Scalar Singlet model, continued

- Solution (problem III)

1. After copying the example program, also add the following block to your makefile (just copy&paste from examples/aux/makefile):

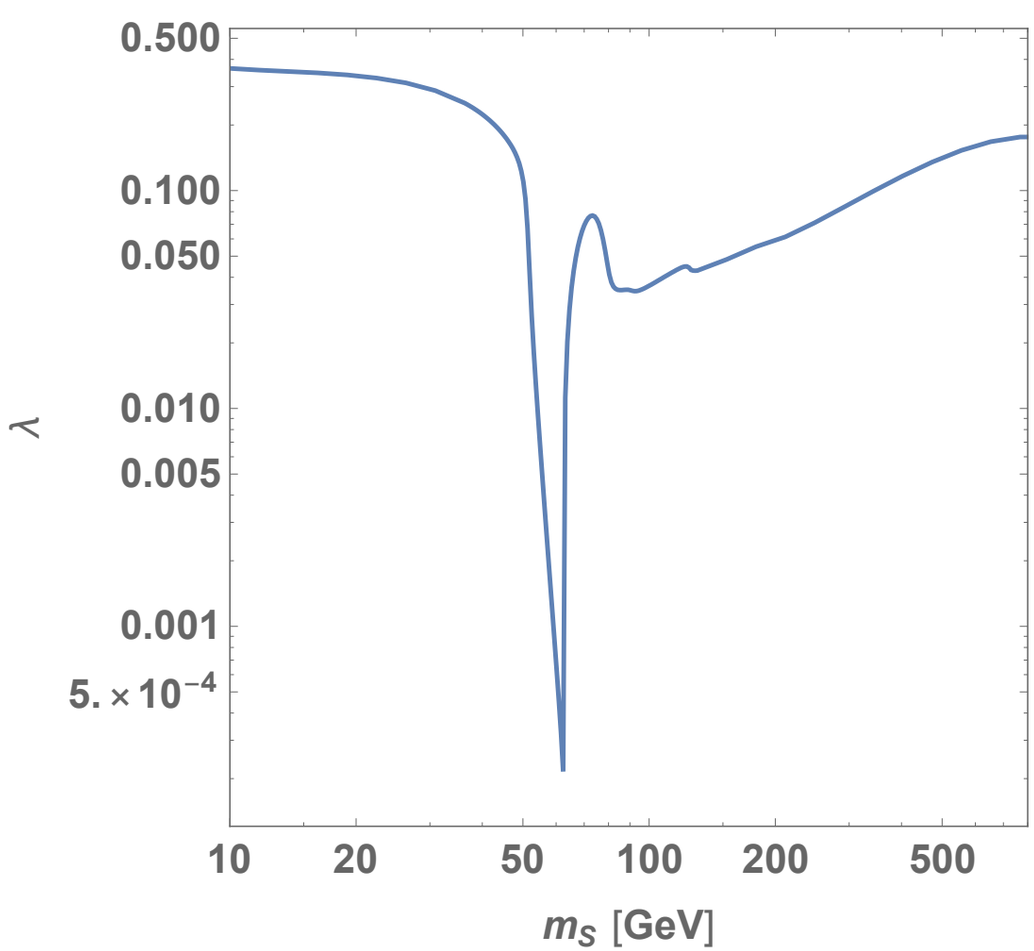
```
ScalarSinglet_RD: DS_MODULE = silveira_zee
ScalarSinglet_RD: INC_MODULE = $(INC_SILVEIRAZEE)
ScalarSinglet_RD: ScalarSinglet_RD.f
ScalarSinglet_RD: $(LIB)/libds_core.a $(LIB)/libds_core_user.a
        $(ADD_SCR) libds_tmp.a $(LIB)/libds_$(DS_MODULE)_user.a $(LIB)/libds_core_user.a \
        $(LIB)/libds_$(DS_MODULE).a $(LIB)/libds_core.a
        $(FF) $(FOPT) $(INC) $(INC_MODULE) -L$(LIB) -o ScalarSinglet_RD ScalarSinglet_RD.f \
        libds_tmp.a
        rm -f libds_tmp.a
```

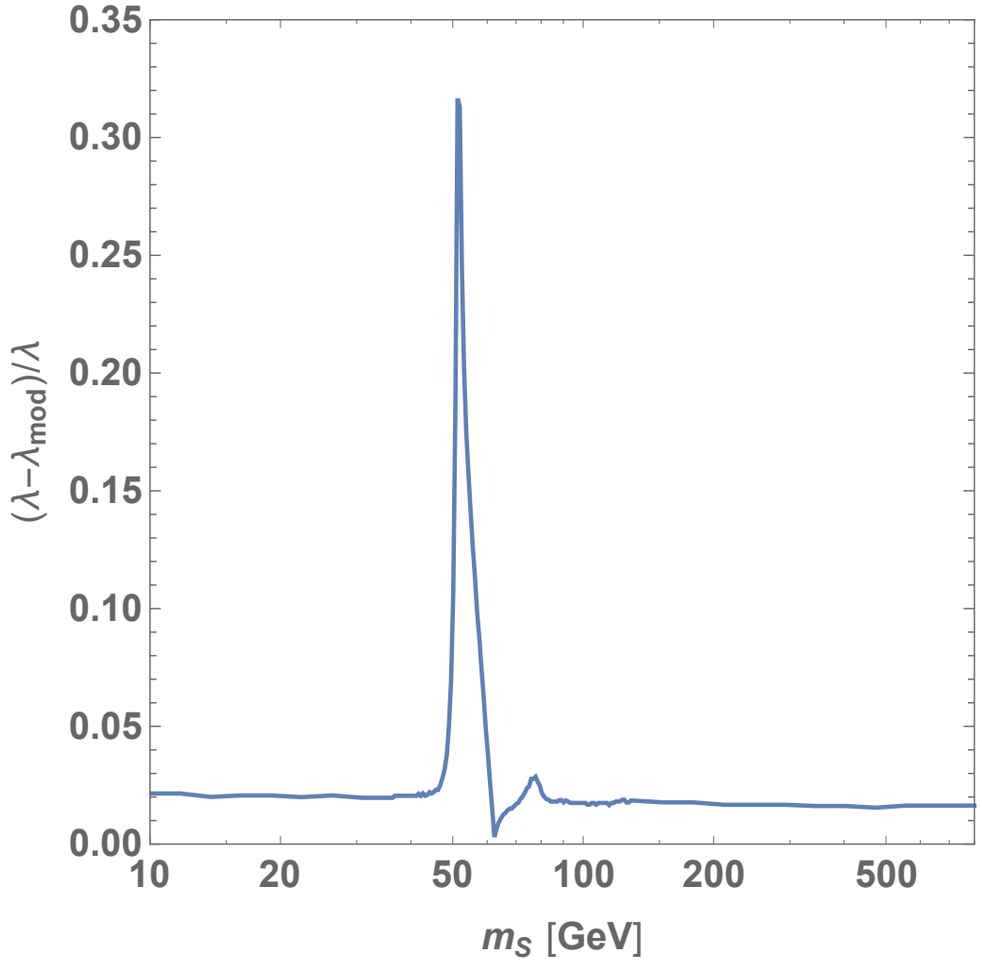
2. Running ScalarSinglet_RD produces a data file ScalarSinglet_RD_acc.dat which you can feed into your favourite plotting program
3. To do the same with the modified annihilation rate, just add 'my_replaceables/dsanwx.f' at the locations indicated by the red arrows

Remember to change the output file name before re-running!

Scalar Singlet model, continued

- Solution (problem III)





As expected, a different energy dependence has the strongest impact close to the resonance

Thermal averages

- Solution (problem IV)

1. We need a little main program to tabulate $\langle \sigma v \rangle$. Possible solution:

```
      program ScalarSinglet_RD
      implicit none
      real*8 inputmass, inputlambda              ! model parameters
      real*8 oh2, xf, Tscan, logdelta            ! relic density + scan
      real*8 dsrdthav, dsanwx, dsrdomega         ! DS functions
      external dsanwx                            ! NB: needed because used as argument!
      integer ierr, iwarn, nfc
      include 'dsmpconst.h' ! contains useful conversion factors etc.

      inputmass   = 51d0
      inputlambda = 0.1d0
      open (unit=20,file='ScalarSinglet_sv_average.dat')

      call dsinit
      call dsgivemodel_silveira_zee(inputlambda,inputmass)
      call dsmodelsetup(ierr,iwarn)
      oh2=dsrdomega(0,20,xf,ierr,iwarn,nfc) ! NB: needed to initialize dsrdthav !!

      logdelta = 0.01          ! log(10)-spacing between masses to tabulate
      Tscan = inputmass/1d2    ! lowest temperature to tabulate
  190 continue
        write(20,*) Tscan, dsrdthav(inputmass/Tscan,dsanwx)*gev2cm3s
        Tscan = Tscan*10**logdelta
        if (Tscan.le.inputmass*5d0) goto 190 ! tabulate up to 5*DM mass

      close(20)
      end
```

Thermal averages

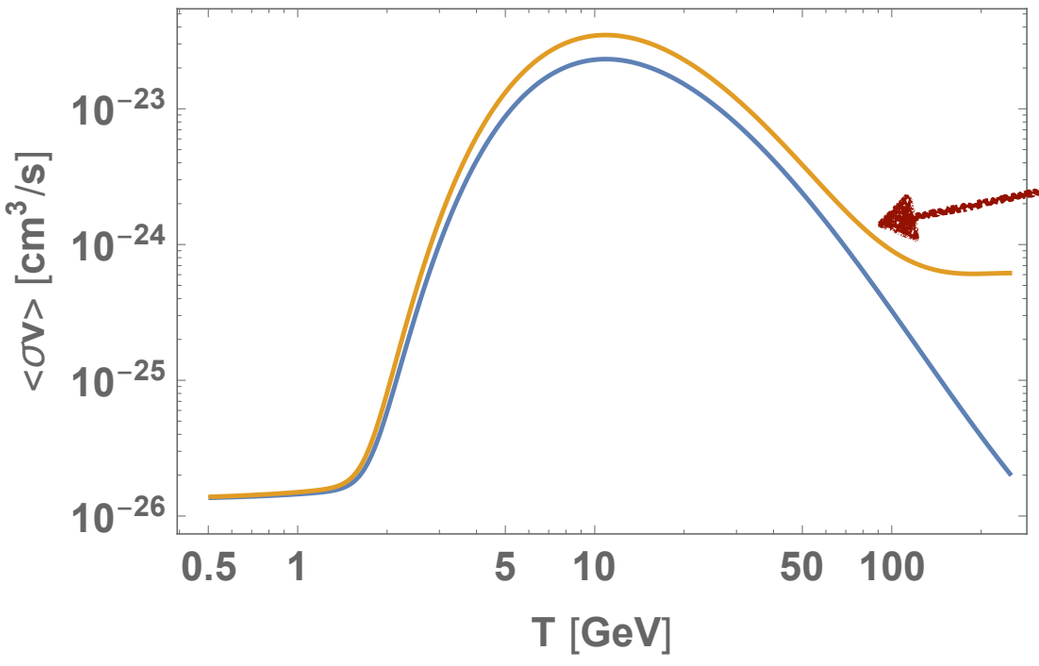
- Solution (problem IV)

2. Then, we need to add the usual block to the makefile:

```
ScalarSinglet_sigma_tab: DS_MODULE = silveira_zee
ScalarSinglet_sigma_tab: INC_MODULE = $(INC_SILVEIRAZEE)
ScalarSinglet_sigma_tab: ScalarSinglet_sigma_tab.f my_replaceables/dsanwx.f
ScalarSinglet_sigma_tab: $(LIB)/libds_core.a $(LIB)/libds_core_user.a
        $(ADD_SCR) libds_tmp.a $(LIB)/libds_$(DS_MODULE)_user.a $(LIB)/libds_core_user.a $
(LIB)/libds_$(DS_MODULE).a $(LIB)/libds_core.a
        $(FF) $(FOPT) $(INC) $(INC_MODULE) -L$(LIB) -o ScalarSinglet_sigma_tab
ScalarSinglet_sigma_tab.f my_replaceables/dsanwx.f \
        libds_tmp.a
        rm -f libds_tmp.a
```

If you simply comment in/out the new line in your replaced file, you can use the same makefile block for *both* versions

3. Make, run, and plot:



As expected, the additional factor of E^2 leads to an enhancement at high temperatures…