micrOMEGAs

A Tool for Dark Matter and New Physics

Fawzi BOUDJEMA

LAPTh, CNRS, Annecy-le-Vieux, France

micrOMEGAs

A Tool for Dark Matter and New Physics

in collaboration with Genevieve Belanger, Sacha Pukhov and Andrei Semenov

and Pierre Brun, Pierre Salati and Sylvie Rosier

Dark Matter Codes

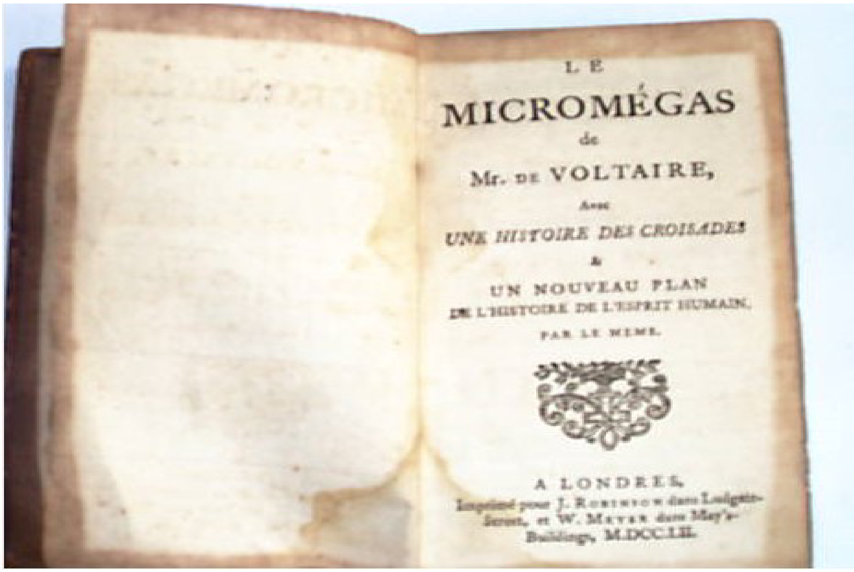
- micrOMEGAs Any model of New Physics/DM, relic density, direct and indirect detection,...
- Dark SUSY P. Gondolo, J. Edsjo, L. Bergstrom, P. Ullio, M. Schelke, T. Baltz, T. Bringmann and G. Duda; Supersymmetry, relic density, direct and indirect detection,...
- IsaTools H. Baer, Balazs, Belyaev (Part of Isajet) Supersymmetry, relic density,(direct and indirect detection,...)
- superIsoRelic A. Arbey, N. Mahmoudi; Supersymmetry, relic density
- Galprop (Propagation), Moskalenko and Strong
- Usine (Propagation) Maurin, Taillet,...
- Big Bang Nucleosynthesis (light elements abundance), Karsten Jedamzik, not public

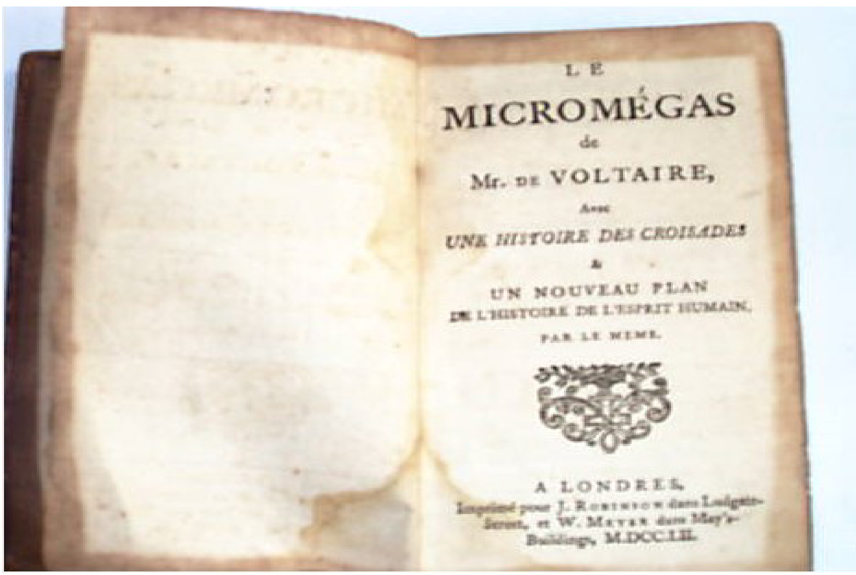
micrOMEGAs

$$\Omega$$

Ω

micrOMEGAs


LE
MICROMÉGAS
de
Mr. DE VOLTAIRE,
UNE HISTOIRE DES CROISADES
&
UN NOUVEAU PLAN
DE L'HISTOIRE DE L'ESPRIT HUMAIN.
PAR LE MEME.
A LONDRES,
M.DCC.LII.



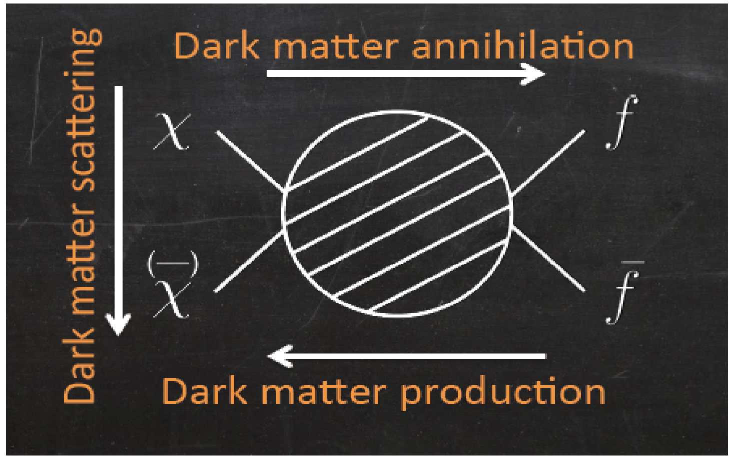
" O atomes intelligents,
dans qui l'Etre éternel
s'est plu à manifester
son adresse et sa puissance,
vous devez sans doute
goûter des joies
bien pures sur
votre globe car,
ayant si peu de matière...,"

Voltaire, Micromegas,
chapitre septième,
conversation avec les hommes

Need powerful, modular and versatile tools

micrOMEGAs: Tools for DM/ Collider Physics/ Flavour for a general NP

Aim



Collider Inputs

SUSY Parameters

$\chi\chi$ Annihilation

χN Interaction

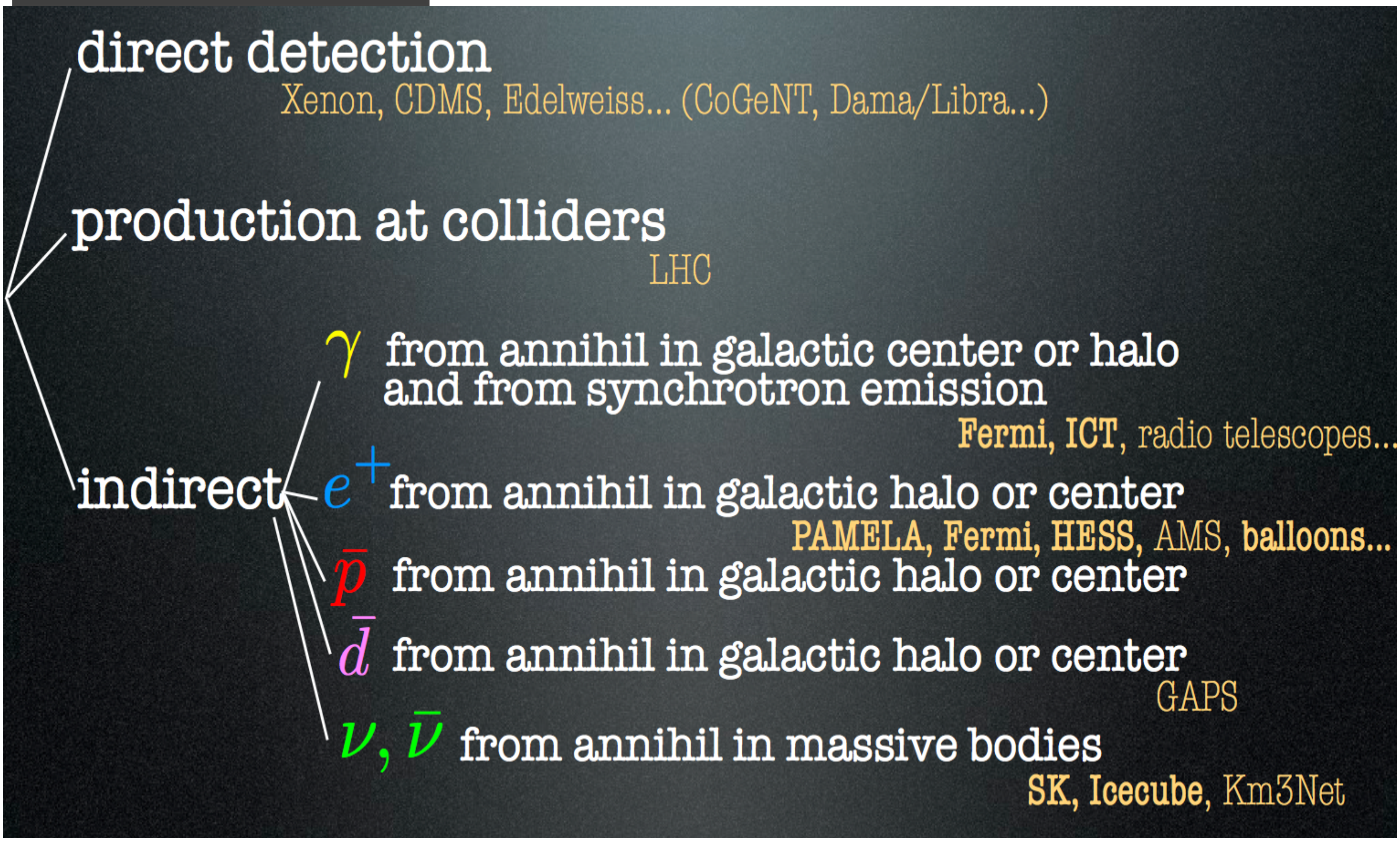
Relic Density

Indirect Detection

Direct Detection

Astrophysical and Cosmological Inputs

.... Relic Density



micrOMEGAs: Guiding Principle

Guiding principles

- Humans make mistakes - computers do not

  Automation (with auto checks)

- Several groups are developing specialized codes

  Link them

- Users might want to improve one aspect

  Modularity

- We do not know what DM is made of

  Possibility to include different DM candidates

- Models are often complex with huge parameter space

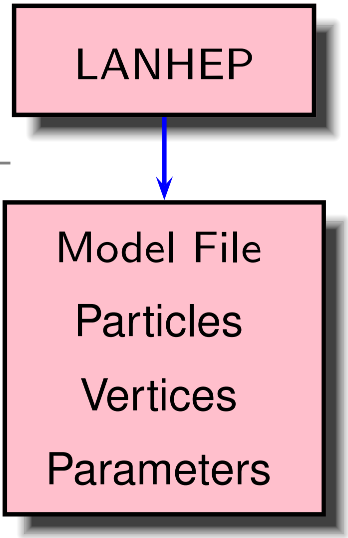
  Speed of execution

- Ready made, stand-alone package for the non-expert

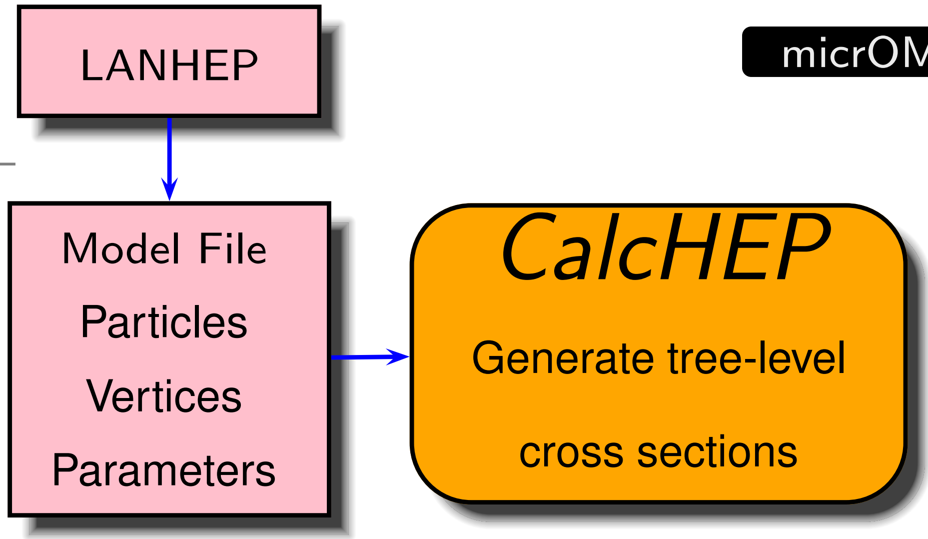
  User friendly

LANHEP

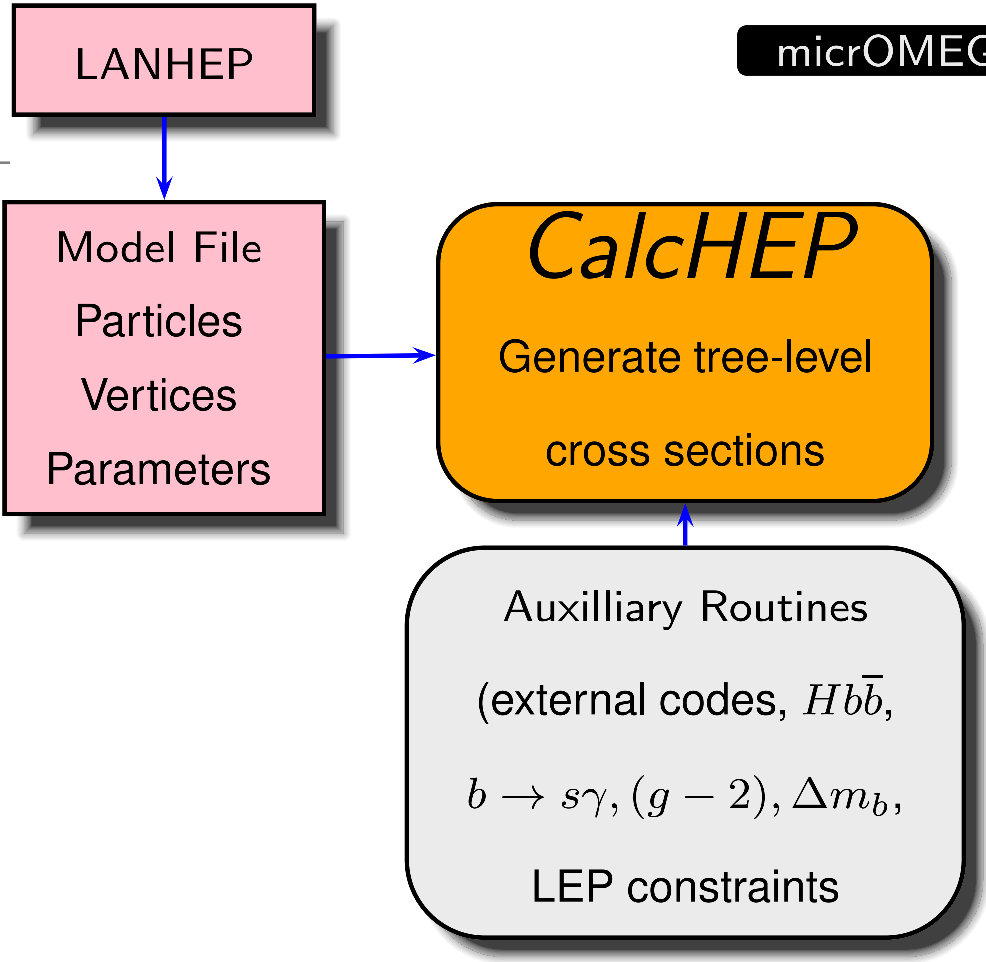
micrOMEGAs

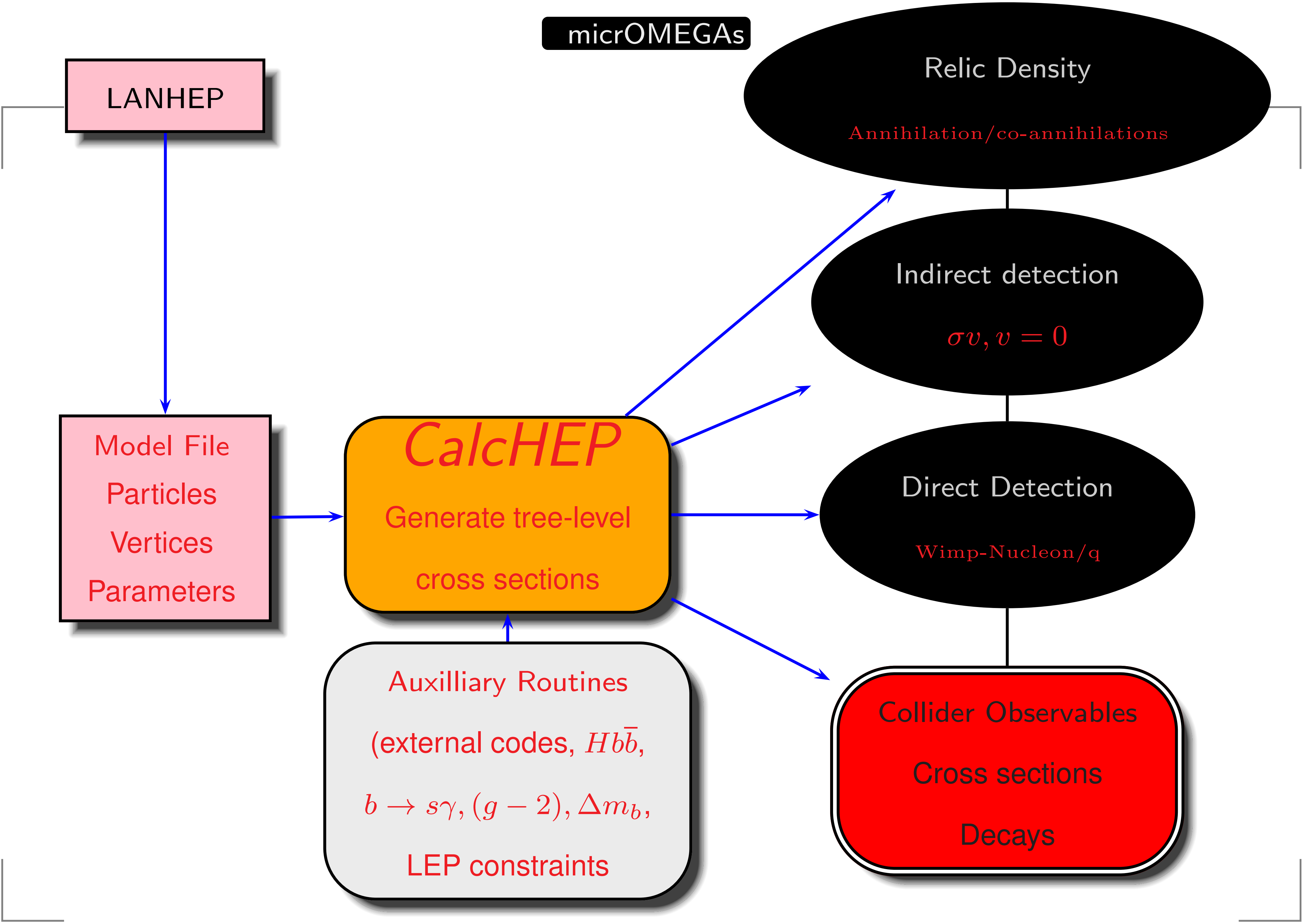


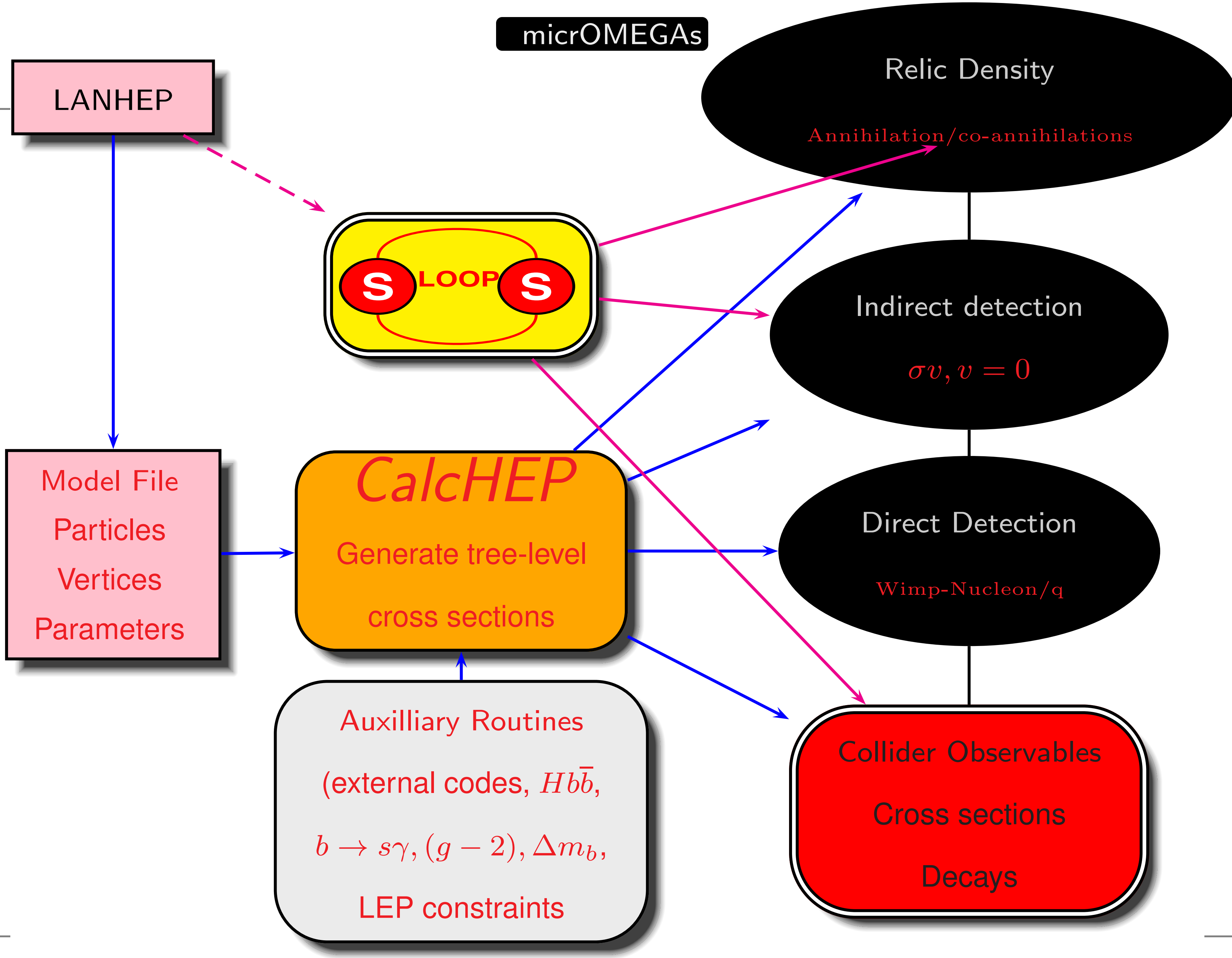
micrOMEGAs


LANHEP
Model File
Particles
Vertices
Parameters
CalcHEP
Generate tree-level
cross sections

micrOMEGAs


LANHEP
Model File
Particles
Vertices
Parameters
CalcHEP
Generate tree-level
cross sections
Auxilliary Routines
(external codes, $Hb\bar{b}$,
$b \to s\gamma, (g-2), \Delta m_b$,
LEP constraints


micrOMEGAs
LANHEP
Relic Density
Annihilation/co-annihilations
Indirect detection
$\sigma v, v = 0$
Model File
Particles
Vertices
Parameters
CalcHEP
Generate tree-level
cross sections
Direct Detection
Wimp-Nucleon/q
Auxilliary Routines
(external codes, $Hb\bar{b}$,
$b \to s\gamma, (g-2), \Delta m_b$,
LEP constraints
Collider Observables
Cross sections
Decays


micrOMEGAs
LANHEP
Model File
Particles
Vertices
Parameters
LOOP
S
S
CalcHEP
Generate tree-level
cross sections
Auxilliary Routines
(external codes, $Hb\bar{b}$,
$b \to s\gamma, (g-2), \Delta m_b$,
LEP constraints
Relic Density
Annihilation/co-annihilations
Indirect detection
$\sigma v, v = 0$
Direct Detection
Wimp-Nucleon/q
Collider Observables
Cross sections
Decays

micrOMEGAs

- given any set of parameters it can identify LSP, NLSP, generate and calculate Ωh^2
- Model defined in Lanhep (more later)
- Fed into CalcHEP ....tree-level, some 3000 processes could be needed.
- Higgs sector (SUSY): improved Higgs masses/mixings (read from FeynHiggs, for example) but interpreted in terms of an effective scalar potential (GI), following FB and A. Semenov (PRD 02)
- Effective Lagrangian also includes important RC (Higgs couplings, Δm_b effects,..)
- Interfaced with Isajet, Suspect, SoftSUSY parameters at high scale run down to the ew scale
- $(g-2)_\mu$, $b \to s\gamma$, $B_s \to \mu^- \mu^+$,..
- NMSSM (with C. Hugonie), CP violation (with S. Kraml), UED, Dirac, host of others
- "open source": procedure to define your own model
- powerful generalised direct detection module
- indirect detection cross sections, interface with propagation, polarisation completed
- SLHA compliant, MCMC interface for parameter scans

micrOMEGAs vs DarkSusy (for example)

- micrOMEGAs

  given any set of parameters it can identify LSP, NLSP, generate and calculate Ωh^2, direct and indirect

  cross sections are generated on the fly. Only those needed are generated. These are then stored, if needed in the future procedure is speedy

  Generalisation to other models easy, same principle: Needs a model file and a quantum number based on same Z_2 (in SUSY $Z_2 = R_p$) or even ....Z_N. Classification is then straightforward.

  set a switch (that can be changed by the user) so that even co-annihilation processes are generated on the fly. The code decides on *its own* when to include these co-annihilations.

- DarkSusy

  comes with a (large) set of codes for cross sections in SUSY.

  you may well have a weirdo SUSY model for which some (co-annihilation) cross sections are not provided, you will have to code them. In principle you could code a cross section from any model

micrOMEGAs: History

History: more than 10 years of micrOMEGAs

- 2001: First release, initial goal : compute the relic density in the MSSM including all processes
- 2004 : Exact numerical solution of relic density + improved MSSM (in particular loop corrected particle masses)
- 2006 : Direct detection
- 2008 : Generalization to arbitrary Particle Physics model
- 2010 : Indirect detection signatures
- 2013 : generalization relic density, Higgs observables, neutrino signature ....

Relic Density: Thermal average

must calculate all annihilation, co-annihilation processes. Each annihilation can consist of tens of cross sections...

$$\chi_i^0 \chi_j^0 \to X_{SM} Y_{SM}, \ \chi_1^0 \tilde{f}_1 \to X_{SM} Y_{SM}, \ldots \qquad v \times \sigma v$$

$$< \sigma v >= \frac{\sum_{i,j} g_i g_j \int_{(m_i+m_j)^2} ds \sqrt{s} K_1(\sqrt{s}/T) \, p_{ij}^2 \sigma_{ij}(s)}{2T \left(\sum_i g_i m_i^2 K_2(m_i/T) \right)^2},$$

p_{ij} is the momentum of the incoming particles in their center-of-mass frame.

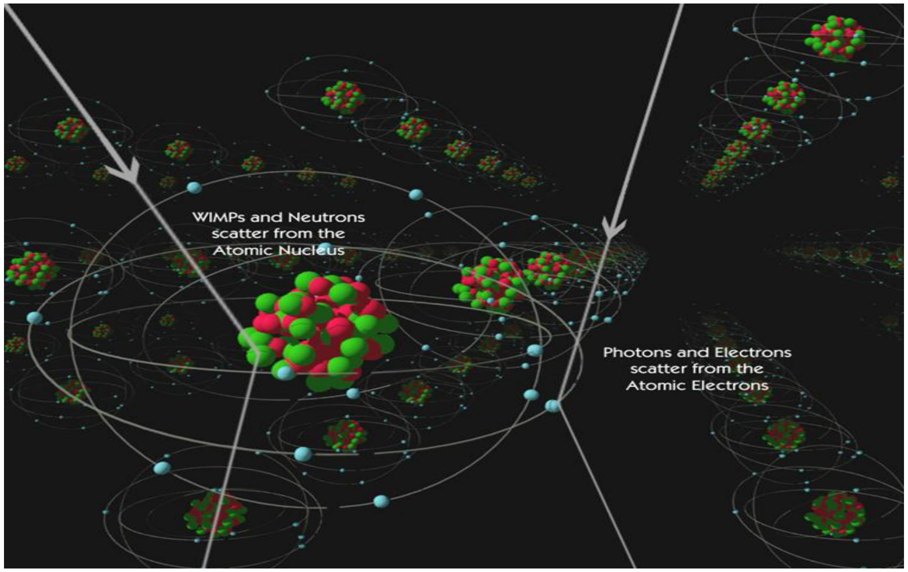
Origin of Boltzman factor $exp(-\delta M/T)$

$$B_f = \frac{K_1((m_i + m_j)/T_f)}{K_1(2m_{\tilde{\chi}_1^0}/T_f)} \approx e^{-X_f \frac{(m_i+m_j-2m_{\tilde{\chi}_1^0})}{m_{\tilde{\chi}_1^0}}} \qquad if \ B_f < B_\epsilon \text{ do not compute}$$

In micrOMEGAs $B_\epsilon = 10^{-6}$ by default. Most often $B_\epsilon = 10^{-2}$ enough for 1% accuracy, only a few processes computed.

In micrOMEGAs $< \sigma v > (T)$ is obtained from direct integration, through adaptive Simpson with two options (fast, default) and accurate (checks for accuracy).

Direct detection

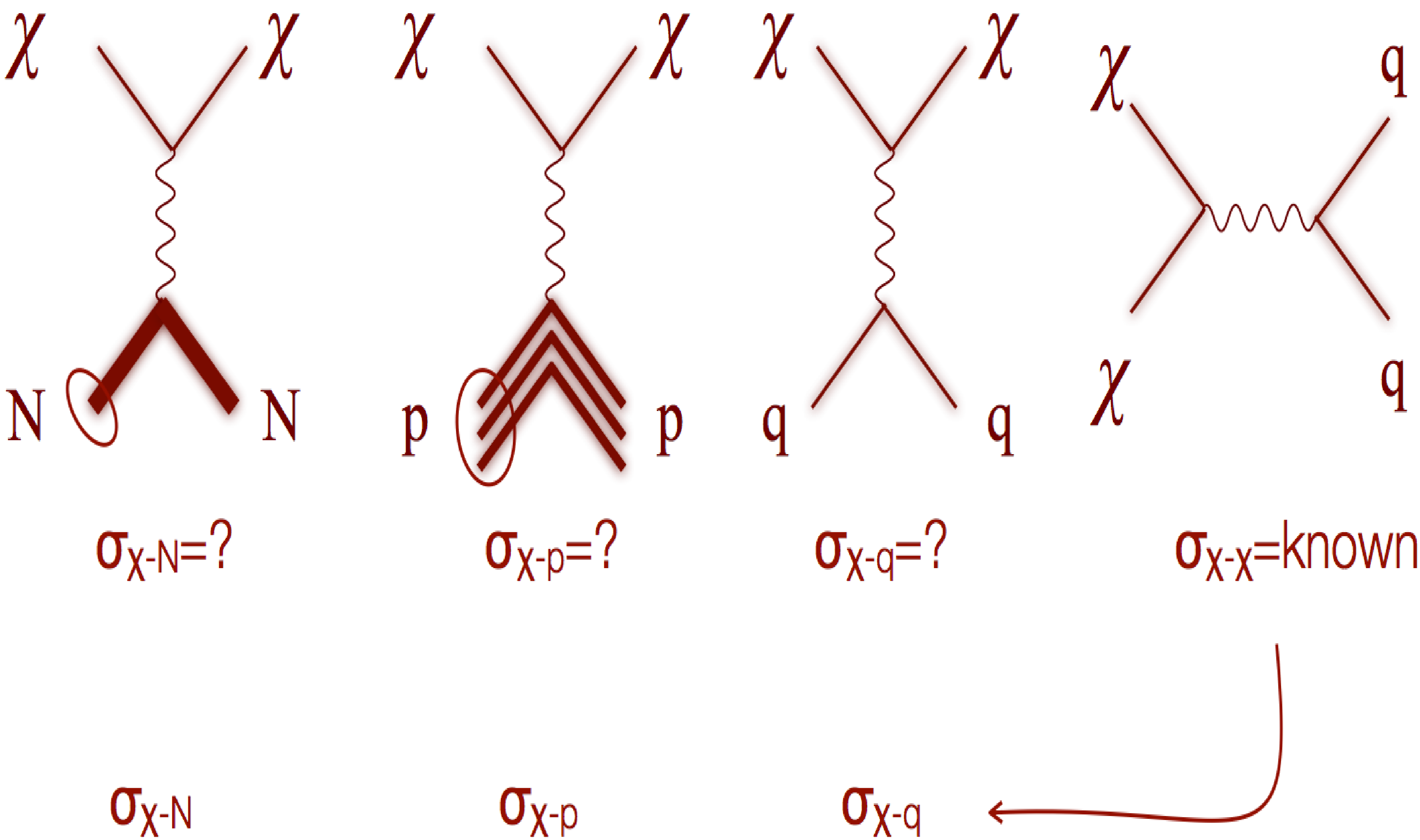


$\chi\mathcal{N} \to \chi\mathcal{N}$ **to** $\chi N \to \chi N \ (N = n, p)$

to $\chi q \to \chi q$

ingredients/Modules: dark matter density and modulation, velocity distribution quark content in nucleon, Nuclear form factors,.....

Direct Detection



Wimp-quark effective Lagrangian, $\psi_N \to \psi_q, \quad \chi \to \mathbf{DM}$

	WIMP Spin	Even Operators $\hat{\mathcal{O}}_{q,e}$ $\hat{\mathcal{O}}'_{q,e}$	Odd Operators $\hat{\mathcal{O}}_{q,o}$ $\hat{\mathcal{O}}'_{q,o}$
		$\hat{\mathcal{O}}_{q,e}$	$\hat{\mathcal{O}}_{q,o}$
SI	0	$2M_\chi \phi_\chi \phi^*_\chi \overline{\psi}_q \psi_q$	$i(\partial_\mu \phi_\chi \phi^*_\chi - \phi_\chi \partial_\mu \phi^*_\chi)\overline{\psi}_q \gamma^\mu \psi_q$
	1/2	$\overline{\psi_\chi} \psi_\chi \overline{\psi}_q \psi_q$	$\overline{\psi}_\chi \gamma_\mu \psi_\chi \overline{\psi}_q \gamma^\mu \psi_q$
	1	$2M_\chi A^*_{\chi\mu} A^\mu_\chi \overline{\psi}_q \psi_q$	$+i(A^{*\alpha}_\chi \partial_\mu A_{\chi,\alpha} - A_\chi{}^\alpha \partial_\mu A^*_{\chi\alpha})\overline{\psi}_q \gamma_\mu \psi_q$
		$\hat{\mathcal{O}}'_{q,e}$	$\hat{\mathcal{O}}'_{q,o}$
SD	1/2	$\overline{\psi}_\chi \gamma_\mu \gamma_5 \psi_\chi \overline{\psi}_q \gamma_\mu \gamma_5 \psi_q$	$-\frac{1}{2}\overline{\psi}_\chi \sigma_{\mu\nu} \psi_\chi \overline{\psi}_q \sigma^{\mu\nu} \psi_q$
	1	$\sqrt{6}(\partial_\alpha A^*_{\chi\beta} A_{\chi\nu} - A^*_{\chi\beta} \partial_\alpha A_{\chi\nu})$ $\epsilon^{\alpha\beta\nu\mu} \overline{\psi}_q \gamma_5 \gamma_\mu \psi_q$	$i\frac{\sqrt{3}}{2}(A_{\chi\mu} A^*_{\chi\nu} - A^*_{\chi\mu} A_{\chi\nu})\overline{\psi}_q \sigma^{\mu\nu} \psi_q$

$$\hat{\mathcal{L}}_{eff}(x) = \sum_{q,s} \lambda_{q,s} \hat{\mathcal{O}}_{q,s}(x) + \xi_{q,s} \hat{\mathcal{O}}'_{q,s}(x)$$

In model files of `micrOMEGAs (CalcHEP)` these operators are added

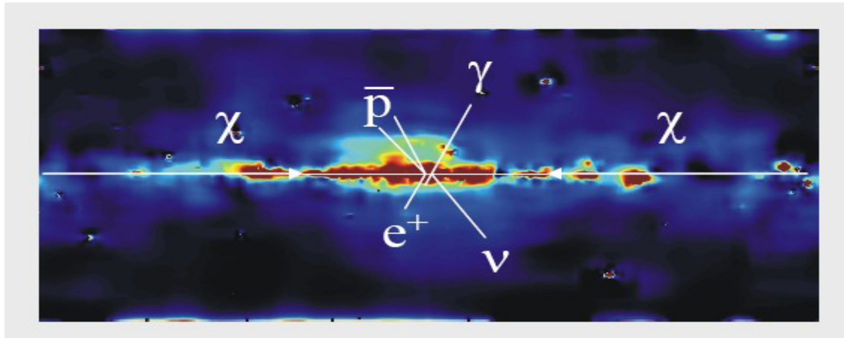
- In the usual approach these low energy operators and their coefficients are extracted by computing WIMP-quark *amplitudes* from Feynman diagrams and using Fierz transformations,..
- in `micrOMEGAs` all operators are defined and only need to extract coefficients automatically
- we compute $\chi q \to \chi q$ at $q^2 = 0$ as a normal cross section but...
- Interference between one projection operator and an effective vertex singles out SI or SD
- The trick is to use also $\chi q \to \chi q$ *vs* $\chi \overline{q} \to \chi \overline{q}$
- with the S-matrix, $\hat{S} = 1 - i\mathcal{L}$ obtained from the complete Lagrangian at the quark level

$$\lambda_{q,e} + \lambda_{q,o} = \frac{-i\langle q(p_1), \chi(p_2)|\hat{S}\hat{\mathcal{O}}_{q,e}|q(p_1), \chi(p_2)\rangle}{\langle q(p_1), \chi(p_2)|\hat{\mathcal{O}}_{q,e}\hat{\mathcal{O}}_{q,e}|q(p_1), \chi(p_2)\rangle}$$

$$\lambda_{q,e} - \lambda_{q,o} = \frac{-i\langle \overline{q}(p_1), \chi(p_2)|\hat{S}\mathcal{O}_{q,e}|\overline{q}(p_1), \chi(p_2)\rangle}{\langle \overline{q}(p_1), \chi(p_2)|\hat{\mathcal{O}}_{q,e}\hat{\mathcal{O}}_{q,e}|\overline{q}(p_1), \chi(p_2)\rangle}$$

- warning: couplings proportional to light quark masses must be kept

Indirect Detection



- ν from the Sun and the Earth (*New in 3_0*)
- γ, ν, charged cosmic rays ($e^+, \overline{p}, \overline{D}$) from annihilation in the galactic halo ($\overline{D}$ in future)
- other signals: synchrotron emission,....? (in progress)

Features in the Indirect Detection Module of micrOMEGas

- Annihilation cross sections for all 2-body tree-level processes for all models.
- Annihilation cross sections including radiative emission of a photon for all models.
- Annihilation cross sections into polarized gauge bosons.
- Annihilation cross sections for the loop induced processes $\gamma\gamma$ and γZ^0 in the MSSM and NMSS (more general models possible)
- Modelling of the DM halo with a general parameterization and with the possibility of including DM clumps.
- Integrals along lines of sight for γ-ray signals.
- Propagation: Work with Pierre Salati and Sylvie Rosier (2-zone diffusion model with Green's function and tabulation. Diffusion parameters compatible with B/C.)
  Computation of the propagation of charged particles through the Galaxy, including the possibility to modify the propagation parameters.
- Effect of solar modulation on the charged particle spectrum.
- Model independent predictions of the indirect detection signal
- The neutrino spectrum originating from dark matter annihilation is also computed. With in version $3_{.}0$ Capture in the Sun and the Earth

N. Baro, FB, G. Chalons, G. Drieu La Rochelle, S. Hao, Ninh Le Duc, A. Semenov, (D. Temes)

Strategy: Exploiting and interfacing modules from different codes

Lagrangian of the model defined in LanHEP

- particle content
- interaction terms
- shifts in fields and parameters
- ghost terms constructed by BRST

$\downarrow$ $\downarrow$

Generic Model
-kinematical structures

Classes Model
-Feynman rules, including CT

$\Downarrow$

Evaluation via FeynArts-FormCalc

LoopTools modified!!
tensor reduction inappropriate for small relative velocities
(Zero Gram determinants)

$\Uparrow$

SloopS, examples for relic

		Tree	$A_{\tau\tau}$	$\overline{\text{DR}}$
$\tilde{\chi}_1^0\tilde{\chi}_1^0 \to W^+W^-$ [26%]	a	$+11.84$	$+4.3\%$	$+5.1\%$
	b	$+4.17$	$+12.7\%$	$+13.4\%$
$\tilde{\chi}_1^0\tilde{\chi}_1^+ \to u\bar{d}$ [12%]	a	$+15.28$	$+6.8\%$	$+7.0\%$
	b	-5.31	$+30.4\%$	$+30.7\%$
$\tilde{\chi}_1^0\tilde{\chi}_1^0 \to Z^0Z^0$ [9%]	a	$+4.28$	$+10.4\%$	$+9.6\%$
	b	$+1.83$	$+12.7\%$	$+12.0\%$
$\tilde{\chi}_1^0\tilde{\chi}_1^+ \to Z^0W^+$ [6%]	a	$+6.99$	$+1.7\%$	$+2.1\%$
	b	-0.51	$+85.6\%$	$+86.5\%$
$\Omega_\chi h^2$		0.00931	0.00909	0.00908
$\frac{\delta\Omega_\chi h^2}{\Omega_\chi h^2}$			-2.4%	-2.5%

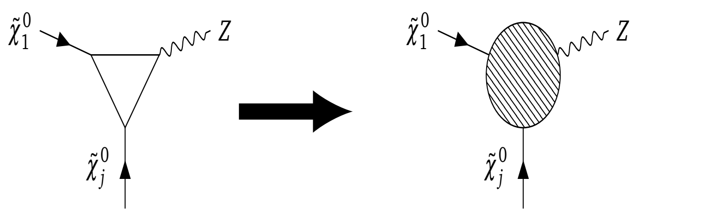
Tree-level values of the s-wave (a) and p-wave (b) coefficients in units $10^{-26}\text{cm}^3\text{s}^{-1}$ *in a higgsino scenario*

Baro, Chalons, Sun Hao FB 2009

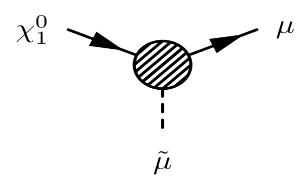
Form Factor Approach

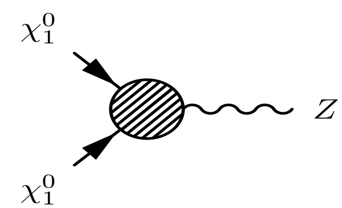
Recent Work: FB, G. Drieu la Rochelle, A. Mariano (see arXiv 2011-2014)

Effective form factors Can we express most of the corrections within a form factor approach. A Born-Improved approximation. Build up a library of form factors to replace tree-level vertices. One can then use tree-level automated calculators and hence easy interface with `micrOMEGAS`.

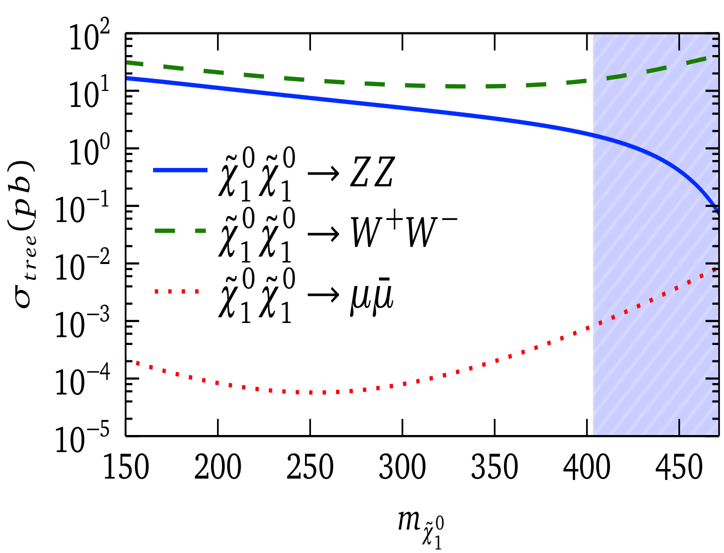


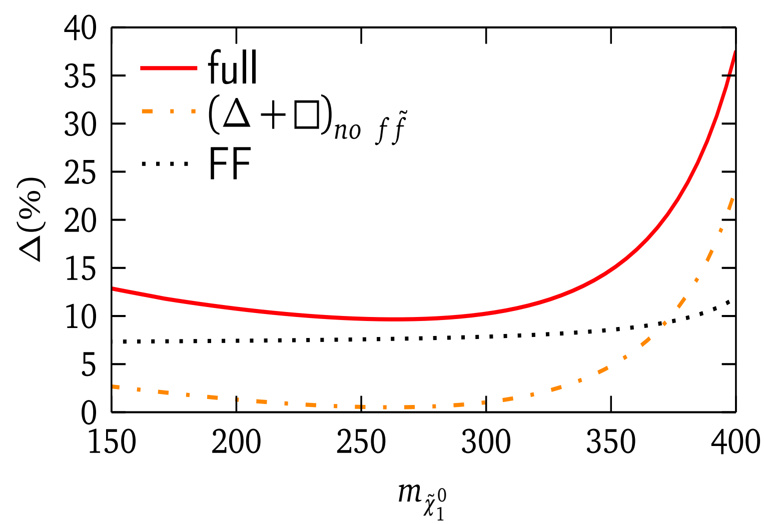
Example of the one-loop vertex diagrams that can be cast into an effective $\tilde{\chi}_1^0\tilde{\chi}_j^0 Z$ vertex.





Performance (difficult one $\chi_1^0\chi_1^0 \to ZZ$, performance better for $\chi_1^0\chi_1^0 \to \mu^+\mu^-$)





micrOMEGAs_3.0: new features

- Generalization of relic density computation

  3-body final state

  Discrete symmetries other than Z_2

  Asymmetric dark matter

  Different universe expansion

- Cross sections and decays: Higgs sector

  Higgs decays into virtual particles

  Loop-induced Higgs decay

- DM detection

  Direct detection

  Neutrino signal from DM capture (reduce uncertainty from strange content, use new lattice results)

Dark matter models

- Models distributed
  - MSSM
  - NMSSM (with C. Hugonie)
  - CPV-MSSM (with S. Kraml)
  - Right-handed neutrino (with G. Servant)
  - Little Higgs (A. Belyaev)
  - Inert Doublet Model
  - Inert doublet+singlet Z3 (with K. Kannike, M. Raidal)
- Models not yet public
  - SUSY N=2 (with K. Benakli, M. Goodsell)
  - UED (with M. Kakizaki)
  - MSSM+RHneutrino (with M. Kakizaki, S. Kraml, E.K. Park)
  - UMSSM (with J. DaSilva,)
  - BMSSM (with G. Drieu La Rochelle)
- Many more models implemented by users

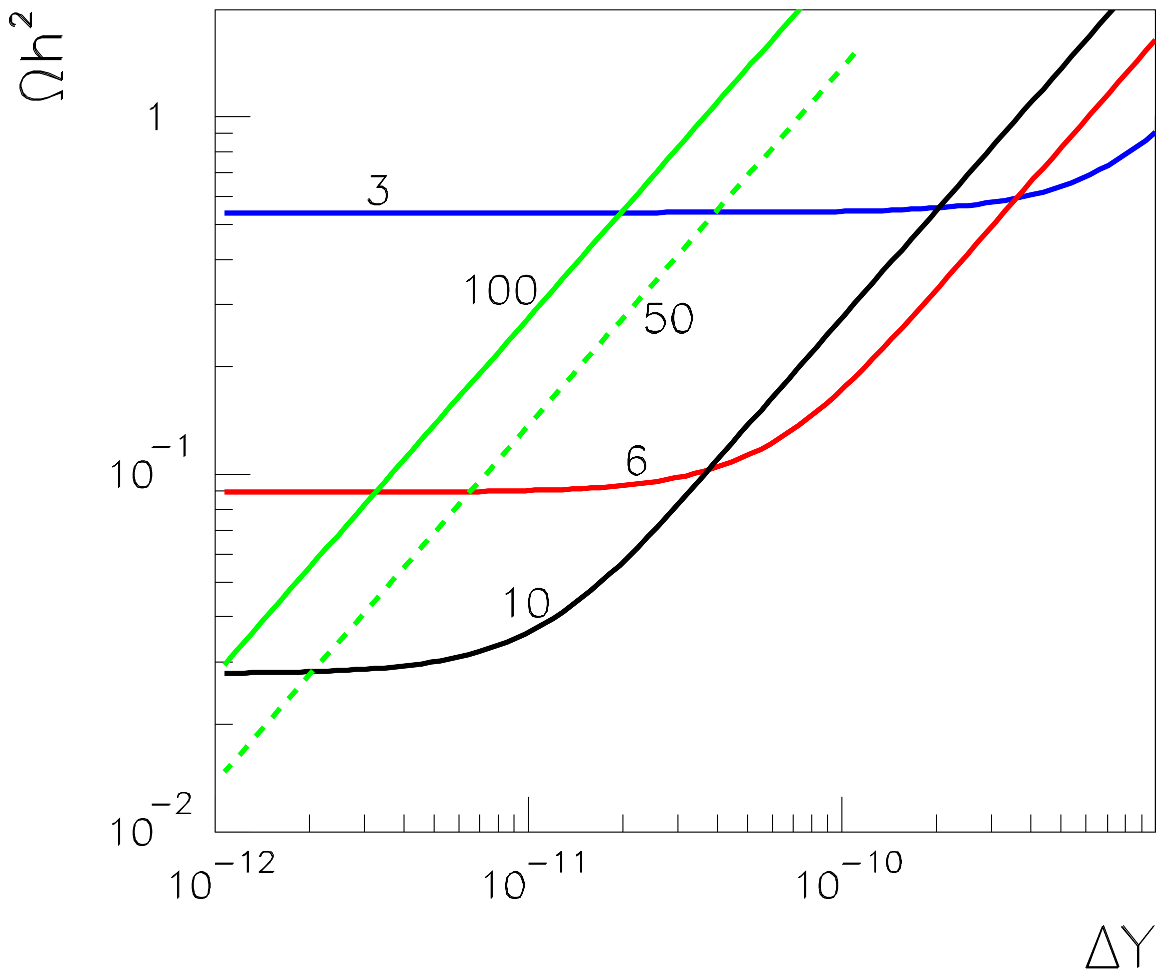
micrOMEGAs_3.0

- Annihilation cross sections for some selected 3-body processes in addition to the 2-body tree-level processes. The 3-body option can be included in the computation of the relic density and/or for annihilation of dark matter in the galaxy.
- Possibility of using different tables for the effective degrees of freedom $(g_{eff}(T), h_{eff}(T))$ in the early Universe
- Annihilation cross sections for the loop induced processes $\gamma\gamma$ and γZ^0 in the NMSSM and the CPVMSSM
- New function for incorporating DM clumps
- New function to define the strange quark content of the nucleon
- The LanHEP source code for new models is included
- New models with scalar DM (Inert doublet model and model with Z_3 symmetry)
- New implementation of the NMSSM which uses the Higgs self-couplings and the particle spectrum calculated in NMSSMTools˙4.0
- New versions of spectrum generators used in the MSSM (Suspect_$2.4.1$) and in the CPVMSSM (CPsuperH2.3)
- Extended routines for flavour physics in the MSSM
- Update in interface tools to read files produced by other codes, this allows easy interface to other codes

We consider a dark matter particle that is not self-conjugate. This occur for example when the DM particle is a Dirac fermion or a complex scalar. We define Y^+ and Y^- as the abundances of the DM particle/anti-particle ($\chi\overline{\chi}$) . At very high temperature we assume that an asymmetry has taken place such that $Y^+ \neq Y^-$ ($\Delta Y = Y^+ - \neq Y^-$) but that at later time the system is at equilibrium. Assume that some symmetry only allows annihilation $\chi^+\chi^- \rightarrow SM$ (no annihilation $\chi^+\chi^+$ for example). The relic density is always larger than in the case of no asymmetry. We can have a situation where only χ^+ survives and hence no indirect signal survives

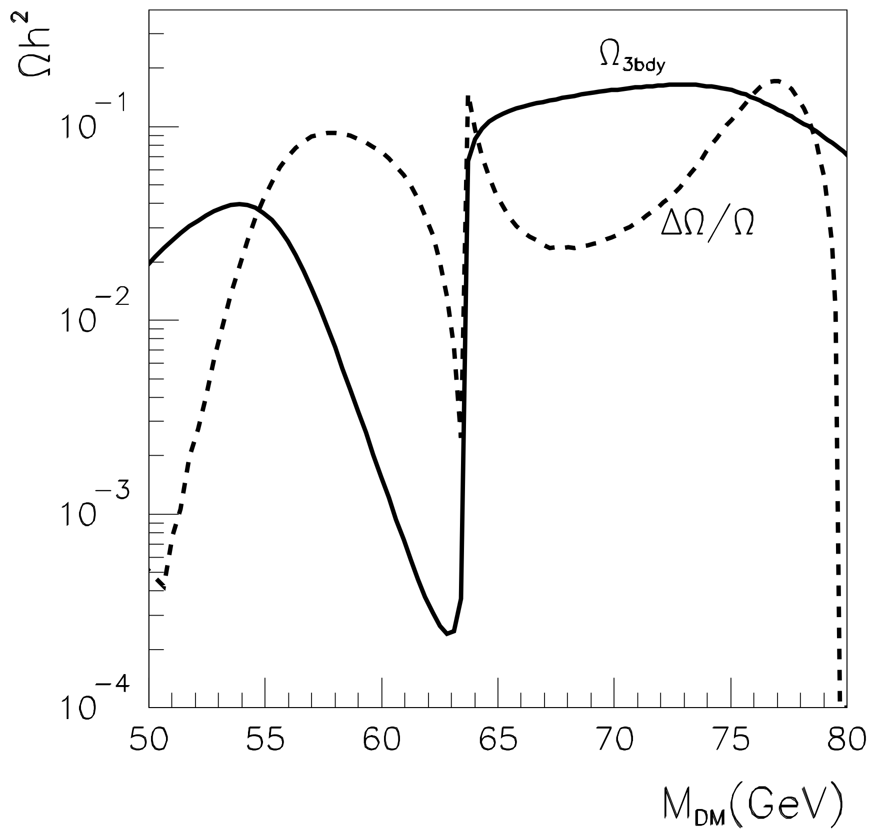
$$\Omega h^2 = \frac{8\pi}{3H_{100}^2} \frac{m_\chi}{M_{\rm Planck}} \frac{\sqrt{Y_0^2 + \Delta Y^2}}{s_0} > \Omega h^2(\Delta Y = 0).$$

micrOMEGAs_3.0: Asymmetric dark matter



Ωh^2 as a function of ΔY for different DM masses in the 4th generation Dirac neutrino dark matter model for DM masses of $3, 6, 10, 50, 100$ GeV as indicated.

Simple observation: $\chi\chi' \to XV$ (V, W, Z) closed but $\chi\chi' \to XV^\star \to Xll'$ open



Ωh^2 as a function of M_{DM} in the MSSM (full) and relative difference between the 3-body and 2-body value (dashed).

DM stabilized with a larger symmetry than Z_2 Ex: Z_3 custodial $SU(2)$ $W^{+\prime}W^{-\prime} \to Z'H$ semi-annihilation.
Example of $\chi_i \chi_j \to \chi_k A$, χ's stable A unstable (decays eventually to SM). Lead to coupled Boltzman equations.

$$\frac{dn}{dt} = -\langle v\sigma^{\chi\overline{\chi}\to XX}\rangle \left(n^2 - {n_{\rm eq}}^2\right) - \frac{1}{2}\langle v\sigma^{\chi\chi\to\overline{\chi}X}\rangle \left(n^2 - n\, n_{\rm eq}\right) - 3Hn.$$

micrOMEGAs_3.0: Gamma-Ray line:

$\gamma\gamma$ and $Z\gamma$ in MSSM and NMSSM

this is done through SloopS

The DM density is given as the product of the local density at the Sun with the halo profile function

$$\rho(r) = \rho_{\odot} F_{halo}(r)$$

Possibility to set different halo profiles `setProfileZhao(`α,β,γ,*rc*`)`
`setProfileEinasto(`α`)`
Clumps $< \rho^2 >$ can be significantly larger than $< \rho >^2$ A simple implementation with all clumps occupy the same small volume V_{cl} with a constant density.

$$< \rho^2 > (r) = \rho(r)(\rho(r) + \rho^{eff}_{clump}(r))$$

or
To be more general, one could assume that ρ_{cl} and f_{cl} depend on the distance from galactic center. The effect of clumping is then described by the equation

$$< \rho^2 > (r) = \rho(r)(\rho(r) + \rho^{eff}_{clump}(r))$$

and the function
- `setRhoClumps(`ρ^{eff}_{clump}`)`

allows to implement a more sophisticated clump structure.

Loop-induced Higgs production and decay: $H \to \gamma\gamma$ and $gg \to H$

(N)NLO corrections to the generic coupling $HF_{\mu\nu}F^{\mu\nu}$ can be be generated for any model. Need to implement the Higgs to scalars/fermions/vector bosons

$$\mathcal{L} = g_{h\psi\psi}\overline{\psi}\psi h + ig'_{h\psi\psi}\overline{\psi}\gamma_5\psi h + g_{h\phi\phi}M_\phi h\phi\phi + g_{hVV}M_V hV_\mu V^\mu$$

Implementation of signal strengths and interface to HiggsBounds

$$\mu^{ggF}_{\gamma\gamma} = \frac{\sigma(gg \to h)_{NP} Br(h \to \gamma\gamma)_{NP}}{\sigma(gg \to h)_{SM} Br(h \to \gamma\gamma)_{SM}}$$

$$\mu^{VBF}_{\gamma\gamma} = \frac{\sigma(WW \to h)_{NP} Br(h \to \gamma\gamma)_{NP}}{\sigma(WW \to h)_{SM} Br(h \to \gamma\gamma)_{SM}}$$

micrOMEGAs_3.0 Dark matter models

The micrOMEGAs distribution now comes with the following models

- MSSM and some of its extensions (NMSSM and CPVMSSM)
- the little Higgs model (LHM),
- a model with a right-handed neutrino (RHNM),
- the inert doublet model (IDM),
- a model with an extended scalar sector and a Z3 symmetry(Z3ID)
- model with a fourth generation of leptons (SM4).

micrOMEGAs_3.0: Neutrino Signals: Earth, Sun,

- Capture Rate Earth and Sun, C_χ from Gould 1987
  DM-Nucleus cross section (ref. direct detection), form-factor
  DM velocity dist. and local density
  Number density of nucleus (Sun: Asplund, Grevesse, Sauval 2004. Earth: McDonough 2003)
- Annihilation of captured DM: $A_{\chi\chi}$
- Evaporation, E_χ. may be important for light (<5 GeV DM)
- Neutrino Flux:

$$\dot{N}_\chi = C_\chi - A_{\chi\chi} N_\chi^2 - E_\chi N_\chi \,,$$

- Neutrino spectra: from decays of fermions, gauge bosons, hadrons,...cascade decays. Effect of neutrino oscillations, from Cirelli et al 2005 (we use their tables).

Future developments

- Indirect:

  Improved propagation (with P. Salati et al)

  Interface USINE, GALPROP, CLUMPY...

- Constraints:

  Improve Collider limits - most likely link to independent code for LHC limits on new particles (sModels, S. Kraml et al)

  Automatisation of new physics contribution to B observables, g-2 etc..

- Include more DM models

- Beyond one-loop: Form Factors and limitations, Sommerfeld resummation, Sudakov and Weak boson radiation for very heavy DM.

Conclusions

- To understand the nature of dark matter clearly requires information and cross checks from cosmology, direct and indirect detection as well as from collider physics
- `micrOMEGAs` is tool to perform these analyses in a generic model that aims at high precision and high level of efficiency

Conclusions

- To understand the nature of dark matter clearly requires information and cross checks from cosmology, direct and indirect detection as well as from collider physics
- `micrOMEGAs` is tool to perform these analyses in a generic model that aims at high precision and high level of efficiency

Soon on your