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GRavitation AstroParticle Physics Amsterdam
University of Amsterdam
erc

Francesca Calore

DarkSUSY: Load it! Run it! Plot it!

CASPAR 2014: Codes in AStroPArticle Research
Hamburg, 17th September 2014

Outline

- Introduction to DarkSUSY
- Layout of the code
- Physics set-up: SUSY models
- Relic density
- Indirect detection rates
- Direct detection rates
- Accelerator constraints

★ Exercises

Dark SUSY

authors: P. Gondolo, J. Edsjö, P. Ullio, L. Bergström,
M. Schelke, E.A. Baltz, T. Bringmann and G. Duda

SUSY models

Direct detection rates

Indirect detection rates

Accurate relic abundance calculation

Accelerator bounds

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Philosophy & Contents

- Modular structure
- Library of subroutines and functions
- Fortran compilers: gfortran, ifort
- Flexible
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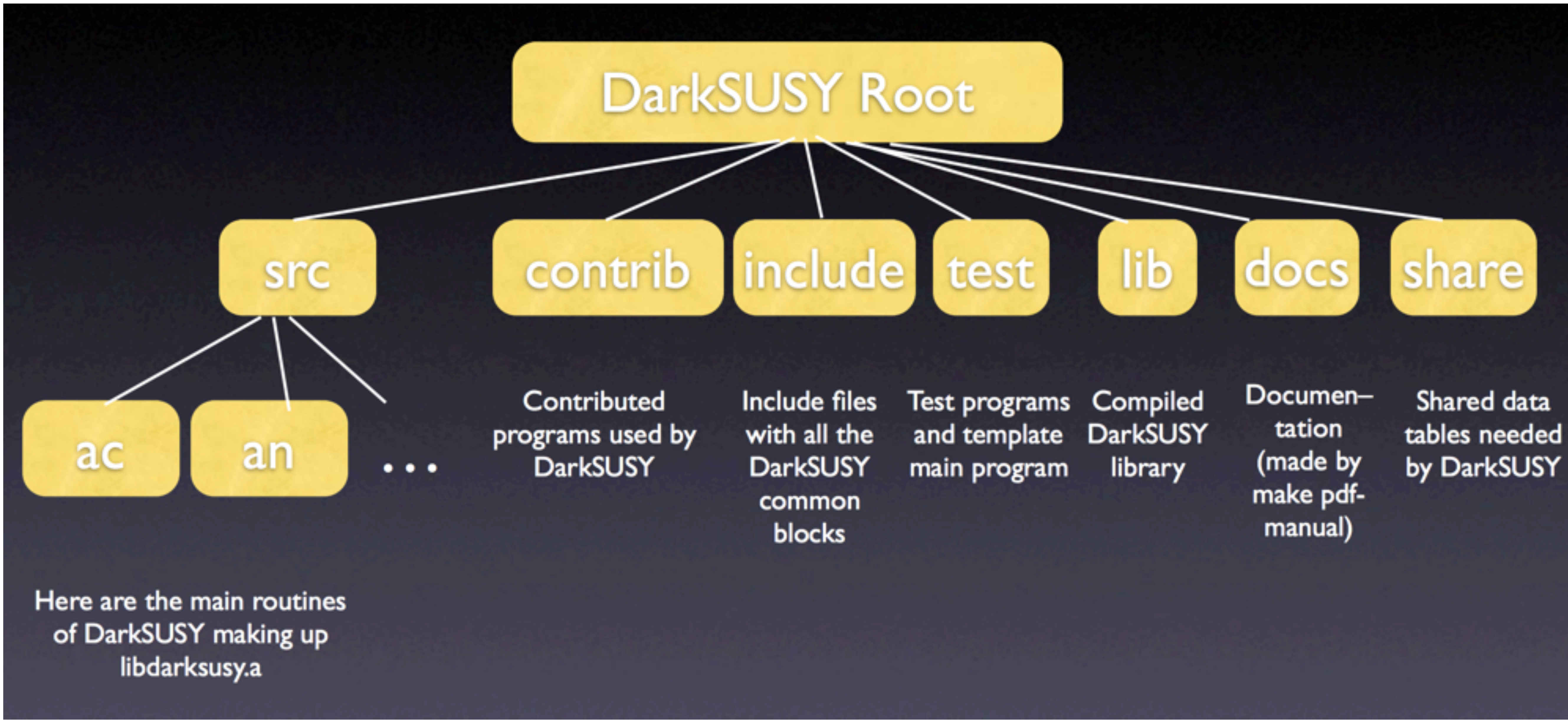
✓ Tool for DM searches: computation of rates for indirect, direct and accelerator searches, relic abundance.

✓ MSSM models: constraints and scans on generic MSSM, mSUGRA, etc.

✓ Advanced indirect detection computations: signals in neutrino telescopes, gamma-ray signals, cosmic-ray positrons, antiprotons and antideuterons.

Layout of DarkSUSY



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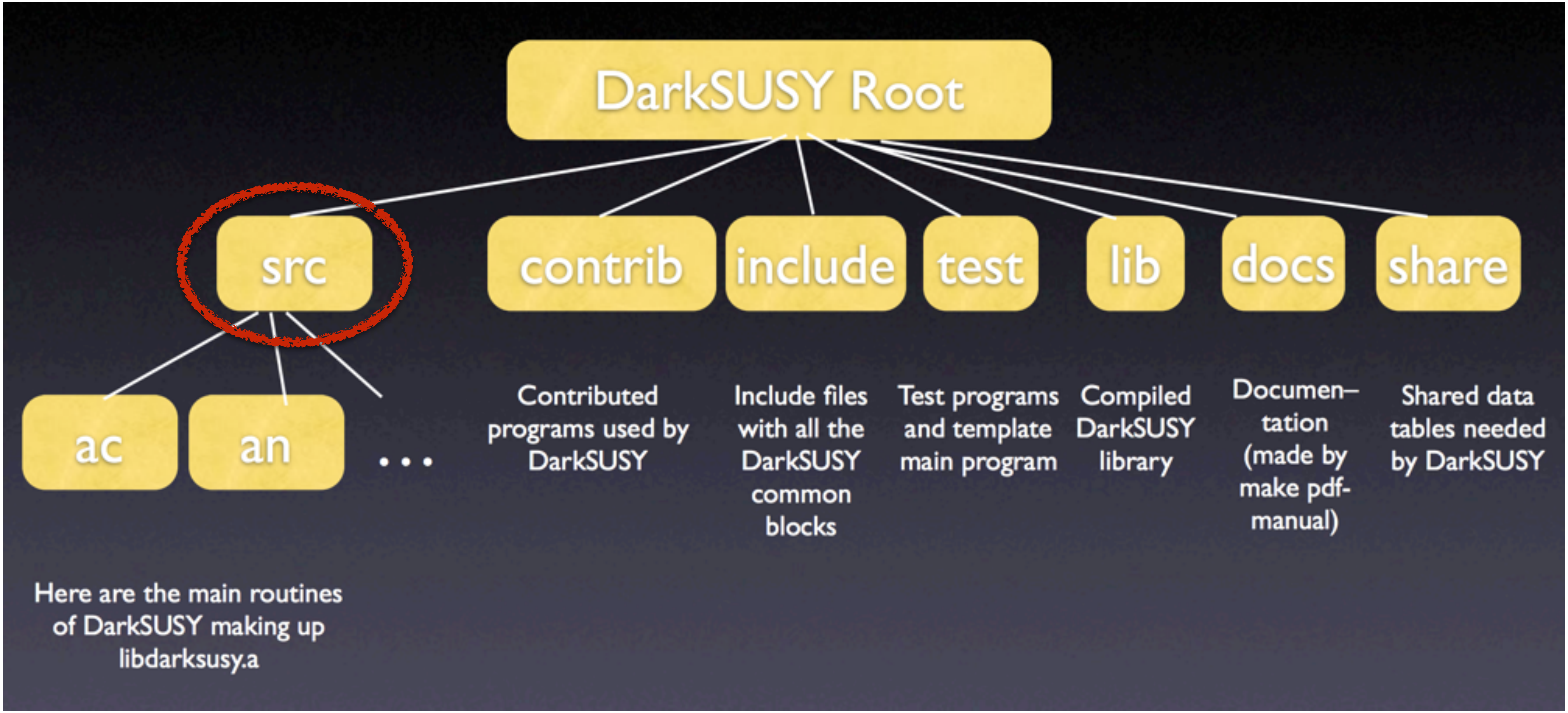


Routines in src/ (1)

- **ac**: accelerator constraints
- **an**: annihilation cross sections for neutralino and chargino coannihilations
- **an1l**: 1-loop annihilation cross sections ($\gamma\ \gamma$ and Z γ)
- **as**: annihilation cross sections for sfermions coannihilations
- **anstu**: auxiliary routines for neutralino and chargino coannihilations

- **bsg**: b $\rightarrow$ s γ routines

- **db**: anti-deuterium
- **dd**: direct detection
- **docs**: general documentation, to be complemented by the more specific documentation in each subdirectory in src/

- **ep**: positron fluxes from the halo

- **ge**: general routines (integrators etc)

Routines in src/ (2)

- **ha**: halo annihilation routines
- **hm**: halo models
- **hr**: rates from halo annihilation

- **ib**: internal bremsstrahlung (photons and positrons)
- **ini**: initialisation routines

- **nt**: rates from neutrino telescopes. Also includes Sun and Earth models for the capture rate calculations

- **pb**: antiproton fluxes from the halo

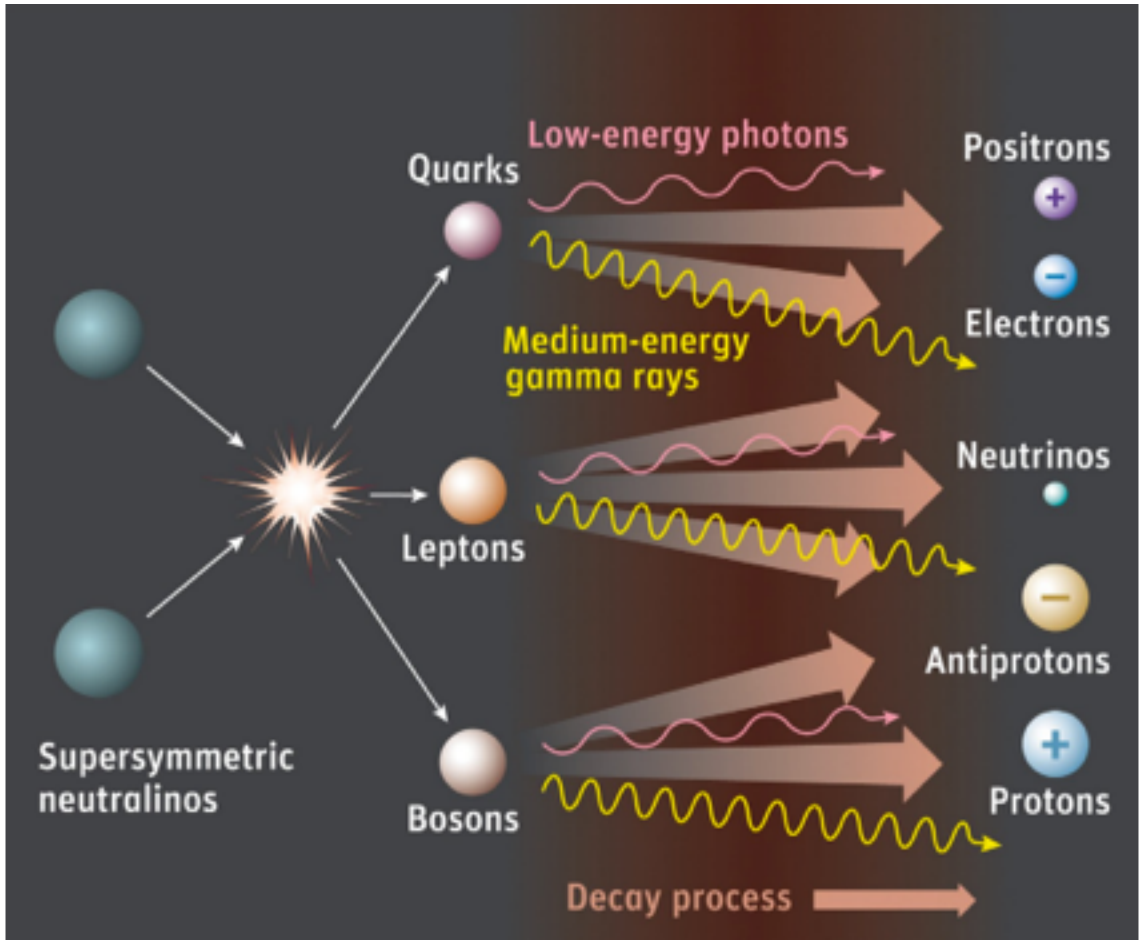
- **rd**: relic density routines (in general format, knows nothing about SUSY)
- **rn**: interface to relic density routines for SUSY neutralinos, these give the relic density of neutralinos
- **rge**: interface to RGE code isasugra for mSUGRA models

Routines in src/ (3)

- **su**: general SUSY routines, mass spectra, vertices etc
- **wa**: WIMP annihilation routines to calculate yields of neutrinos, neutrino-induced leptons (e.g. muons) and hadronic showers from WIMP annihilation in the Earth/Sun. Note: these routines know nothing about SUSY, the interface to SUSY is done with dswasetup in the nt set of routines
- **xcern**: a few needed routines from CERNLIB
- **xcmlib**: a few needed routines from CMLIB
- **xfeynhiggs**: interface routines to FeynHiggs
- **xgalprop**: interface routines to galprop
- **xhdecay**: interface routines to HDecay

Physics set-up

Physic set-up: SUSY models



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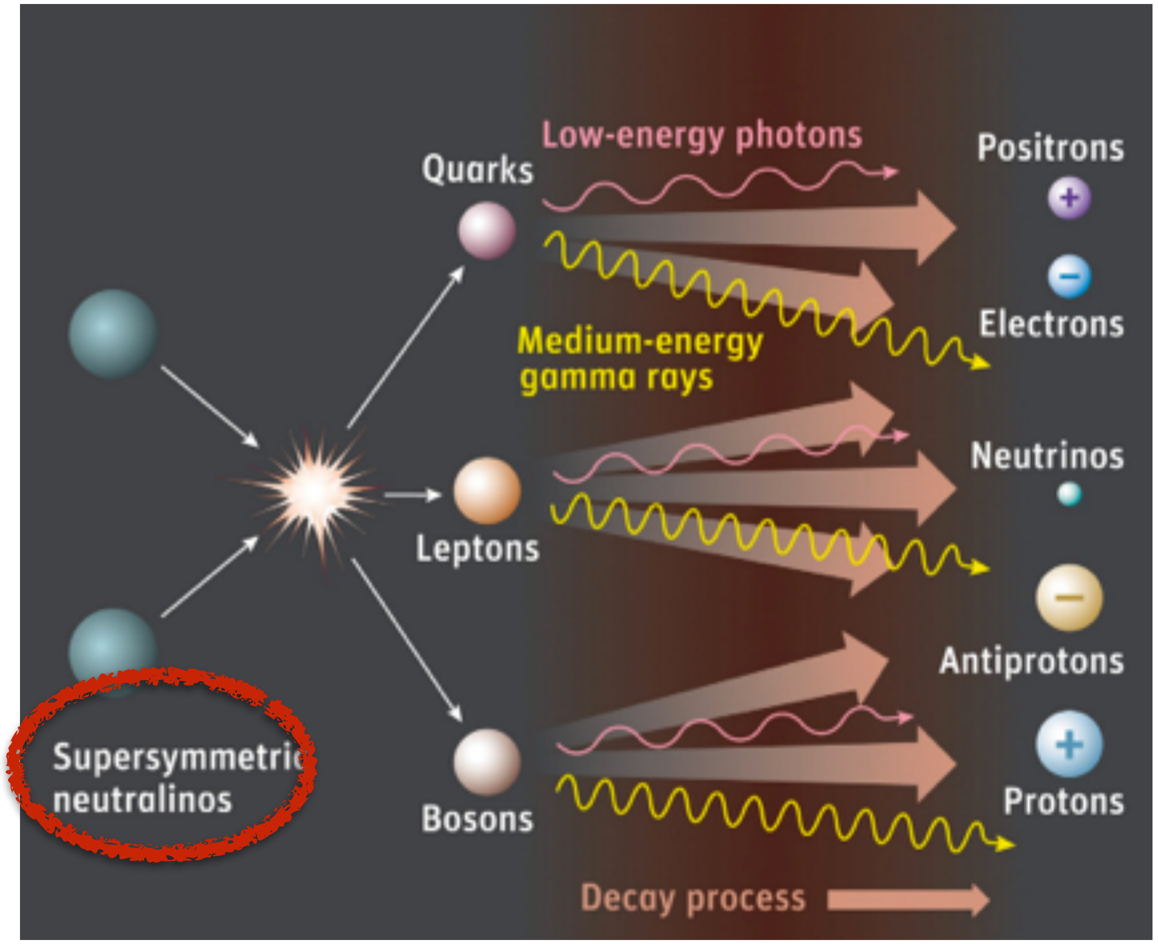

DarkSUSY has been set-up for the analysis of generic SUSY models with a large number of free parameters.

Advanced and accurate calculations in the full MSSM framework.

$$\frac{dN_X}{dE} \qquad X = e^+, \bar{p}, \gamma, \nu, \ldots$$

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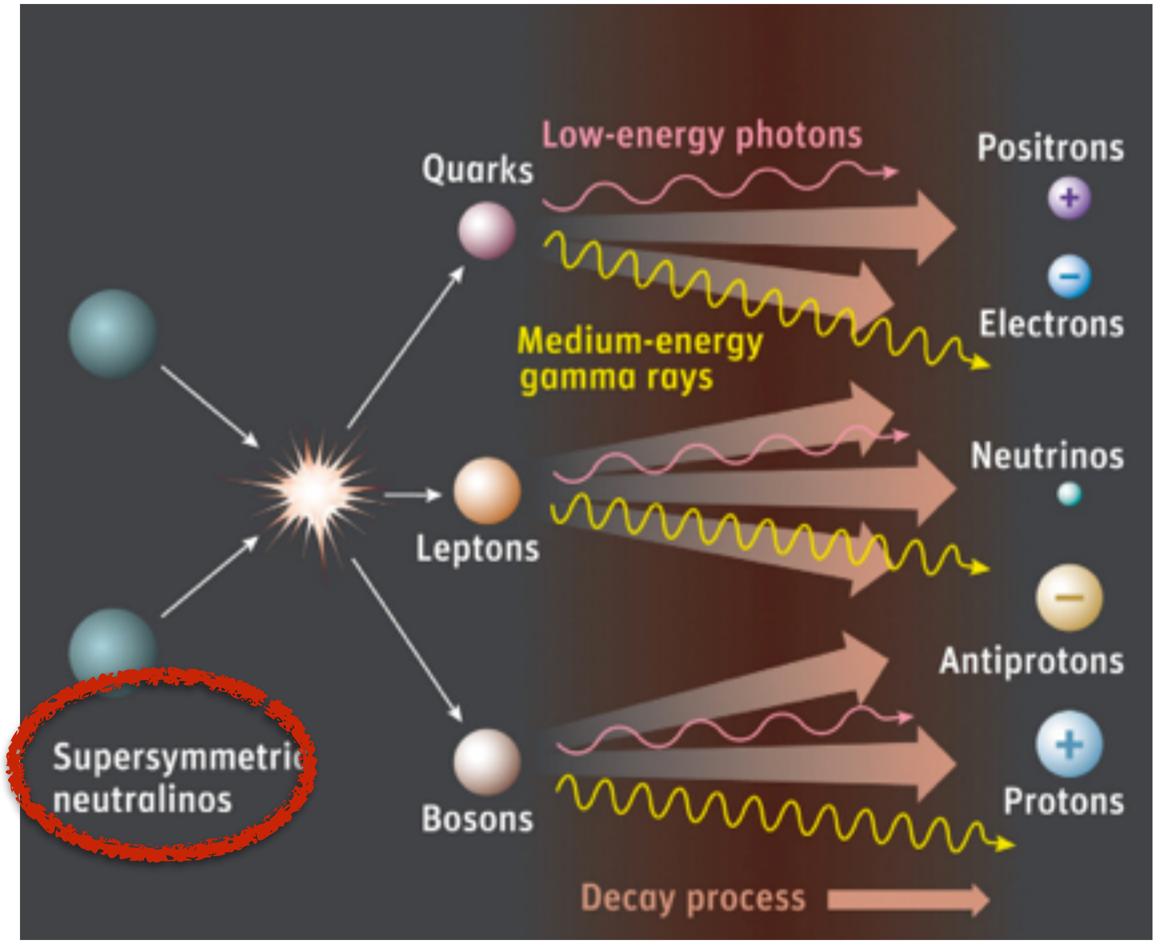

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Example: differential energy gamma-ray flux

$$\frac{\mathrm{d}\Phi_\gamma}{\mathrm{d}E_\gamma}(E_\gamma, \phi, \theta, \Delta\Omega) = \frac{\langle \sigma v \rangle}{2m_\chi^2} \cdot \sum_i B_i \frac{dN_\gamma^i}{dE_\gamma} \frac{1}{4\pi} \int_0^{\Delta\Omega} \mathrm{d}\Omega \int_{\mathrm{l.o.s}} \rho^2(s(R, \phi, \theta)) ds$$

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- Input parameters at EW scale (MSSM) or at GUT scale (mSUGRA)
- Higgs sector with FeynHiggs
- Higgs decay widths from literature (or from Hdecay, future FeynHiggs)
- mSUGRA interfaces: ISASUGRA
- SUSY Les Houches Accord 2 implemented (slha files)

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Theoretical SUSY framework:

We work in the framework of the minimal $N = 1$ supersymmetric extension of the standard model defined by, besides the particle content and gauge couplings required by supersymmetry, the superpotential

$$W = \epsilon_{ij}\left(-\hat{\mathbf{e}}_R^{*}\mathbf{Y}_E\hat{\mathbf{l}}_L^{i}\hat{H}_1^{j} - \hat{\mathbf{d}}_R^{*}\mathbf{Y}_D\hat{\mathbf{q}}_L^{i}\hat{H}_1^{j} + \hat{\mathbf{u}}_R^{*}\mathbf{Y}_U\hat{\mathbf{q}}_L^{i}\hat{H}_2^{j} - \mu\hat{H}_1^{i}\hat{H}_2^{j}\right) \tag{2}$$

and the soft supersymmetry-breaking potential

$$\begin{aligned} V_{\text{soft}} = \; & \epsilon_{ij}\left(-\tilde{\mathbf{e}}_R^{*}\mathbf{A}_E\mathbf{Y}_E\tilde{\mathbf{l}}_L^{i}H_1^{j} - \tilde{\mathbf{d}}_R^{*}\mathbf{A}_D\mathbf{Y}_D\tilde{\mathbf{q}}_L^{i}H_1^{j} + \tilde{\mathbf{u}}_R^{*}\mathbf{A}_U\mathbf{Y}_U\tilde{\mathbf{q}}_L^{i}H_2^{j} - B\mu H_1^{i}H_2^{j} + \text{h.c.}\right) \\ & + H_1^{i*}m_1^2H_1^{i} + H_2^{i*}m_2^2H_2^{i} \\ & + \tilde{\mathbf{q}}_L^{i*}\mathbf{M}_Q^2\tilde{\mathbf{q}}_L^{i} + \tilde{\mathbf{l}}_L^{i*}\mathbf{M}_L^2\tilde{\mathbf{l}}_L^{i} + \tilde{\mathbf{u}}_R^{*}\mathbf{M}_U^2\tilde{\mathbf{u}}_R + \tilde{\mathbf{d}}_R^{*}\mathbf{M}_D^2\tilde{\mathbf{d}}_R + \tilde{\mathbf{e}}_R^{*}\mathbf{M}_E^2\tilde{\mathbf{e}}_R \\ & + \frac{1}{2}M_1\tilde{B}\tilde{B} + \frac{1}{2}M_2\left(\tilde{W}^3\tilde{W}^3 + 2\tilde{W}^+\tilde{W}^-\right) + \frac{1}{2}M_3\tilde{g}\tilde{g}. \end{aligned} \tag{3}$$

Here i and j are SU(2) indices ($\epsilon_{12} = +1$), $\mathbf{Y}$'s, $\mathbf{A}$'s and $\mathbf{M}$'s are 3×3 matrices in generation space, and the other boldface letter are vectors in generation space.

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$$\mathcal{M}_{\tilde{\chi}^0_{1,2,3,4}} = \begin{pmatrix} M_1 & 0 & -m_Z s_W c_\beta & +m_Z s_W s_\beta \\ 0 & M_2 & +m_Z c_W c_\beta & -m_Z c_W s_\beta \\ -m_Z s_W c_\beta & +m_Z c_W c_\beta & \delta_{33} & -\mu \\ +m_Z s_W s_\beta & -m_Z c_W s_\beta & -\mu & \delta_{44} \end{pmatrix},$$

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$$\mathcal{M}_{\tilde{\chi}^\pm} = \begin{pmatrix} M_2 & \sqrt{2} m_W \sin\beta \\ \sqrt{2} m_W \cos\beta & \mu \end{pmatrix},$$

$$\begin{aligned} \tilde{\chi}_i^- &= U_{i1} \tilde{W}^- + U_{i2} \tilde{H}_1^-, \\ \tilde{\chi}_i^+ &= V_{i1} \tilde{W}^+ + V_{i2} \tilde{H}_1^+. \end{aligned}$$

Physic set-up: SUSY models

Low-energy phenomenological MSSM (MSSM-7)

$$\mathbf{A}_U = \mathrm{diag}(0, 0, A_t)$$
$$\mathbf{A}_D = \mathrm{diag}(0, 0, A_b)$$
$$\mathbf{A}_E = 0$$
$$\mathbf{M}_Q = \mathbf{M}_U = \mathbf{M}_D = \mathbf{M}_E = \mathbf{M}_L = m_0 \mathbf{1}.$$

$$M_1 = \frac{5}{3} \tan^2 \theta_w M_2 \simeq 0.5 M_2,$$
$$M_2 = \frac{\alpha_{ew}}{\sin^2 \theta_w \alpha_s} M_3 \simeq 0.3 M_3.$$

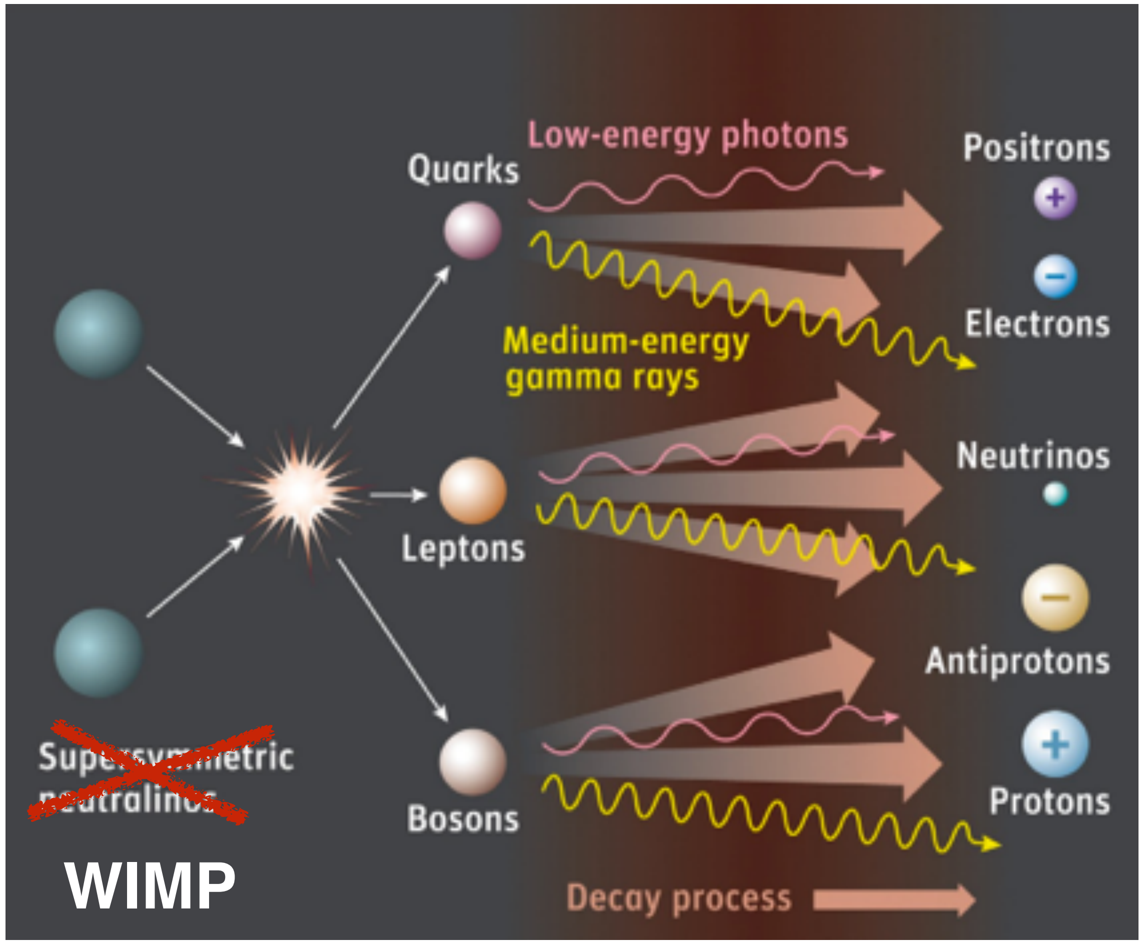
Note, however, that this specific choice is not needed by DarkSUSY, more general models are possible.

dsgive_model: sets an MSSM-7 model
dsgive_model13: sets an MSSM-13 model

- One can also set these low-energy parameters with an external program, like ISASUGRA
- For consistency, in that case we use the spectrum calculation by that external program and just transfer these values to DarkSUSY

dsgive_model_isasugra: sets an m-SUGRA model

Physic set-up: simplified models



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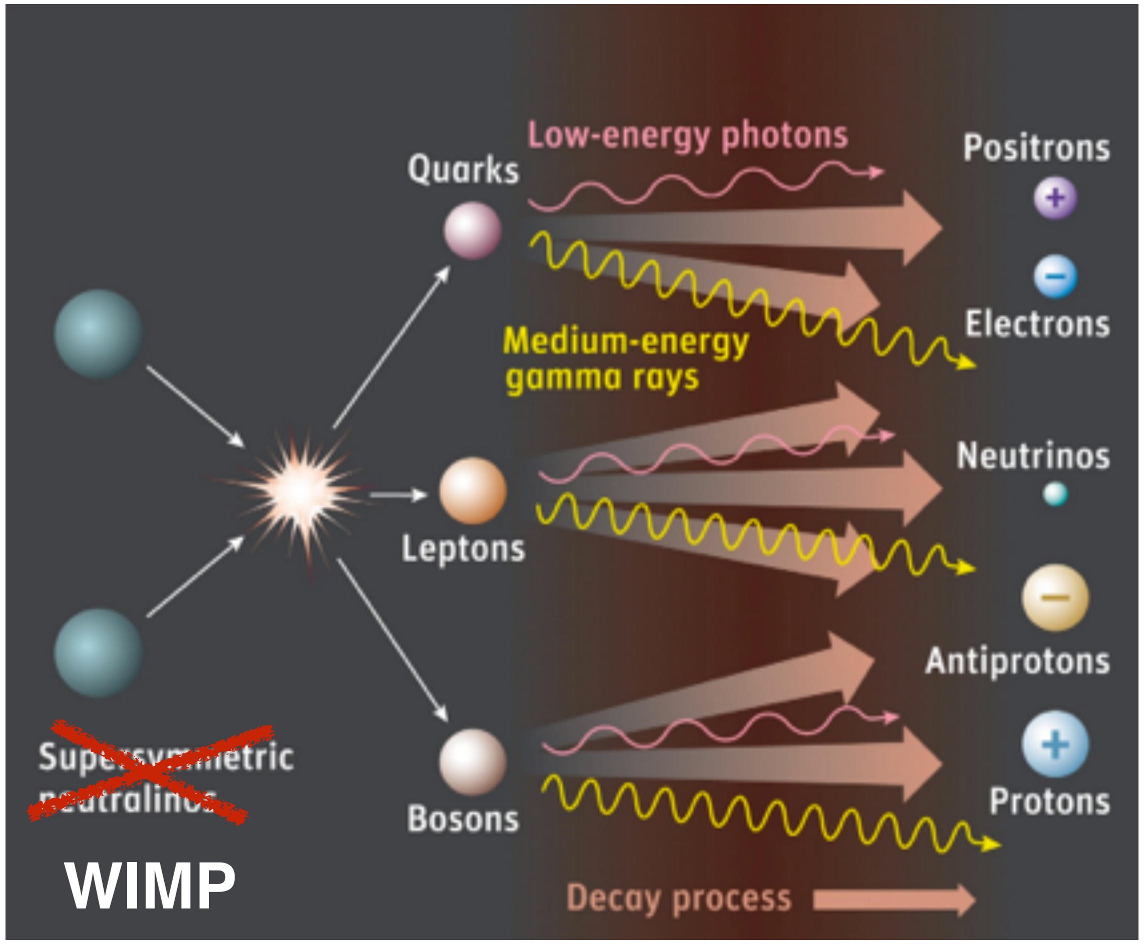

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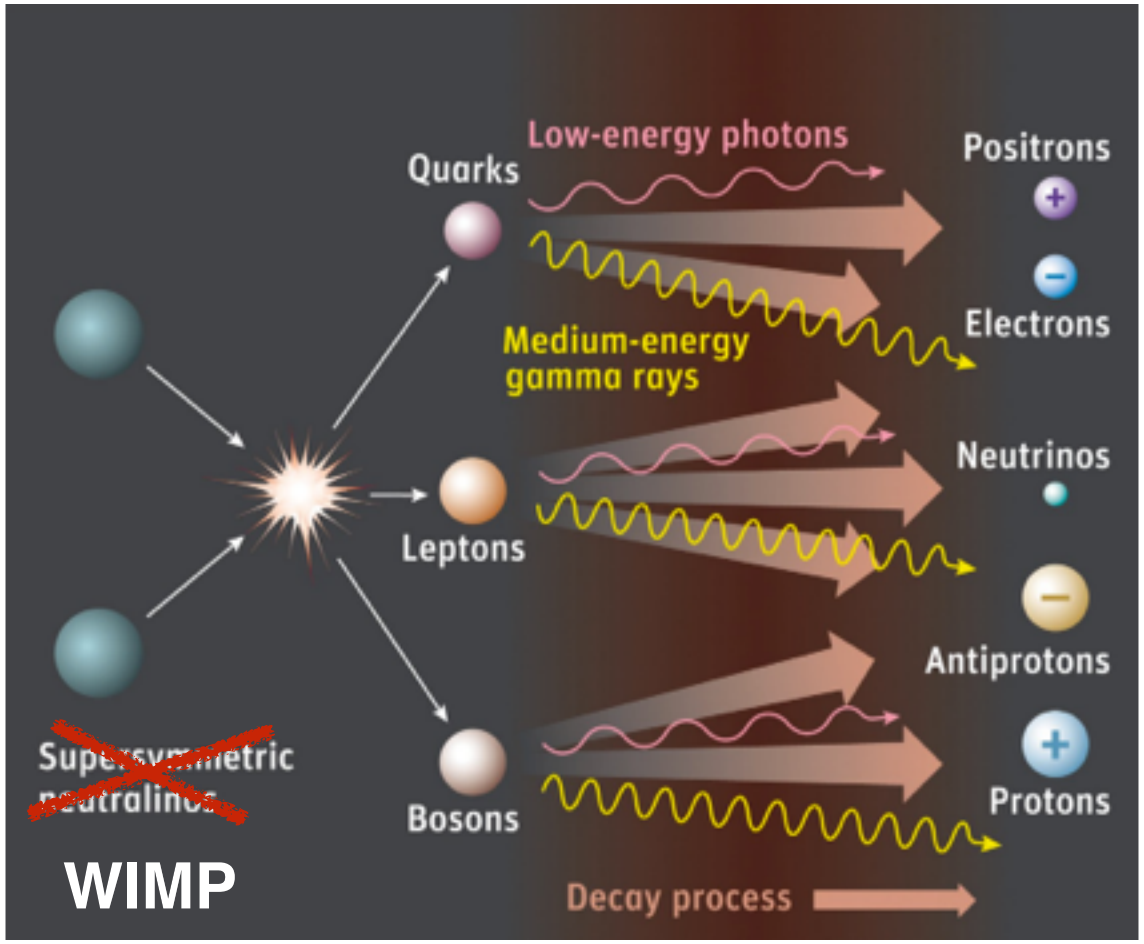

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$$B_i \equiv 1$$

Relic Density

Relic Density

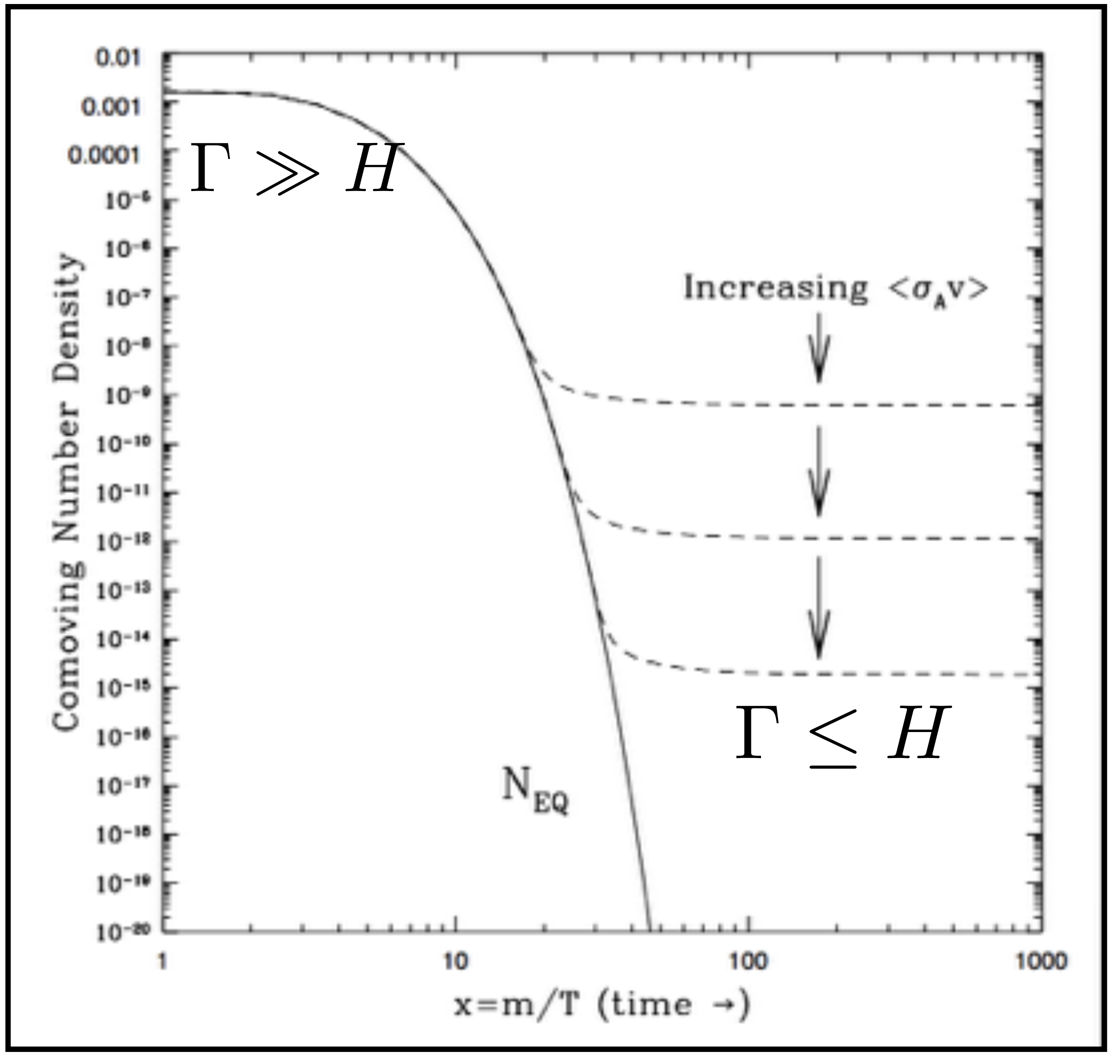
Freeze out of a thermal relic in the early Universe

$$\Gamma = \langle \sigma_{\rm ann} v \rangle \, n_\chi$$

$$H(T) = 1.66 \, g_*^{1/2} \, \frac{T^2}{M_{\rm Pl}}$$

$$\Gamma \simeq H \rightarrow T_f \simeq \frac{m_\chi}{20}$$

$$\Omega_\chi h^2 \simeq \frac{3 \times 10^{-27} {\rm cm}^3 {\rm s}^{-1}}{\langle \sigma_{\rm ann} v \rangle}$$



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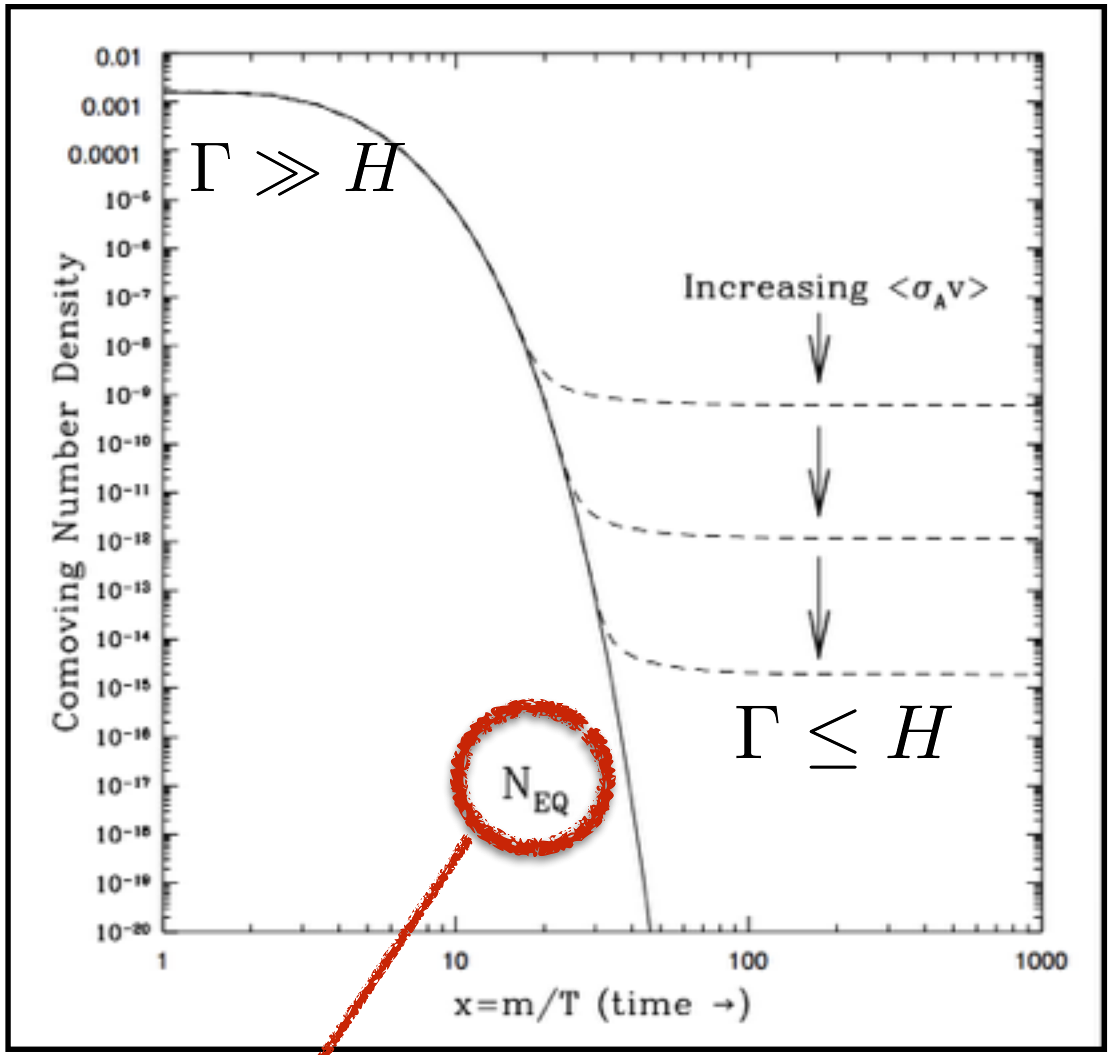

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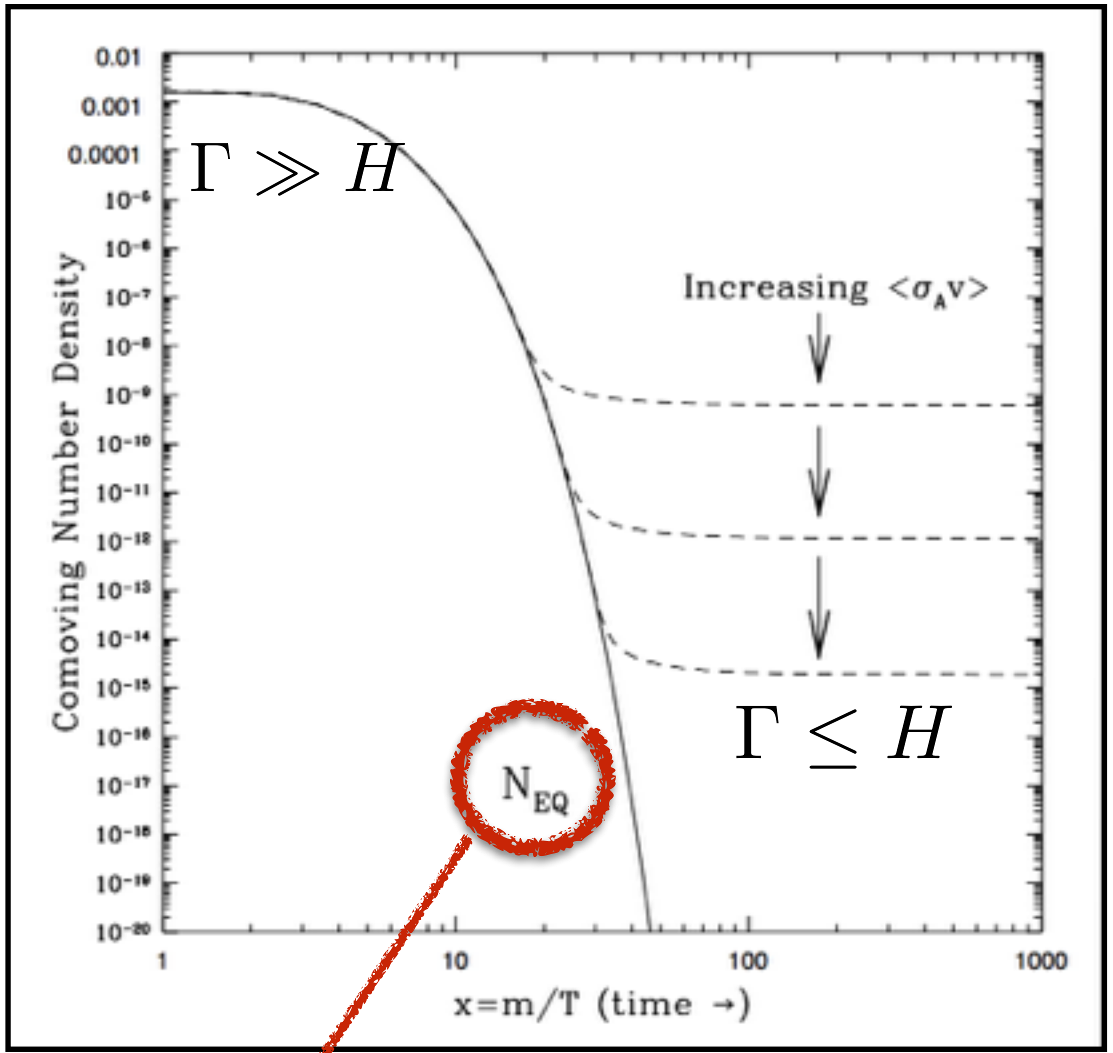
Fixed by observations!

Computed by DarkSUSY!



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Relic Density

How does DarkSUSY compute the relic density?

- It solves the Boltzmann equation,

$$\frac{dn}{dt} = -3Hn - \langle \sigma_{\mathrm{ann}} v \rangle \left(n^2 - n_{\mathrm{eq}}^2\right)$$

  properly computing the thermal average <·> and including the full annihilation cross section (including all final states, resonances and thresholds).
- It includes all so-called coannihilations between all neutralinos, charginos and sfermions.

Remark: Only annihilation/coannihilation
No scattering and decay
Sum over **all** SUSY particles

Relic Density

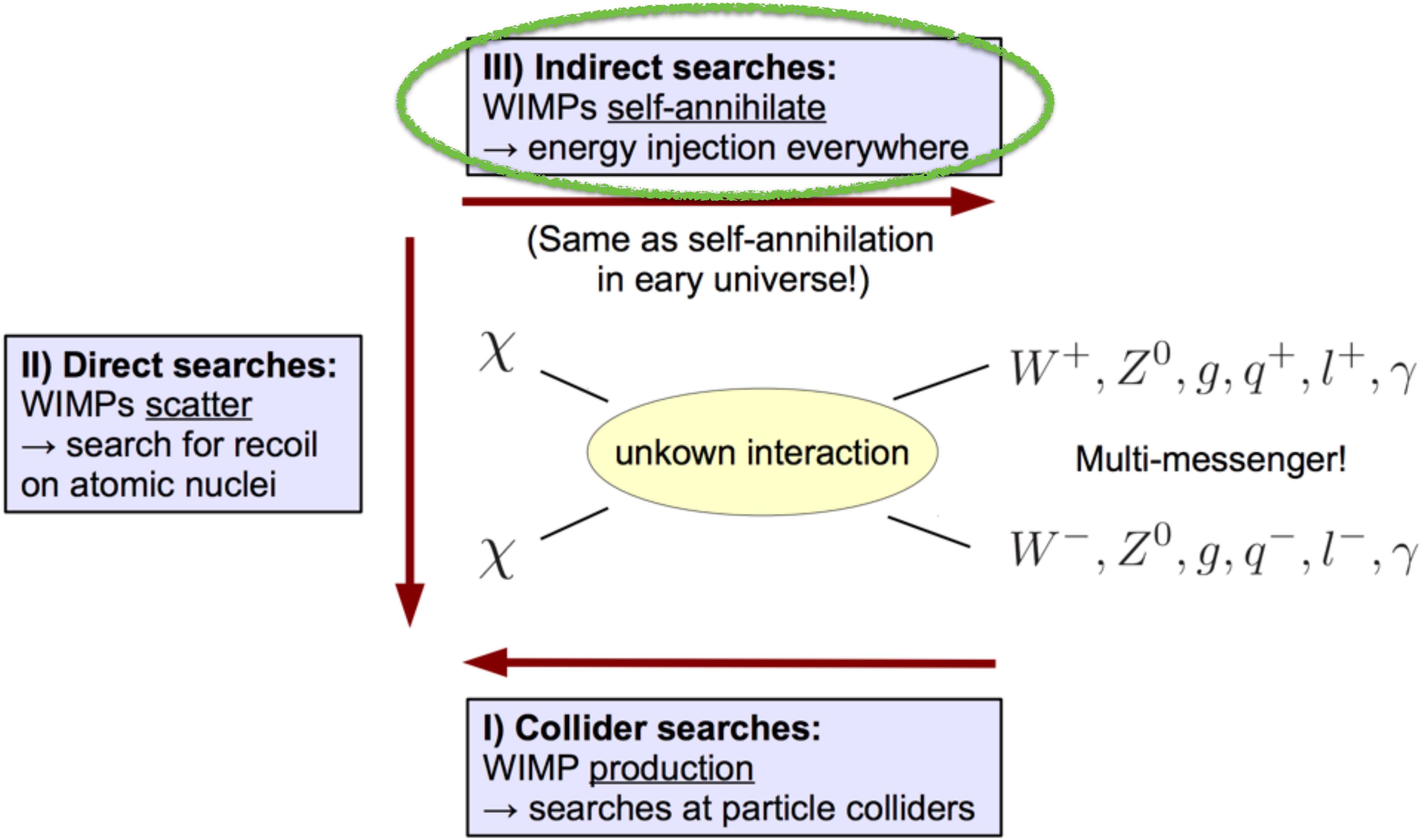
DarkSUSY routines for relic density:

- The main routine for SUSY neutralinos is dsrdomega that calculates the relic density of neutralinos
- However, the relic density routines are more general than that and can be used for any WIMP with a call to dsrdens.

```
Call dsrdens(wrate,npart,mgev,dof,nrs,rm,rw,nt,tm,oh2,tf,ierr,iwar)
where you have to supply:
wrate – invariant effective annihilation rate (function)
npart – number of coannihilating particles
mgev – mass of these particles
dof – internal degrees of freedom of these particles
nrs – number of resonances
rm – mass of resonances
rw – width of resonances
nt – number of thresholds
tm – equivalent mass of thresholds
The routine then returns:
oh2 – omega h^2
tf – freeze-out temperature
```

Detection strategies with DarkSUSY

WIMP detection strategies



courtesy of C.Weniger

Indirect DM detection

Indirect detection differential and integrated rates for:

- Gamma rays from the halo
- Antiprotons from the halo
- Antideuterium from the halo
- Positrons from the halo
- Neutrinos from the Sun/Earth

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Particle Physics Factor
Spectral information

Astrophysical Factor
Angular information

$\langle \sigma v \rangle$ src/an/dssigmav.f

$\frac{dN_\gamma^i}{dE_\gamma}$, B_i } src/ha/dshayield.f, src/ha/dshaloyield.f

ρ src/hm/dshmset.f

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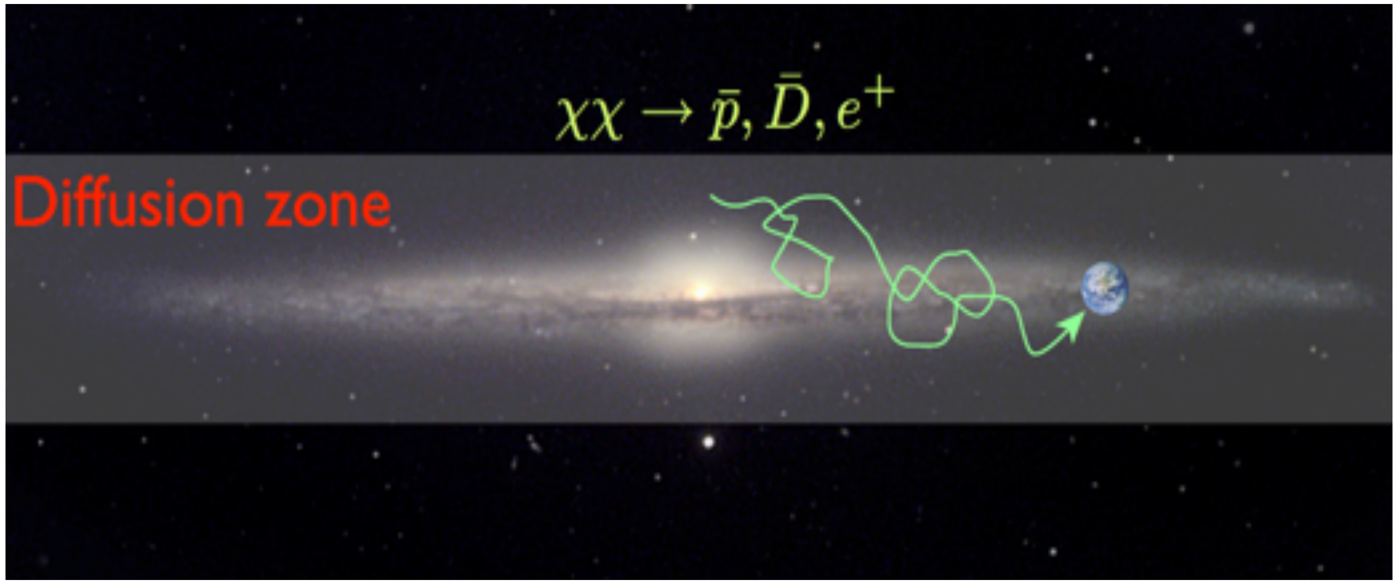
→ src/an/dshrgacontdiff.f or src/an/dshrgacont.f
src/an/dshrgaline.f

Indirect DM detection

Indirect detection differential and integrated rates for:

- Positrons from the halo



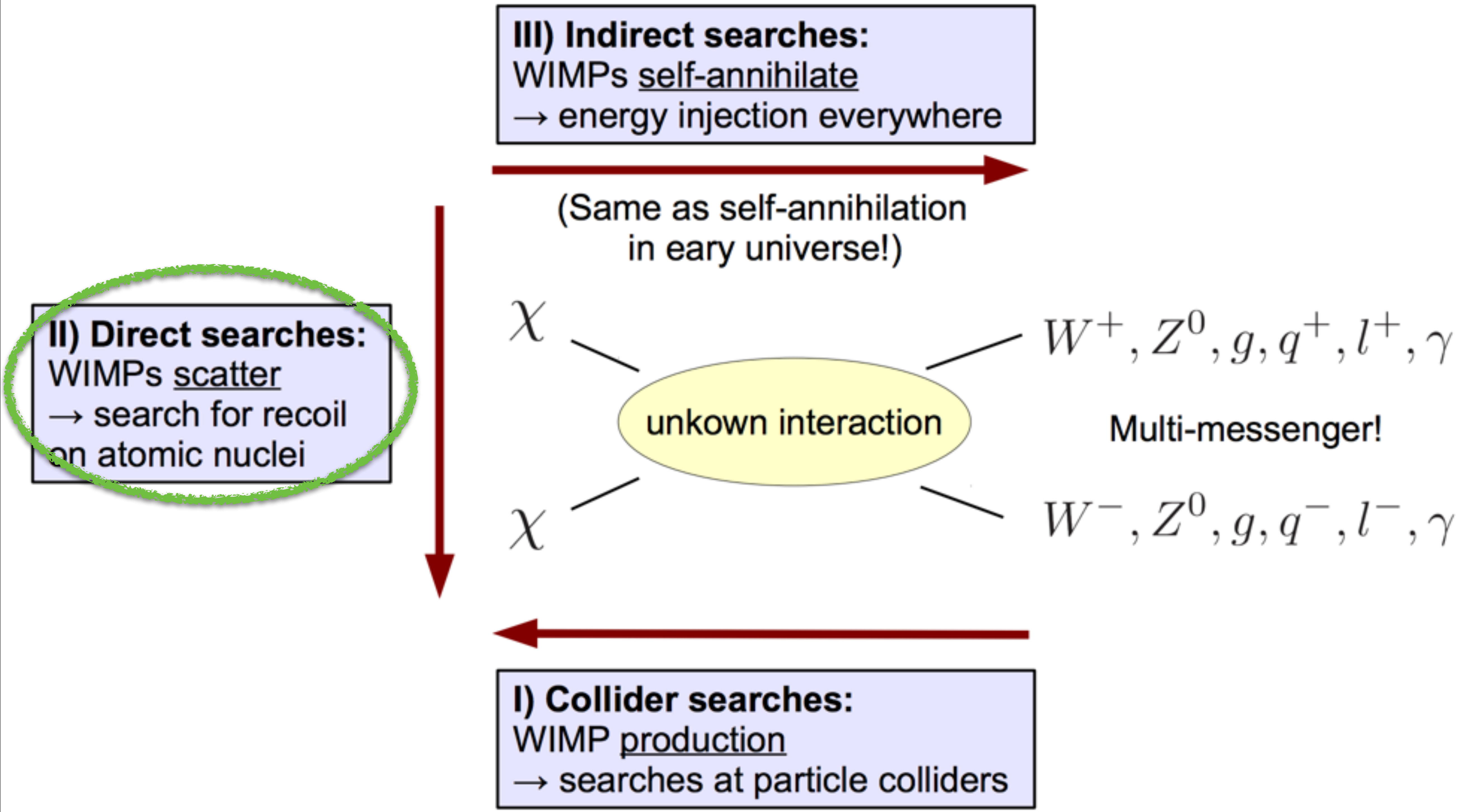
Spectrum at the source, then cosmic-ray propagation down to Earth:

- src/ep/dsepset.f sets the diffusion model, including energy losses.
- src/ep/dsepdiff.f calculates positron fluxes.

Prompt spectrum from DM annihilation:

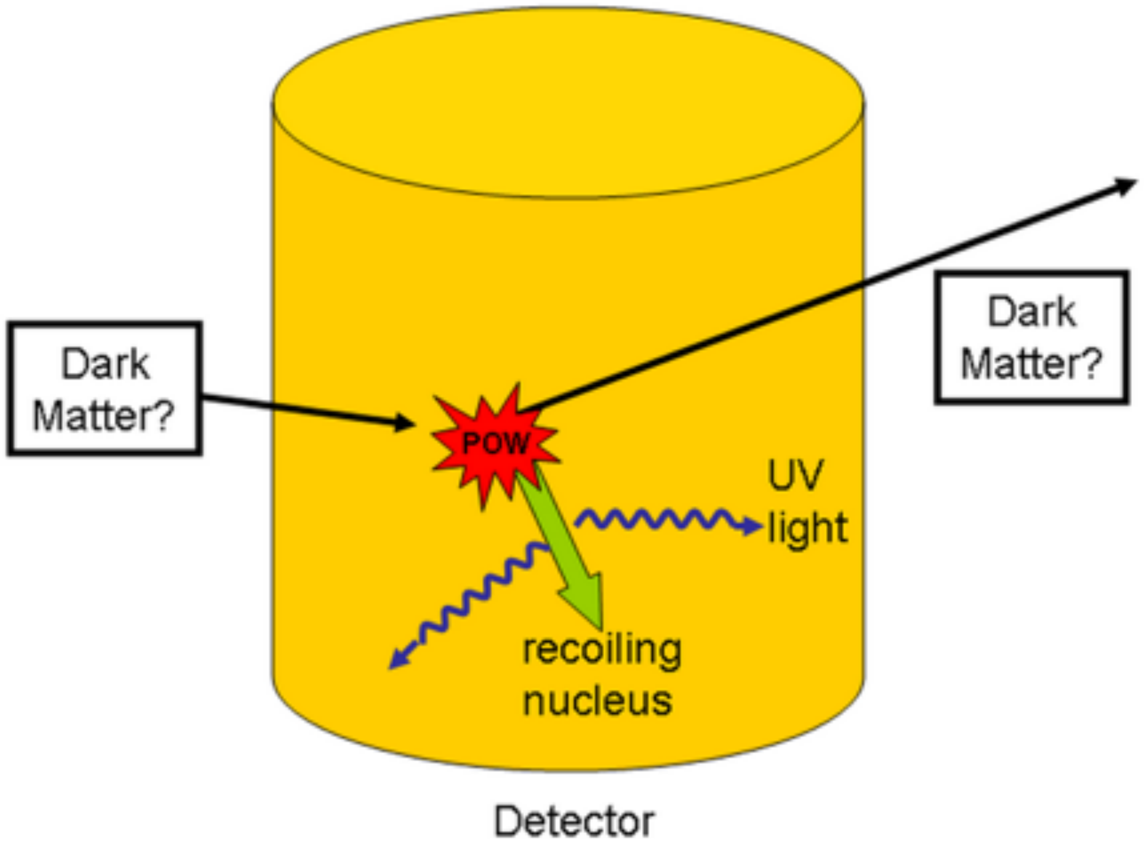
- Enhancement from IB contribution, fully implemented.
- src/ha/dshaloyield.f calculates the differential or integrated spectrum.

WIMP detection strategies



courtesy of C.Weniger

Direct DM detection



- WIMP + nucleus → WIMP + nucleus
- Measure of recoil energy of the nucleus
- Suppress background enough to be sensitive to a signal
- Search for an annual modulation due to the Earth's motion in the halo (e.g. DAMA/LIBRA experiment)

Interesting quantities:

- spin-dependent and spin-independent cross sections off nucleons.
- direct detection rates in function of the recoil energy.

Remark: Direct detection experiments have really started to explore the MSSM parameter space!

Direct DM detection

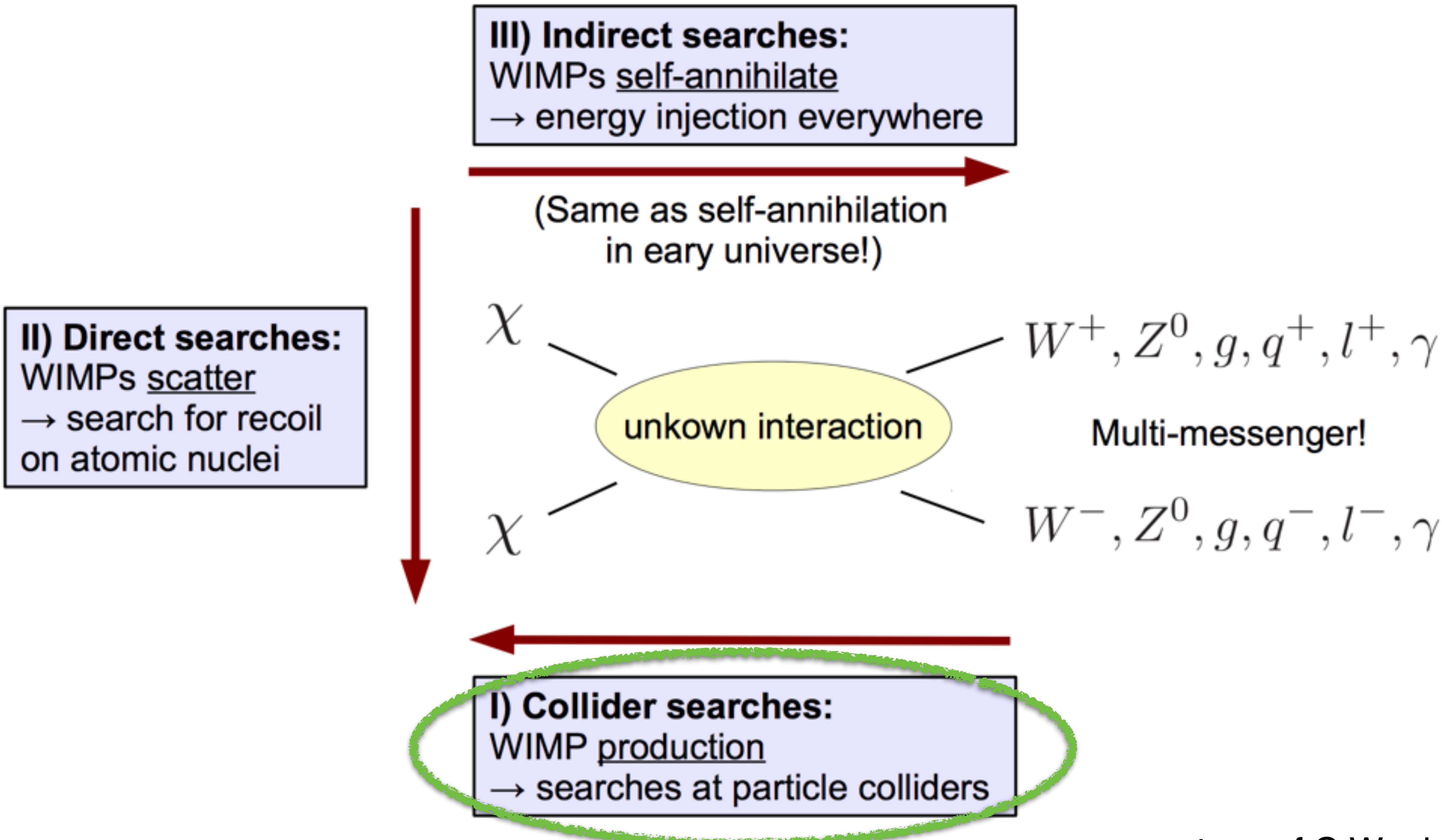
How does DarkSUSY compute DD observables?

- DarkSUSY computes spin-independent and spin-dependent cross sections on protons and nucleons.
- Useful for the comparison with current experimental results.
- Routines for calculating the differential rate on several targets, including the form factor calculation.
- **Caveat**: large uncertainties on form factors and quark content of the nucleon.

DarkSUSY routines for direct detection:

- src/dd/dsddneunuc.f: computes spin-independent and spin-dependent cross sections off protons and nucleons, in units of cm^2.
- src/dd/dsdddrde.f: computes differential scattering rates on various targets as a function of time (it can be used to predict annual modulation signals), in units of counts/kg-day-keV.

WIMP detection strategies



courtesy of C.Weniger

Accelerator constraints

- Accelerator constraints are most easily checked with a call to call dsacbnd(excl), excl is non-zero if the model is excluded.
- For backwards-compatibility, DarkSUSY keeps old versions of the accelerator constraints as well, but dsacbnd always points to the latest set of constraints.
- Default set of constraints ‘pdg2002c’. To change it, you should call dsacset and check its available set of options.
- See dsacbnd9.f for latest included bounds: lower bounds of chargino, gluino and squark masses, invisible Z width and Higgs mass bound, etc.

Caveat: Accelerators constraints are **not** updated to the latest accelerators results!

DarkSUSY Tutorial

Download & Install

http://www.fysik.su.se/~edsjo/darksusy/

Current version

- **Current version:** darksusy-5.1.1.tar.gz
- **News:** Bug fixes (more automatic configure script, binary files causing problems on some systems deleted, corrected generic WIMP program in misc).
- **Release date:** March 1, 2013
- **Tested on:** Linux / Mac OS X with gfortran (version 4.2 or later required) or ifort. **Note:** g77 support is dropped.
- **System requirements:** You need to have approximately 400 MB of hard disk space. The download itself is about 100 MB. Perl is required for the make to proceed properly.

Download & Install

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Download & Install

http://www.fysik.su.se/~edsjo/darksusy/

```
$ tar -xzvf darksusy-5.1.1.tar.gz
$ cd darksusy-5.1.1
$ ./conf.gfortran
$ make
$ make install
```

DONE?!
READY TO GO!

Download & Install

http://www.fysik.su.se/~edsjo/darksusy/

```
$ tar -xzvf darksusy-5.1.1.tar.gz
$ cd darksusy-5.1.1
$ ./conf.gfortran
$ make
$ make install
```

If you want to install DarkSUSY elsewhere (for the library and tables, usually in share), instead do:

```
$ ./configure --prefix=<install-dir>
$ make
$ make install
```

Other options can also be given at configure time, e.g:

```
$ ./configure F77=ifort FFLAGS= FOPT=-O
```

to compile with ifort instead of the default gfortran (if available).

Manual

A quick manual (not fully up-to-date yet) is distributed with DarkSUSY and created with:

```
$ make pdf-manual
```

to make the default manual, or:

```
$ make pdf-manual-short
```

to make a short version (without subroutine headers).

Also see the headers of various subroutines for instructions (they can be more useful than the manual sometimes).

Typical Program

```
program …
implicit none

real*8 … ! definition of variables and functions called

include … ! include required modules, e.g. 'dsmssm.h'

c This call initialises the DarkSUSY package.
c Check out c src/ini/dsinit.f if you want to see what it
c does.

call dsinit
write (*,*) 'DarkSUSY initialized'

[make general settings]
[determine your model parameters your way]
[then calculate what you want]
```

See test/dstest.f as a reference!

Settings

General routines setting:

- Essentially all the packages in DarkSUSY have a corresponding *set routine that determines how those routines are going to be used, which parameter sets to use, etc.
- As an example, call dshmset (‘default’) chooses the default halo model (NFW).
- All these *set routines are called with the argument ‘default’ by dsinit, but can be changed later by the user.

How to run a script?

Look into test/makefile

```
$ cd test
$ nano makefile
```

- Check installation folder: prefix=
- Define commands for makefile:

```
dstest : dstest.f $(LIB)/libdarksusy.a $(LIB)/libisajet.a
        $(FF) $(FOPT) $(INC) -L$(LIB) -o dstest dstest.f \
        -ldarksusy -lHB -lFH
```

Run the script test/dstest.f

```
$ make dstest
make: `dstest' is up to date.
$ ./dstest &> out &
$ nano out
```

How to run a script?

```
 ********************************************************
 *** Welcome to DarkSUSY version                     ***
 *** darksusy-5.1.1                                            ***
 ********************************************************

 Initializing DarkSUSY...
[…]
***** MODEL: JE56A_000881 *****
[…]
   Neutralino mass =    381.49536018437527
   Gaugino fraction =   0.80017344515335709
   H1 mass =     926.19328732872054        2.0232974526262533
   H2 mass =     123.66699022930607        3.9318930663253884E-003
   H3 mass =     925.90886000000000        2.1164678471354139
   H+- mass =    929.64055132578301        1.9412066702012420
 Calculating omega h^2 without coannihilations, please be patient…
[…]
 Calculating scattering cross sections...
   sigsip (pb) =    5.4014844940191810E-009
[…]
 Calculating gamma ray fluxes...
   fluxgacdiff =    1.9466096750513645E-012  ph/(cm^2 s GeV)
       fluxgac =    5.0670561889799238E-010  ph/(cm^2 s)
      fluxgaga =    5.6245800731894324E-016  ph/(cm^2 s)
       fluxgaz =    3.4259181882023676E-015  ph/(cm^2 s)
   nsigvgacont =    64632.998292566190
  nsigvgacdiff =    32824.594649122002       GeV^-1
     nsigvgaga =    7.1744512140497749E-002
      nsigvgaz =   0.43699409706591746
[…]
```

```
$ make dstest
make: `dstest' is up to date.
$ ./dstest &> out &
$ nano out
```

Exercises overview

1. Computing prompt photons and positrons spectra for DM annihilation into quarks or leptons, 100% branching ratio.

2. Plotting spectra.

3. Computing prompt photons and positrons spectra for DM annihilation for a concrete SUSY model.

Exercise 1: spectrum 100% BR

DM model:

- 100% BR into quarks or leptons.
- Spectrum of prompt photons and positrons (or electrons).
- output: file with E, dN/dE.

Program example: Settings

```
      program dmspec
      implicit none

      integer BRch, yieldk,istat, i
      real*8 mwimp,result1,egev
      real*8 dshayield

      include 'dsmssm.h'
      include 'dsio.h'
      include 'dsidtag.h'
      include 'dshacom.h'
      include 'dshrcom.h'
```

Exercise 1: spectrum 100% BR

Program example: Compute the **photon** spectrum

```
      call dsinit
      write (*,*) 'DarkSUSY initialized'

c     Define WIMP mass ad 100% channel
      mwimp=1000.
      BRch=25 ! bbar

c     Differential gamma-ray flux
      yieldk=152 ! integrated above the threshold: 52

c     Open a file
      open (unit=11,file=‘mwimp1000gev_bbar_gamma.dat')
c     Loop on energies to get the differential flux
      do i=[…]
      egev=[…]
      result1=dshayield(mwimp,egev,BRch,yieldk,istat)
      write(11,*) egev,result1
      enddo
      close(11)

      end
```

Exercise 1: spectrum 100% BR

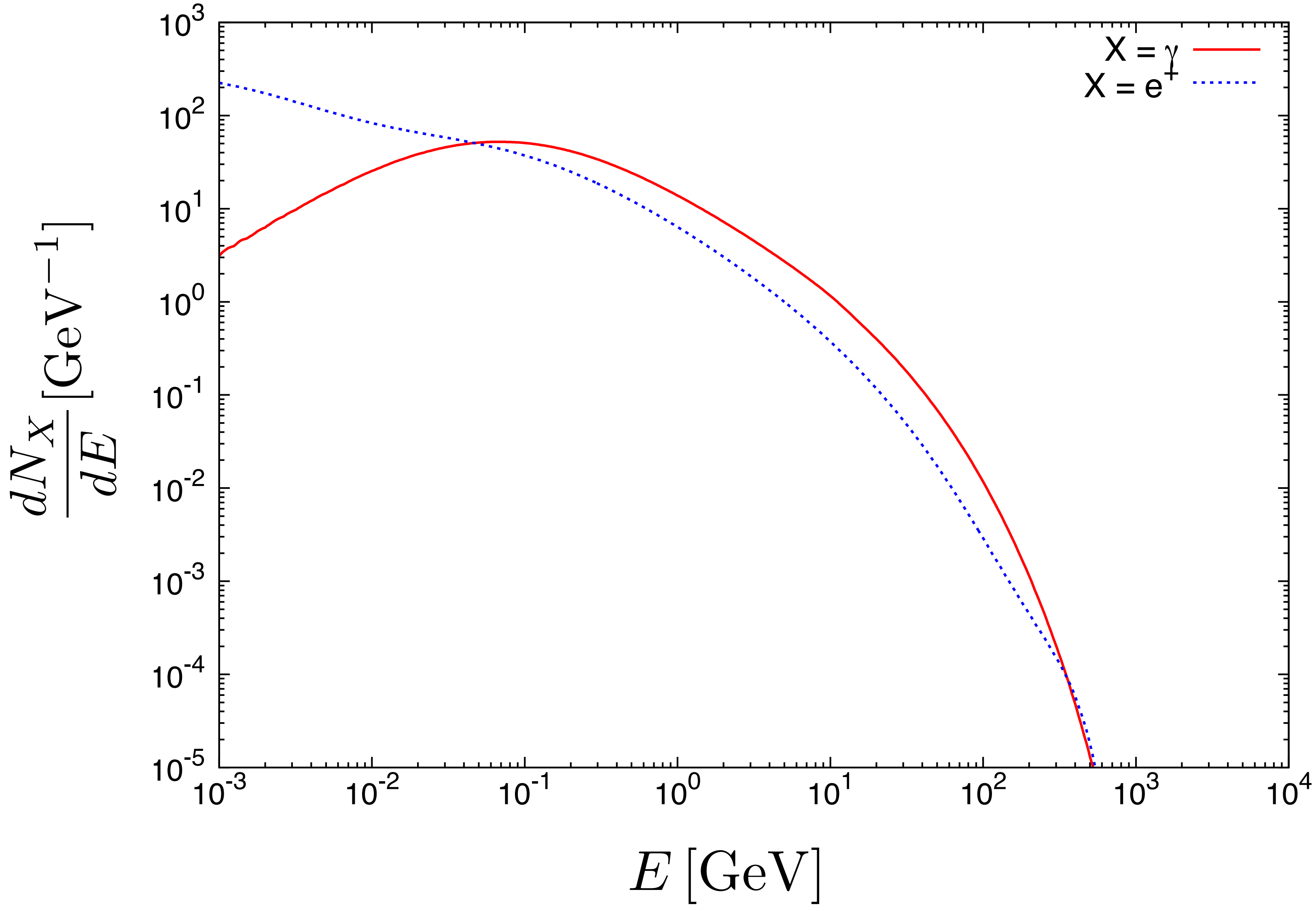
Program example: Compute the **positron** spectrum

```
      call dsinit
      write (*,*) 'DarkSUSY initialized'

c     Define WIMP mass ad 100% channel
      mwimp=1000.
      BRch=25 ! bbar

c     Differential gamma-ray flux
      yieldk=152 ! integrated above the threshold: 52
                   151
c     Open a file
      open (unit=11,file=‘mwimp1000gev_bbar_gamma.dat')
c     Loop on energies to get the differential flux
      do i=[…]
      egev=[…]
      result1=dshayield(mwimp,egev,BRch,yieldk,istat)
      write(11,*) egev,result1
      enddo
      close(11)

      end
```

Look into src/ha/dshayield.f for channels ID

Exercise 2: plotting spectra

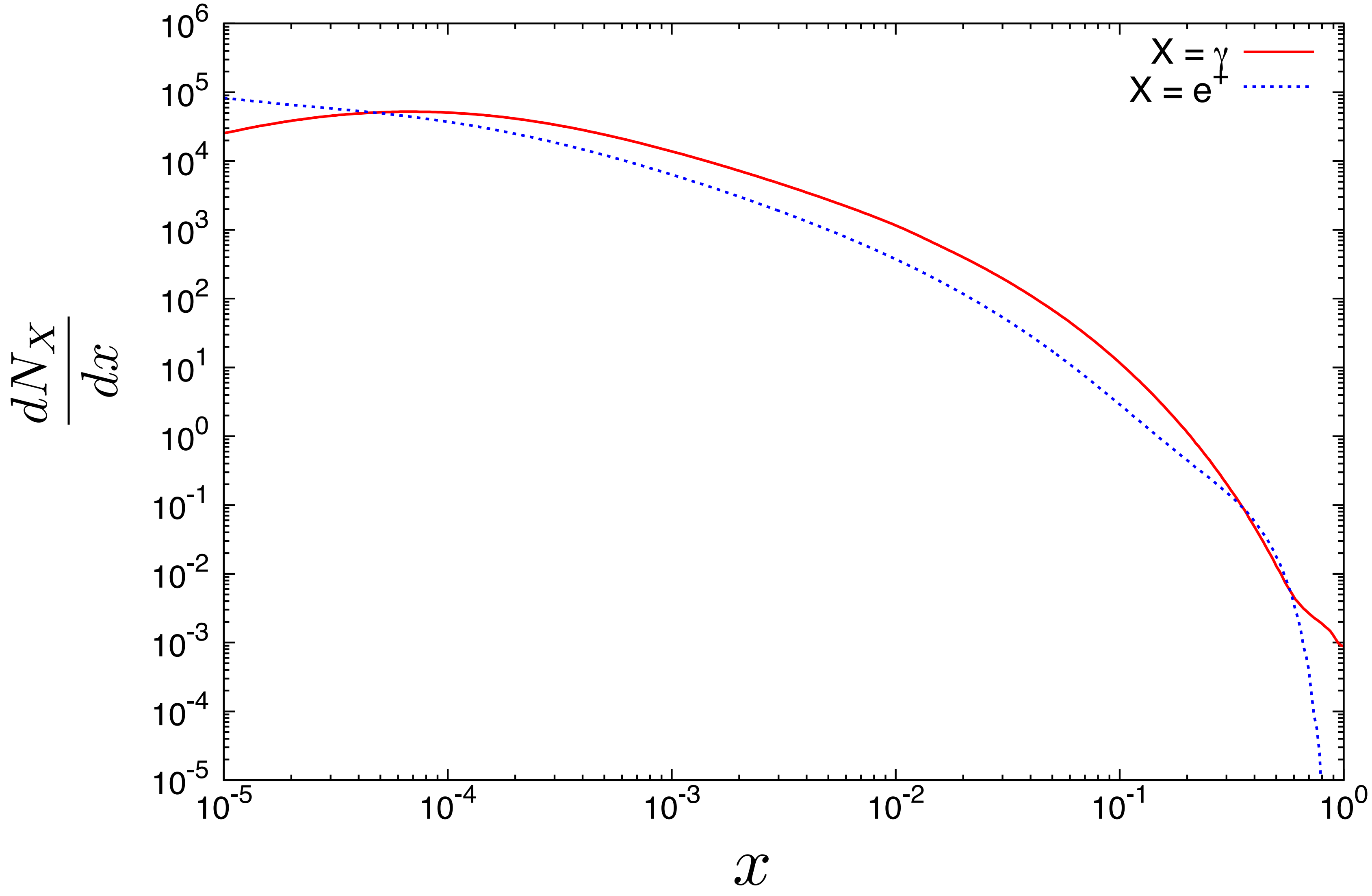
Plotting different spectral quantities from the output file (.dat file)



$$\frac{dN_X}{dE}$$

Exercise 2: plotting spectra

Plotting different spectral quantities from the output file (.dat file)

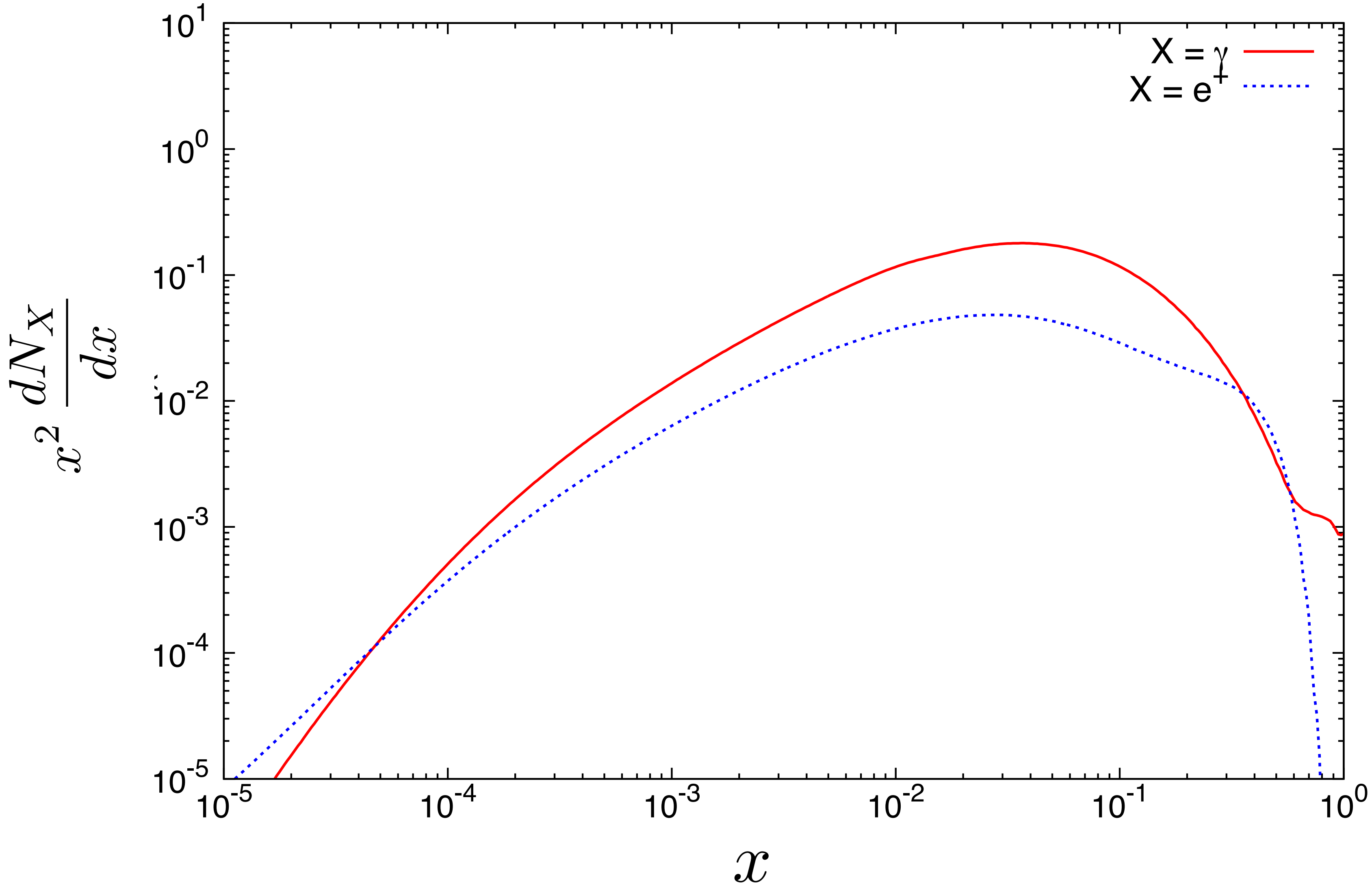


$$x \equiv \frac{E_X}{m_\chi}$$

$$\frac{dN_X}{dx} \equiv m_\chi \frac{dN_X}{dE}$$

Exercise 2: plotting spectra

Plotting different spectral quantities from the output file (.dat file)



$$x \equiv \frac{E_X}{m_\chi}$$

$$x^2 \frac{dN_X}{dx}$$

For comparison to data, it is often plotted:

$$E^2 \frac{dN_X}{dE}$$

Exercise 3: spectrum concrete MSSM

DM model:

- MSSM-7 concrete model: in test/dstest.mod keep only JE56A_002352
- Spectrum of prompt photons and positrons (or electrons).
- output: file with E, dN/dE.

Program example: Settings

```
      program dmspec_MSSM
      implicit none

      […]
      integer modtype
      character slhafile*80
      integer iend
      integer unphys,excl,hwarning

      include 'dsmssm.h'
      include 'dsio.h'
      include 'dsidtag.h'
      include 'dshacom.h'
      include ‘dshrcom.h'
      […]
```

Exercise 3: spectrum concrete MSSM

Program example: Read in model in the form of .mod file

```
c      Read in models from .mod file
       open (unit=11,file='dstest.mod')
       read (11,*) ! this skips the header

       open (unit=30,file='dstest2.tmp')

       iend=0

 1000  call read_model(11,0,iend,ierr)

       if (ierr.ne.0) then
          write (*,*) 'Error while reading dstest.mod'
          write (*,*) 'The DarkSUSY test cannot continue'
          stop
       else if (iend.eq.1) then
          goto 2000 ! exit program
       else
          call dswrite(0,0,'Parameters read from file dstest.mod')
       endif
```

Exercise 3: spectrum concrete MSSM

Program example: Read in model in the form of .mod file

```
c      Read in models from .mod file
       open (unit=11,file='dstest.mod')
       read (11,*) ! this skips the header

       open (unit=30,file='dstest2.tmp')

       iend=0

 1000  call read_model(11,0,iend,ierr)

       else if (iend.eq.1) then
          goto 2000 ! exit program
       else
          call dswrite(0,0,'Parameters read from file dstest.mod')
       endif
```

subroutine at the end of
test/dstest.f
dsgive_model(mu,m2,ma,tanbe,mqtild,at,ab)

Exercise 3: spectrum concrete MSSM

Program example: Initialise model and get some interesting information

```
      write(*,*) ' '
      write(*,*) '***** MODEL: ',idtag,' *****'

      call dssusy(unphys,hwarning)

      write(*,*) ' Neutralino mass mx = ‘,mass(kn(1))
      write(*,*) '  Gaugino fraction = ',
     &     dsabsq(neunmx(1,1))+dsabsq(neunmx(1,2))
      […]
```

Exercise 3: spectrum concrete MSSM

Program example: Compute the **photon** spectrum

```
c     Differential gamma-ray flux
      yieldk=152 ! integrated above the threshold: 52
      mwimp=mass(kn(1))

      call dshasetup

      open (unit=11,file='mwimp_MSSM_gamma.dat')
      do i=1,501
      egev=dexp(dlog(0.001d0)
    &         +(dlog(mwimp)-dlog(0.001d0))/500.d0*(i-1))
      result1=dshaloyield(egev,yieldk,istat)
      write(11,*) egev,result1
      enddo
      close(11)

      end
```

Exercise 3: spectrum concrete MSSM

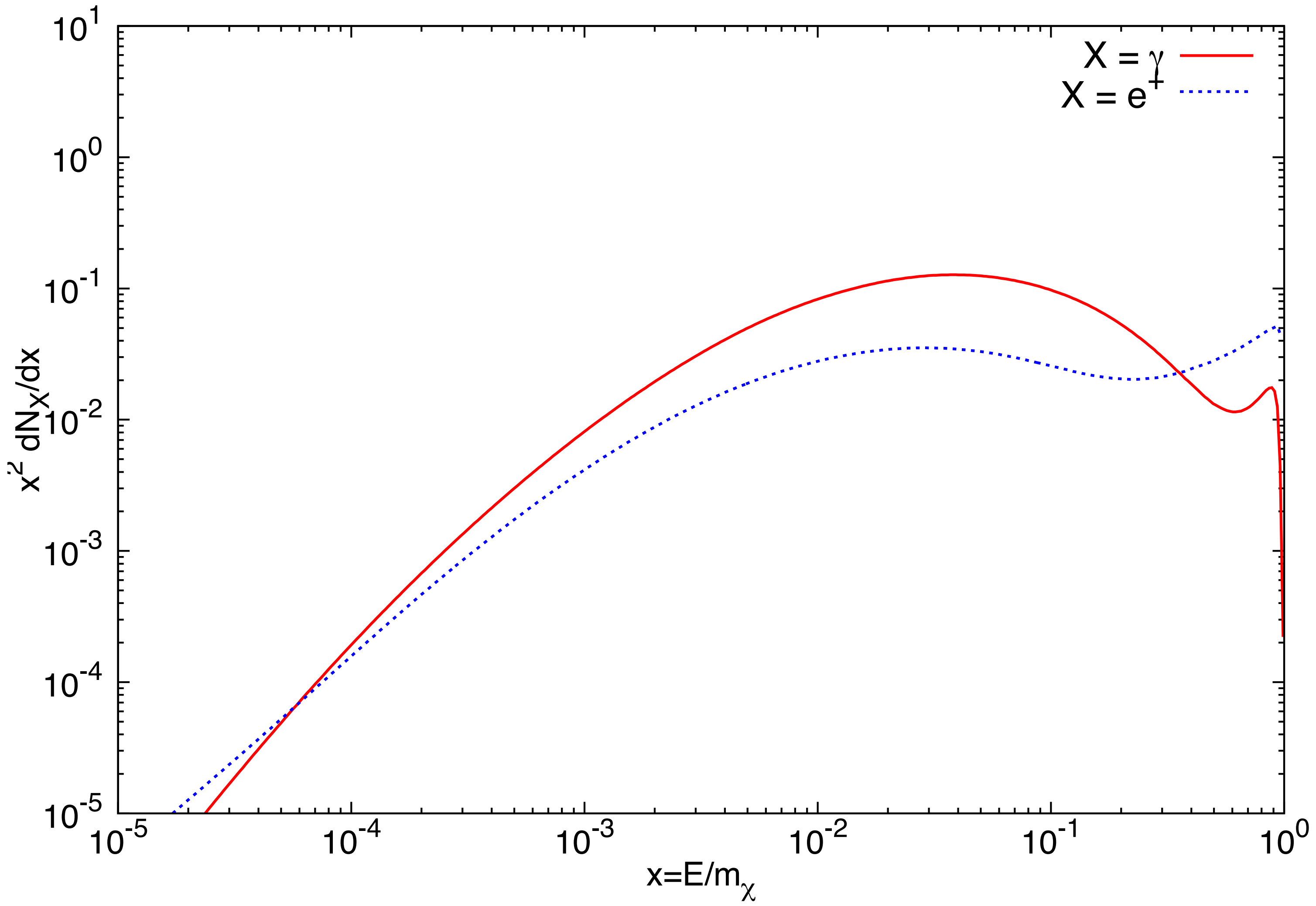
Program example: Compute the **photon** spectrum

```
c      Differential gamma-ray flux
       yieldk=152 ! integrated above the threshold: 52
       mwimp=mass(kn(1))

       call dshasetup

       open (unit=11,file='mwimp_MSSM_gamma.dat')
       do i=1,501
       egev=dexp(dlog(0.001d0)
     &          +(dlog(mwimp)-dlog(0.001d0))/500.d0*(i-1))
       result1=dshaloyield(egev,yieldk,istat)
       write(11,*) egev,result1
       enddo
       close(11)

       end
```

Exercise 3: spectrum concrete MSSM

DS model: JE56A_002352

$$\mu,\ \tan\beta,\ M_2,\ m_A,\ A_t,\ A_b,\ m_0$$



$$x^2\,\frac{dN_X}{dx}$$

$$m_\chi = 988\ \mathrm{GeV}$$

What would you learn?

1. How DarkSUSY is structured and what we can do with this tool for DM searches.

2. How to compute prompt photons and positrons spectra for DM annihilation in the framework of:
   - Simplified models: 100% branching ratio into quarks or leptons.
   - Concrete MSSM models.

3. Plotting spectra.