5.$[illegible]66 G[illegible]	$\eta_B =$ [illegible]$.55$	

- $\Delta M_{B_s^0}$ an[illegible] $\Delta M_{B_d^0}$ [illegible] For t[illegible] a[illegible]ron[illegible] para[illegible]t[illegible]rs w[illegible] fo[illegible]ow [illegible]

$$\bar{P}_1^{LR} = -\text{[illegible]},\ \bar{P}_2^{LR} = -\text{[illegible]},\ \bar{P}_1^{SLL} = -\text{[illegible]},\ \bar{P}_1^{SLL} = -\text{[illegible]}.$$

[illegible]r[illegible] a[illegible]n[illegible]ng para[illegible]t[illegible]rs us[illegible] ar[illegible] g[illegible]v[illegible]n [illegible]n ta[illegible] [illegible] va[illegible]u[illegible]s of t[illegible] a[illegible] [illegible]onstants an[illegible] [illegible]ang[illegible] us[illegible]ng t[illegible] F[illegible]HA[illegible] o[illegible] `FCONST` [illegible] t[illegible] B-[illegible]son [illegible]ass[illegible]s [illegible] us[illegible]ng t[illegible] F[illegible]HA[illegible] o[illegible] `FMASS` [illegible] an[illegible] M

5. Extensions to SLHA

In t s s t on w s r t SPheno sp fi t ns ons to t Y s Hou s A or (HA) [, 5] start first w t t ns ons to st ng o s an t n s uss n w o s w t r ontro t av our of SPheno or onta n a t ona o para t rs for t ns ons Not , t at a a t ona Yu awa oup ngs av n p nt n o p for s an t orr spon ng nfor at on an pass us ng t orr spon ng o s start ng w t IM [ ]

. . Extensions of existing b ocks

. . . B ock MINPAR

In as of t n ng t o a n a $SU(5)$ as us n [8] t s o g ts t n t fo ow ng ntr s

$SO($) s a w r t un v rsa soft Y r a ng para t rs ar fin

8 tra D-t r s u to t r a ng of $SO($) to $SU(5)$

λ- oup ng of t H ggs -p t to t $\bar{5}_H$

λ'- oup ng of t H ggs -p t to t 5_H

. .2. B ock MODSEL

In t as t at g n rat on ng s sw t on, t ntr 6 onta ns a non- ro va u , t n n p n nt of t s va u flavour v o at on s sw t on n t (s) p ton as w as n t (s)quar s tor v n sw t s av n a to flag 3 (part ont nt), of w , , an orr spon to t t ns ons propos n [6]

n u s t part ont nt of a n a $SU(5)$ o tw n M_{GUT} an a us r os n $SO($) s a , w r t Y oun ar on t ons ar s t ta s of t s o ar s r n [8] In t s as t ass para t rs of t r g t an n utr nos ar stor n t o MNURNURIN (s t on 5) an t orr spon ng n utr no Yu awa oup ngs an stor n t o YNURLHUIN (s t on 5) ata s un rstoo to fin at t G -s a a t ona $SU(5)$ para t rs as w as t $SO($) s a ar sp fi as t ns ons of t o MINPAR, s s t on 5

3 n u s t r r g t- an (s)n utr nos w t a o on ass for a t r n utr nos n utr no Yu awa oup ngs Y_ν an sp fi at t G -s a , s s t on 5 , an t ass of t r g t-n utr nos at t r prop r s a , s s t on 5

5 n u s on pa r of 5-p t to r a t s saw II w r t for u as of [o] n u ng t or- r t ons pr s nt n [8] an t -oop ontr ut ons to t RGEs of t gaug oup ngs an gaug no ass para t rs av n p nt s s an a t rnat v to flag n g t ng t -oop runn ng of t s saw para t rs tw n t tr p t s a an t G -s a s p s so w at ss a ura o par to t o p t as ut s a goo appro at on, w t r at v fi r n sn r66 6(r) 666 3(n) o [( ) 3(r)-6 8 (o)8 o 6 (g)-5 5(t) 5 8 66 (r)-666 3 5 8] -o

11 n u s on H ggs tr p t to r a t s saw II w r t for u as of [ ] n u ng t orr t ons pr s nt n [ ] an t - oop ontr ut ons to t GEs of t gaug oup ngs an gaug no ass para t rs av n p nt a t ona o ata ar sp n M15T15TBIN, YHD15THDIN, YHU15TBHUIN an YL15TLIN, s s t ons , , an , r sp t v

. . New input b ocks

o of t s o s av o part of t proposa g v n n r f [6] SEESAWGENERATIONS In t output t o s w g v n w t out t n ng IN. It s un rstoo t at t nput va u s ar g v n at t G s a as a fau t

. . . B ock M15IN

s g v s t ass M_T of t 15-p t at t G s a In a t on t n s (,) av to g v n to a t -g n rat on as o pat w t t as of s v ra g n rat ons of 15-p ts ata ar g v n n t for at

```
(2x,2i3,2x,1p,e16.8,0p,2x,'# ',a)
```

At t s a M_T t 15-p t s sp t nto t r r nt r pr s nat ons not S, T, an Z [ ] w av r nt ass s u to GE ts orr spon ng output o s at t s s a ar M15S15SB, M15T15TB an M15Z15ZB an t sa ata for at as for M15IN s us

. . . B ock M15T15TBIN

s g v s t ass M_T of t ( ) tr p t at t G s a In a t on t n s (,) av to g v n to a t -g n rat on as o pat w t t as of s v ra g n rat ons of tr p ts ata ar g v n n t for at

```
(2x,2i3,2x,1p,e16.8,0p,2x,'# ',a)
```

. . . B ock M24IN

H r on an sp t ass atr of t -p ts M_{Wij} at M_{GUT} for t s saw t p III o us ng t for u as of [ ] w r t ata ar g v n n t FORTRAN for at

```
(1x,2i3,3x,1p,e16.8,3x,'#',a)
```

w r t first two nt g rs n t for at orr spon to i an j an t ou pr s on nu r to t ass para t r

At t r nt s a s orr spon ng to t ass para t rs of t $SU( )$ tr p ts t var ous ass atr s for t ass s of t s ng t, $SU( )$-tr p t, t $SU( )$-o t t an t X-part s ar g v n n t o s M24B24B, M24W24W, M24G24G an M24X24X, r sp t v

. . . B ock MNURNURIN

In t s o on an sp t ass s of t r g t- an n utr nos w t n t s saw I o ass s m_{Ri} ar sp n t FORTRAN for at

```
(1x,2i3,3x,1p,e16.8,3x,'#',a).
```

Not , t at t progra assu s t at t ass para t rs ar g v n n t as s w r t ass atr of t r g t an s n utr nos s agona

. . . B ock NeutrinoBoundsIn

On an us SPheno to o ta n -par t v o at ng para t rs ons st nt w t n utr no ata orr spon ng fau t va u s ar g v n n ta s o an us to o t FORTRAN for at s

```
(1x,i2,3x,1p,e16.8,0p,3x,#,1x,a)}
```

an t ntr s orr spon to

Table 2: Default values for fitting R-parity violating parameters if the entries in block NeutrinoBoundsIn are not specified. The values are taken from [122] and correspond to the 1 range but for $|U_{e3,max}|^2$ which is 90% CL.

$\tan^2\theta_{atm,min}$	[illegible]	$\tan^2\theta_{sol,min}$	[illegible]6	$\lvert U^2_{e3,min}\rvert^2$	
$\tan^2\theta_{atm,max}$	[illegible]	$\tan^2\theta_{sol,max}$	[illegible]	$\lvert U_{e3,max}\rvert^2$	[illegible]
$\Delta m^2_{atm,min}$	[illegible] $\cdot$ [illegible]$^{-21}$ G[illegible]^2	$\Delta m^2_{sol,min}$	[illegible] $\cdot$ [illegible]$^{-23}$ G[illegible]^2		
$\Delta m^2_{atm,max}$	[illegible] $\cdot$ [illegible]$^{-21}$ G[illegible]^2	$\Delta m^2_{sol,max}$	[illegible] $\cdot$ [illegible]$^{-23}$ G[illegible]^2		

[illegible] $\Delta m^2_{atm,min}$ ow r oun on t at osp r ass r n n GeV^2

$\Delta m^2_{atm,max}$ upp r oun on t at osp r ass r n n GeV^2

[illegible] $\tan^2\theta_{atm,min}$ ow r oun on t tan squar of t at osp r ng ang

$\tan^2\theta_{atm,max}$ upp r oun on t tan squar of t at osp r ng ang

[illegible] $\Delta m^2_{sol,min}$ ow r oun on t so ar ass r n n GeV^2

6 $\Delta m^2_{sol,max}$ upp r oun on t so ar ass r n n GeV^2

$\tan^2\theta_{sol,min}$ ow r oun on t tan squar of t so ar ng ang

[illegible] $\tan^2\theta_{sol,max}$ upp r oun on t tan squar of t so ar ng ang

[illegible] $|U^2_{e3,min}|^2$ ow r oun on t ng nt U_{e3} squar (r a tor ang)

[illegible] $|U^2_{e3,max}|^2$ upp r oun on t ng nt U_{e3} squar

[illegible]. B ock SPhenoInput

s o s ts t SPheno sp ags F AN for at s

```
(1x,i2,3x,1p,e16.8,0p,3x,#,1x,a)}
```

an t ntr s orr spon to

[illegible] s ts t rror v

[illegible] t t A onv nt ons [illegible] ar us

[illegible] ta s a sp tru w s g v n an t rna progra

ntro u s an t ns on of t HA output n t as of avour v o at on avour or r stat s ar us nst a of ass or r stat s

6 [illegible] t n t n utr no Yu awa oup ngs w s t at t arg st of t orr spon ng s saw part nst a of at m_{GUT} s app s for a t r s saw t p s

[illegible] tart ng w t v rs on [illegible] t for u as of [illegible] ar us to r su t ra n an t r s n t a u at on of t Yu awa oup ngs of b-quar an τ pton as t s prov s t nu r a sta t for arg tr n ar oup ngs In as on wants to us t pr v ous p nt on for t s r su at on on as to s t t s ntr to [illegible]

[illegible] tart ng w t v rs on [illegible] t r nor st on s a M_{EWSB} s a u at us ng t tr - v va u s of t stop ass s n ontrast to pr v ous v rs ons w r t oop- orr t ass s a n us In as on wants to us oop- orr t ass s, on as to s t t s ntr to [illegible]

[illegible] [illegible] t n t ran ng rat os of t Y an H ggs part s ar a u at , t n t s a u- at on s o tt s ts n u va u for a ran ng rat os, so t at t app ars n t output

f t n t ran ng rat os of t a s $h \to VV^*$ ar fo w t t ran ng rat os of t -s v tor oson, ot rw s t s ran ng rat os ar wr tt n as - o a s s t faut

f t n t ross s t ons of Y an H ggs part s n e^+e^- ann at on ar a u at , f t n t s a u at on s o tt

s ts t nt r of ass n rg E_{cms}

s ts t tron po ar sat on P_m

s ts t pos tron po ar sat on P_p

w t r to us n t a stat ra at on n t a u at on of t ross s t ons

6 s ts n u va u for a ross s t on, so t at t app ars n t output

s ts t va u of $M_{\rm GUT}$, ot rw s $M_{\rm GUT}$ s t r n t on t on

. . B ock Y24IN

H r on an sp f t n utr no Yu awa Y_{ij}^{III} oup ng at M_{GUT} for t s saw t p III o us ng t for u as of [ ] w r t ata ar g v n n t FORTRAN for at

```
(1x,2i3,3x,1p,e16.8,3x,'#',a)
```

w r t first two nt g rs n t for at orr spon to i an j an t ou pr s on nu r to Yu awa oup ng

. . B ock YHD15THDIN

H r on an sp f t Yu awa λ_1 oup ng at M_{GUT} for t s saw t p II o w r t ata s g v n n t FORTRAN for at

```
(1x,3i3,3x,1p,e16.8,3x,'#',a)
```

w r t nt g rs n t s for at ar a as n t p nt o on on H_d an pa r of -p ts (tr p ts) ar pr s nt ou pr s on nu r g v s t Yu awa oup ng

. 0. B ock YHU15TBHUIN

H r on an sp f t Yu awa λ_2 oup ng at M_{GUT} for t s saw t p II o w r t ata s g v n n t FORTRAN for at

```
(1x,3i3,3x,1p,e16.8,3x,'#',a)
```

w r t nt g rs n t s for at ar a as n t p nt o on on H_u an pa r of -p ts (tr p ts) ar pr s nt ou pr s on nu r g v s t Yu awa oup ng

. . B ock YL15TLIN

H r on an sp f t n utr no Yu awa Y_{ij}^{T} oup ng at M_{GUT} for t s saw t p II o us ng t for u as of [o] w r t ata s g v n n t FORTRAN for at

```
(1x,3i3,3x,1p,e16.8,3x,'#',a)
```

w r t first nt g rs n t s for at orr spon s to i, t s on s a wa s as t r s on tr p t pr s nt an t r on orr spon s to j ou pr s on nu r g v s t orr spon ng ntr of t Yu awa oup ng

. . B ock YNURLHUIN

s o sp f s t n utr no Yu awa oup ngs Y_ν at t G s a an t orr spon ng sup rpot nt a t r s g v n $W = Y_{\nu,ij}\nu_i^C L_j H_u$ It s assu t at t r g t- an n utr nos ar n t ass g n as s r a parts ar sp f n t o YNuRLHuIN w t t F AN for at

```
(1x,3i3,3x,1p,e16.8,3x,'#',a)
```

an t ag nar parts n t o IMYNuRLHuIN w t t sa F AN nput t r r nt g r s a wa s as on H_u s ons r n t p nt o

. New output b ocks

. . B ocks to transfer data to HiggsBounds

progra HiggsBounds [,] an us to a u at onstra nts fro t H ggs s tors n a arg ass of o s For t ata transf r t a t ona o s HiggsBoundsInputHiggsCouplingsBosons an HiggsBoundsInputHiggsCouplingsFermions ar r qu r [6] w r var os rat os of oup ngs ar stor In HiggsBoundsInputHiggsCouplingsFermions t rat os of oup ngs of h^0, H^0 an A^0 to t r g n rat on f r ons ar stor , w r as HiggsBoundsInputHiggsCouplingsBosons onta ns t rat os of oup ngs to gaug osons In t att r as w g v a r qu r tr n ar oup ngs n u ng t oop n u oup ng to g uons w r w av ta n t for u as of r f [6] r qu r oop- n u quart oup ngs of on H ggs oson to two g uons an on Z- oson s not a u at an , t us, s t to ro

.9. *B ock* SEESAWGENERATIONS

s g v s t nu r of g n rat ons of av part s nvo v n t orr spon ng s saw - an s [6] H r t first ntr g v s t fi an t s on t nu of g n rat ons For t first ntr t fo ow ng nu rs ar us

r g t- an n utr nos

-p ts

-p ts

ata s g v n n t FORTRAN for at

```
(1x,i2,3x,i3,"# ",a)
```

. *B ock* SPhenoLowEnergy

In t s o t a u at va u s of t ow n rg o s rva s ar g v n

$BR(b \to s\gamma)$

$BR(b \to s\mu^+\mu^-)$

$BR(b \to s \sum_i \nu_i\nu_i)$

$BR(B^0_d \to e^+e^-)$

$BR(B^0_d \to \mu^+\mu^-)$

6 $BR(B^0_d \to \tau^+\tau^-)$

$BR(B^0_s \to e^+e^-)$

$BR(B^0_s \to \mu^+\mu^-)$

$BR(B^0_s \to \tau^+\tau^-)$

$BR(B_u \to \tau^+\nu)$

$BR(B_u \to \tau^+\nu)/BR(B_u \to \tau^+\nu)_{SM}$

$\Delta(M_{B^0_s})$ [n ps^{-1}]

$\Delta(M_{B^0_d})$ [n ps^{-1}]

6 ϵ_K

$\Delta(M_K)$

$BR(K_L \to \pi^0\nu\nu)$

$BR(K^+ \to \pi^+\nu\nu)$

Y ontr ut on to t ano a ous agn t o nt of t tron $\Delta(\frac{g-2}{2})_e$

Y ontr ut on to t ano a ous agn t o nt of t uon $\Delta(\frac{g-2}{2})_\mu$

Y ontr ut on to t ano a ous agn t o nt of t tau $\Delta(\frac{g-2}{2})_\tau$

tr po o nt of t tron d_e

tr po o nt of t uon d_μ

tr po o nt of t tau d_τ

6 $BR(\mu \to e\gamma)$

$BR(\tau \to e\gamma)$

8 $BR(\tau \to \mu\gamma)$

o $BR(\mu^+ \to e^+e^+e^-)$

$BR(\tau^+ \to e^+e^+e^-)$

$BR(\tau^+ \to \mu^+\mu^+\mu^-)$

Y ontr ut on to t ρ-para t r

$BR(Z^0 \to e^\pm\mu^\mp)$

$BR(Z^0 \to e^\pm\tau^\mp)$

$BR(Z^0 \to \mu^\pm\tau^\mp)$

Not , t at for t a u at on of a o s rva s w n u a p as s an flavour ng

6. Installation and implementing new models

6. . Insta ation

SPheno an own oa fro

http://projects.hepforge.org/spheno/

w r t at st tar- a SPheno3.x.y.tar.gz an foun as w as o r v rs ons npa ng w r at t r tor SPheno3.x.y w r x an y ar nt g rs orr spon ng to t su -v rs on s r tor w onta n t fo ow ng su r tor s

- bin r t uta SPheno w stor
- doc onta ns t SPheno o u ntat ons
- include r a t o - fi s ar stor
- input onta ns nput a p fi s
- lib r t rar libSPheno.a w stor
- output onta ns t output fi s orr spon ng to t a p s stor n input
- src onta ns t sour o

r tor SPheno3.x.y onta ns a a fi w an us to o p SPheno fau t o p r s Int s fort ut t p ng make F90=compiler on t onso on an us a fr rnt o p r w r compiler as to r p a t o p r s na fo ow ng o p rs av n a NAG nagfor a an g

It s w nown t at o p at on of t o u RGEs.F90 an t onsu ng u to t ngt of t - oop GEs for t s saw o s of t p II an t p III For t s r ason t ar not o p fau t If t orr spon ng GEs s ou n u t n t n

PreDef = -DGENERATIONMIXING -DONLYDOUBLE

s ou r p a

PreDef = -DGENERATIONMIXING -DONLYDOUBLE -DSEESAWIII

a -DSEESAWIII

In t as t at on want to av qua rup pr s on n var ous parts of t o nst a of ou pr s on on as to ta out t -DONLYDOUBLE n t n nt on a ov Not t at t s an su stant a s ow own SPheno or ov r not a parts ar t p nt w t qua rup pr s on a n fo us as n on t oop fun t ons as w as on ng tw n n utra nos an n utr nos n as of -par t v o at on

6.9. I p e enting new ode s

N w o s an as p nt us ng t SARAH pa ag [1 , 18] For t s purpos on as to put t o g n rat SARAH n a n w r tor w t n t r tor SPheno3.x.y an run t orr spon ng a fi An a t ona uta w stor n t r tor bin

7. Input and output

tart ng w t v rs on SPheno 3 1 t r ar two a n fi r n s w t r sp t to t nput an output

1 SPheno a pts on t HA nput for at as sp fi an a t output s g v n n t s for- at In s t on 5 w av s r t t ns ons to ontro progra sp fi f atur s as w as o t ns ons org na SPheno nput us ng t fi s HighScale.in, StandardModel.in an Control.in as w as t output n t fi SPheno.out av n sa D ta rror ssag s an warn ngs w a so wr tt n to t fi Messages.out

On an prov nput na an output na as o an n opt ons w r t first (s on) na , f pr s nt, s nt rpr t as nput (output) fi na , g

SPheno InName OutName

ta s InName for t fi onta n ng t nput an w wr t t output to t fi OutName In as t at t fi InName s not foun SPheno w oo for a fi a LesHouches.in as fau t fau t na for t output s SPheno.spc ngt of t na s InName an OutName ust not 6 ara t rs

8. Conclusions and comments

SPheno s onstant v op ng n part u ar n v w of p nt ng a t ona o s an ow n rg o s rva s In a t on t s p an

- to p nt t ss ng p s of t HA onv nt ons as st n app n App n B
- ng tw n A_0 an H_0 n as of C p as s
- ow n rg o s rva s for t as of R-par t v o at on
- n as of ow n rg o s rva s t so- a F avour s Hou s A or [1] as n v op to g v ta nfor at on g t va u s of t son o fi nts orr spon ng stan ar for t output w w t n t n t rat ons art a nfor at on for C_7, C_8, C_9, C_{10} an C_{11} s g v n start ng w t v rs on 3 3

In s t on s v ra a ron para t rs for t a u at on of ow n rg o s rva s ar ar - o n t progra It s p ann to onstru t rout n s to a ow us r fin ang s n t futur t n ng t a ov nt on F avour s Hou s A or

Acknowledgements

t an s H rr ro for prov ng rout n s for t a u at on of t flavour v o at ng t r o a s of ptons an t a for prov ng rout n s for t t r - o a s of s ptons an sn utr nos aut ors t an H rs for an va ua o nts on t progra an ts an ng s wor as n support DFG pro t nu r PO-1337/1-1

Appendix A. Default SM values

fo ow ng fau t va u s w us f not g v n n t fi LesHouches.in

- CK - atr o f nst n para t rs $\lambda =$. 6 $A =$, $\rho =$. , $\eta =$.
- gaug s tor $1/\alpha_{em}(\ ) =$. $m_Z =$. G , $G_F =$. 66 · $^{-5}$G $^{-2}$, $\alpha_s^{\overline{MS}}(m_Z) =$.
- pton ass s $m_e =$, $m_\mu =$ .6 , $m_\tau =$. G
- quar ass s $m_u($ G $) =$, $m_d($ G $) =$, $m_s($ G $) =$, $m_c(m_c) =$. G , $m_b(m_b) =$. G , $m_t =$. G , t top ass s nt rpr t as on-s ass

Appendix B. Unsupported SLHA features

H r w st t f atur s of t HA onv nt ons [,] w ar not t support

- In Block EXTPAR t fo ow ng ntr s ar urr nt gnor

  po ass of t arg H ggs oson
  (G B on) $U(1)_Y$ ss ng r n
  (G B on) $SU(\ )_L$ ss ng r n
  (G B on) $SU(3)_C$ ss ng r n

- t Block QEXTPAR
- t Block RVLAMLLEIN
- t Block RVLAMLQDIN
- t Block RVLAMUDDIN
- t Block RVTLLEIN
- t Block RVTLQDIN
- t Block RVTUDDIN
- t Block RVDIN
- t Block RVM2LH1IN

s f atur s w p nt w t n t n t up at s

Appendix C. Error messages and warnings, interpretation of the variable kont

H r w s r ow to nt rpr t t va u s of t var a kont w s us n t rror s st of SPheno orr spon ng warn ngs an rror ssag s ar a so g v n n t fi , ssag s out f t rror v s s t to t appropr at va u

-1 st p s g ts to s a n rout n ODEint

- a a va u > 1 ^{36} ODEint

-3 too an st ps ar r qu r n rout n ODEint

- oun ar on t ons annot fu fi n rout n ODEintB

-5 a a va u > 1 ^{36} ODEintB

-6 st p s g ts too s a n rout n ODEintB

- too an st ps ar r qu r n rout n ODEintB

8 oun ar on t ons annot fu fi n rout n ODEintC

9 a a va u > 1 ^{36} ODEintC

-1 st p s g ts too s a n rout n ODEintC

-11 too an st ps ar r qu r n rout n ODEintC

-1 st p s g ts too s a n rout n rkqs

-13 t s of t arra s o not at n rout n ComplexEigenSystems

-1 pot nt a nu r a pro s n rout n ComplexEigenSystems

-15 t s of t arra s o not at n rout n RealEigenSystems

-16 pot nt a nu r a pro s n rout n RealEigenSystems

-1 t s of t arra s o not at n rout n tqli

-18 too an t rat ons n rout n tqli

-19 too g a ura r qu r n rout n Dgauss

- too g a ura r qu r n rout n DgaussInt

- 1 pr s on pro n rout n Kappa

- st p s g ts too s a n rout n IntRomb

- 3 too an st ps ar r qu r n rout n IntRomb

- s ngu ar atr n rout n GaussJ

- 5 s ngu ar atr n rout n InverseMatrix

- 6 nv rs on fa n rout n InvMat3

- st ps un rflow n rout n bsstep

- 8 too u trapo at on n rout n pzextr

- 9 too u trapo at on n rout n rzextr

-3 atr onta ns NaN n rout n RealEigenSystems

-31 atr onta ns NaN n rout n ComplexEigenSystems

Appendix C.9. Modu e StandardMode

-1 1 rout n `CalculateRunningMasses` $Q_{low} > m_b(m_b)$

-1 rout n `CalculateRunningMasses` a($Q_{low}, m_b(m_b) > Q_{max}$)

Appendix C. Modu e SusyMasses

- 1 n gat v ass squar n rout n `ChargedScalarMassEps1nt`
- n gat v ass squar n rout n `ChargedScalarMassEps3nt`
- $|Y_\tau|^2 <$ n rout n `CharginoMass3`
- 5 $|Y_\tau|^2 <$ n rout n `CharginoMass5`
- 6 n gat v ass squar n rout n `PseudoScalarMassEps1nt`
- n gat v ass squar n rout n `PseudoScalarMassEps3nt`
- 8 n gat v ass squar n rout n `PseudoScalarMassMSSMnt`
- 1 n gat v ass squar n rout n `ScalarMassEps1nt`
- 11 n gat v ass squar n rout n `ScalarMassEps3nt`
- 1 n gat v ass squar n rout n `ScalarMassMSSMeff`
- 13 n gat v ass squar n rout n `ScalarMassMSSMnt`
- 15 $m^2_{S^0_1} <$ n rout n `ScalarMassMSSMeff`
- 16 $m^2_{P^0_1} <$ n rout n `ScalarMassMSSMeff`
- 1 $m^2_{S^+} <$ n rout n `ScalarMassMSSMeff`
- n gat v ass squar n rout n `SfermionMass1Eps1`
- 1 n gat v ass squar n rout n `SfermionMass1Eps3`
- n gat v ass squar n rout n `SfermionMass1MSSM`
- 3 n gat v ass squar n rout n `SfermionMass3MSSM`
- n gat v ass squar n rout n `SquarkMass3Eps`
- 5 $m^2_{\tilde\nu} <$ n rout n `TreeMassesEps1`
- 6 $m^2_{\tilde\nu} <$ n rout n `TreeMassesMSSM`
- $m^2_{A^0} <$ n rout n `TreeMassesMSSM`
- 8 $m^2_{H^+} <$ n rout n `TreeMassesMSSM`
- o $m^2_{\tilde\nu} <$ n rout n `TreeMassesMSSM2`
- 3 $m^2_{A^0} <$ n rout n `TreeMassesMSSM2`
- 31 $m^2_{H^+} <$ n rout n `TreeMassesMSSM2`
- 3 $m^2_{\tilde\nu} <$ n rout n `TreeMassesMSSM3`

Appendix C. . Modu e InputOutput

-3 rout n LesHouches_Input un nown ntr for B o ODE

-3 3 rout n LesHouches_Input o ust sp for para t rs

-3 rout n LesHouches_Input un nown ntr for B o INPAR

-3 5 rout n LesHouches_Input o as not n sp o p t

-3 6 rout n LesHouches_Input a s r ous rror as n part of t nput

-3 rout n LesHouches_Input H ggs s tor as not n fu sp

-3 8 rout n ReadMatrixC n s t g v n oun ar s

-3 0 rout n ReadMatrixR n s t g v n oun ar s

-3 1 rout n ReadVectorC n s t g v n oun ar s

-3 11 rout n ReadVectorR n s t g v n oun ar s

-3 1 rout n ReadMatrixC n s t g v n oun ar s

Appendix C. . Modu e SugraRuns

- 1 rout n BoundaryEW n gat v s a ar ass squar as nput

- rout n BoundaryEW $m_Z^2(m_Z) <$

- 3 rout n BoundaryEW s n$^2 \theta_{\overline{DR}} <$

- rout n BoundaryEW $m_W^2 <$

- 5 rout n BoundaryEW t r $m_{l_DR}/m_l <$ .1 or $m_{l_DR}/m_l >$ 1

- 6 rout n BoundaryEW t r $m_{d_DR}/m_u <$ .1 or $m_{d_DR}/m_d >$ 1

- rout n BoundaryEW t r $m_{u_DR}/m_d <$ .1 or $m_{u_DR}/m_u >$ 1

- 8 rout n RunRGE nt r ng non-p rtur at v r g

- 0 rout n RunRGE nor $g_1 \neq g_2$ at $M_{\rm GUT}$ n t r an ot r un at on

- 1 rout n RunRGE nt r ng non-p rtur at v r g at $M_{\rm GUT}$

- 11 rout n RunRGE nt r ng non-p rtur at v r g at M_{H_3}

- 1 rout n Sugra run not onv rg

- 13 rout n Calculate_Gi_Yi $m_Z^2(m_Z) <$

- 1 rout n Calculate_Gi_Yi too an t rat ons to a u at $m_b(m_b)$ n t $\overline{MS}$ s

- 15 rout n Sugra $|\mu|^2 <$ at m_Z

Appendix C.6. Modu e LoopMasses

-5 1 n gat v ass squar n rout n `SleptonMass_1L`

-5 p^2 t rat on not onv rg n rout n `SleptonMass_1L`

-5 3 n gat v ass squar n rout n `SneutrinoMass_1L`

-5 p^2 t rat on not onv rg n rout n `SneutrinoMass_1L`

-5 5 n gat v ass squar n rout n `SquarkMass_1L`

-5 6 p^2 t rat on not onv rg n rout n `SquarkMass_1L`

-5 $m^2_{h^0} <$ n rout n `LoopMassesMSSM`

-5 8 $m^2_{A^0} <$ n rout n `LoopMassesMSSM`

-5 9 $m^2_{H^+} <$ n rout n `LoopMassesMSSM`

-51 $|\mu|^2 > 1^{20}$ n rout n `LoopMassesMSSM`

-511 $|\mu|^2 <$ n rout n `LoopMassesMSSM`

-51 $m^2_Z(m_Z)^2 <$ n rout n `LoopMassesMSSM`

-513 $m^2_{h^0} <$ n rout n `LoopMassesMSSM_2`

-51 $m^2_{A^0} <$ n rout n `LoopMassesMSSM_2`

-515 $m^2_{H^+} <$ n rout n `LoopMassesMSSM_2`

-516 $|\mu|^2 > 1^{20}$ n rout n `LoopMassesMSSM_2`

-51 $|\mu|^2 <$ n rout n `LoopMassesMSSM_2`

-518 $m^2_Z(m_Z)^2 <$ n rout n `LoopMassesMSSM_2`

-519 $m^2_{h^0} <$ n rout n `LoopMassesMSSM_3`

-5 $m^2_{A^0} <$ n rout n `LoopMassesMSSM_3`

-5 1 $m^2_{H^+} <$ n rout n `LoopMassesMSSM_3`

-5 $|\mu|^2 > 1^{20}$ n rout n `LoopMassesMSSM_3`

-5 3 $|\mu|^2 <$ n rout n `LoopMassesMSSM_3`

-5 $m^2_Z(m_Z)^2 <$ n rout n `LoopMassesMSSM_3`

-5 5 n gat v ass squar n rout n `Sigma_SM_chirally_enhanced`

Appendix C.7. Modu e TwoLoopHiggsMass

-6 1 rout n `PiPseudoScalar2` $m^2_{\tilde{t}} <$

-6 rout n `PiPseudoScalar2` $m^2_{\tilde{b}} <$

-6 3 rout n `PiPseudoScalar2` $m^2_{\tilde{\tau}} <$

-6 rout n `PiScalar2` $m^2_{\tilde{t}} <$

-6 5 rout n `PiScalar2` $m^2_{\tilde{b}} <$

-6 6 rout n `PiScalar2` $m^2_{\tilde{\tau}} <$

-6 rout n `Two_Loop_Tadpoles` $m^2_{\tilde{t}} <$

-6 8 rout n `Two_Loop_Tadpoles` $m^2_{\tilde{b}} <$

-6 9 rout n `Two_Loop_Tadpoles` $m^2_{\tilde{\tau}} <$

Appendix C.. Modu e Mathe aticsQP

-1 1 t s of t arra s o not at n rout n `ComplexEigenSystems_DP`

-1 pot nt a nu r a pro s n rout n `ComplexEigenSystems_DP`

-1 3 t s of t arra s o not at n rout n `ComplexEigenSystems_QP`

-1 pot nt a nu r a pro s n rout n `ComplexEigenSystems_QP`

-1 5 t s of t arra s o not at n rout n `RealEigenSystems_DP`

-1 6 pot nt a nu r a pro s n rout n `RealEigenSystems_DP`

-1 t s of t arra s o not at n rout n `RealEigenSystems_QP`

-1 8 t s of t arra s o not at n rout n `Tqli_QP`

-1 o too an t rat ons n rout n `Tqli_QP`

-1 1 too an t rat ons n rout n `Tql2_QP`

Appendix D. Loop corrections

H r w st t prov nts w av n p nt n SPheno w t r sp t to r f [ ]

- n t 1- oop orr t ons to t g u no ass w us for t g uon ontr ut on

$$\Delta(\ \ _{\tilde g}) = -\frac{3 g_3^2}{8\pi^2}\left(B_1(p^2, m^2_{\tilde g,T},\ ) - \ B_1(p^2, m^2_{\tilde g,T},\ )\right) \qquad (D\ 1)$$

w r $m_{\tilde g,T}$ s t tr v g u no ass an w r u s for $p^2 = m^2_{\tilde g,T}$ to t for u a

$$\Delta(\ \ _{\tilde g}) = -\frac{g_3^2}{16\pi^2}\left(15 + o\ \ og\left(\frac{Q^2}{m^2_{\tilde g,T}}\right)\right) \qquad (D\ \ )$$

of r f [ ]

- In a t on flavour v o at on as n ta ng nto a ount an t orr spon ng for u as an foun n [5 6]

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