Direct detection module in micrOMEGAs_2:

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Status of micrOMEGAs.

micrOMEGAs is a package for evaluation of different Dark Matter properties. It is based on the package CalcHEP of automatic generation of matrix elements. It works in the following manner:

```
numout* cc=newProcess("e,E->2*x", "eE_2x");
```

a) Checks the presence of shared library eE_2x.so in the code
if it absences looks for it on the disk
if it absences compiles it by CalcHEP.
c) Then the library is linked in runtime and address of attached code assigned to 'cc' variable.

Now cross section of this reaction can be calculated by

```
cs= cs22(cc,n_channel,Pcm,cosmin,cosmax,&err);
```

Access to all variables is realized according to their names as they presented in the model:

```
assignValW("tb",10.);
```

It is assumed that there is Z_2 symmetry and names of odd particles starts from the $\backsim$ symbol. The lightest odd particle is detected automatically and treated as a DM candidate.

Now we have
Modules: Omega, Annihilation spectra (for direct detection), Cross sections, Constraints.
User languages: C, C++, Fortran.
Unix dialects: Linux, OSF1, Darwin,CYGWIN.
Models: MSSM (SuSpect, SoftSusy, SPheno, Isajet), NMSSN(NMSSMTools), CPVMSSM(CPsuperH), LittleHiggs, RHNM(based on KK).

Now we add a new module which allows to calculate direct detection reaction for generic model implemented in micrOMEGAs/CalcHEP.

Direct detection.

Direct detection module calculates reaction of **DM** *particles with detector. The main output value is*

$$dN/dE$$

distribution of recoil nuclei of detector over energy for **1kg** *of detector material and* **1 year** *of exposure time. In general it depends on:*

a)density of **DM** *near the Earth, -input parameter.*

b) **DM** *velocity distribution, -input parameter.*

c) interaction of **DM** *with color particles, - calculated by CalcHEP.*

d) nucleon form factors, implemented as they are known; can be changed.

e) nuclei form factors- all known ones are implemented.

The command is

$$\textbf{nEnents = nucleusRecoil}(\rho_{DM}, \frac{1}{v}\frac{dn_{DM}}{dv}, A, Z, J, S_{00}, S_{01}, S_{11}, \textbf{box}, \frac{dN}{dE})$$

For this function we have predefined constants like `Z_Ge`, `J_Ge73` *and codes for form factors like* `S00Ge73(p),...,S11Ge73(p)`. *This service is available for*

$$^{19}F,\ ^{23}Na,\ ^{27}Al,\ ^{29}Si,\ ^{39}K,\ ^{73}Ge,\ ^{93}Nb,\ ^{125}Te,\ ^{127}I,\ ^{129}Xe,\ ^{131}Xe,\ ^{207}Pb.$$

DM -nucleon-nucleus interactions.

Velocities of DM have to be about rotation velocity of Sun (≈220 km/s). For typical DM and nucleus masses it leads to collisions with transfer momentum

$$\Delta p \approx 100 MeV \approx 1/(2fm)$$

For one side it is small enough to use $\Delta p = 0$ limit for DM-nucleon collision, but nuclei form factors surely have to be taken into account.

DM-nucleon collision at rest can be presented as a sum of 2 orthogonal amplitudes, scalar one and vector one. Scalar DM-proton and DM-neutron amplitudes lead to scalar DM-nucleus amplitude

$$\lambda_P Z + \lambda_N (A - Z)$$

So, the corresponding cross section is enhanced by the A^2 factor. Form factor for such interaction is well known, it is a Fourier transform of nucleus density.

As for vector interaction, we know that angular momenta of protons (as well as neutrons) have a trend to compensate one other. So

$$\vec{J}_P = S_p^A \vec{J}_A / |J_A|$$

where S_p^A is about 0 - 0.5. So the vector ***DM**-nucleus amplitude appears about*

$$S_P^A \xi_P + S_N^A \xi_N$$

where ξ_P and ξ_N are nucleon amplitude. In this case A-enhancement is absent. Because of periphery nucleons mainly contribute to J_N we have non-trivial form factors for protons and neutrons. At $\Delta p \neq 0$ $\vec{J}_P$ and $\vec{J}_N$ become non-collinear and the third form factor appears. So there are 3 form factors S_{00}, S_{01}, S_{11} which we substitute in the ***nucleusRecoil** function. For realization of these form factors we use resent review of* ***Bednyakov and Simkovic**.*

DM - quark elastic scattering.

We don't restrict ourself by Majorana **DM**. Spin of **DM** particle could be **0, 1/2, 1**, and it can be described as well as by neutral or complex field. In case of complex field DM-quark interactions can be separated on **even** and **odd** ones respect to $DM - \overline{DM}$ swapping.

	J_{DM}	Even operators	Odd operators
	0	$\phi_\chi \phi_\chi^* \overline{\psi}_q \psi_q$	$-i(\partial_\mu \phi_\chi \phi_\chi \chi^* - \phi_\chi \partial_\mu \phi_\chi^*)\overline{\psi}_q \gamma^\mu \psi_q$
SI	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	$M_\chi A_{\chi,\mu} A_\chi^\mu \overline{\psi}_q \psi_q$	$+i(A_\chi^{*\alpha} \partial_\mu A_{\chi,\alpha} - A_\chi{}^\alpha \partial_\mu A_{\chi\alpha}^*)\overline{\psi}_q \gamma_\mu \psi_q$
SD	1/2	$\overline{\psi}_\chi \gamma_\mu \gamma_5 \psi_\chi \overline{\psi}_q \gamma_\mu \gamma_5 \psi_q$	$\overline{\psi}_\chi \sigma_{\mu\nu} \psi_\chi \overline{\psi}_q \sigma^{\mu\nu} \psi_q$
	1	$\frac{\sqrt{3}}{2}(\partial_\alpha A_{\chi,\beta} A_{\chi\nu} - A_{\chi\beta} \partial_\alpha A_{\chi\nu})\epsilon^{\alpha\beta\nu\mu} \overline{\psi}_q \gamma_5 \gamma_\mu \psi_q$	$i\frac{\sqrt{3}}{2}(A_{\chi\mu} A_{\chi\nu}^* - A_{\chi\mu}^* A_{\chi\nu})\overline{\psi}_q \sigma^{\mu\nu} \psi_q$

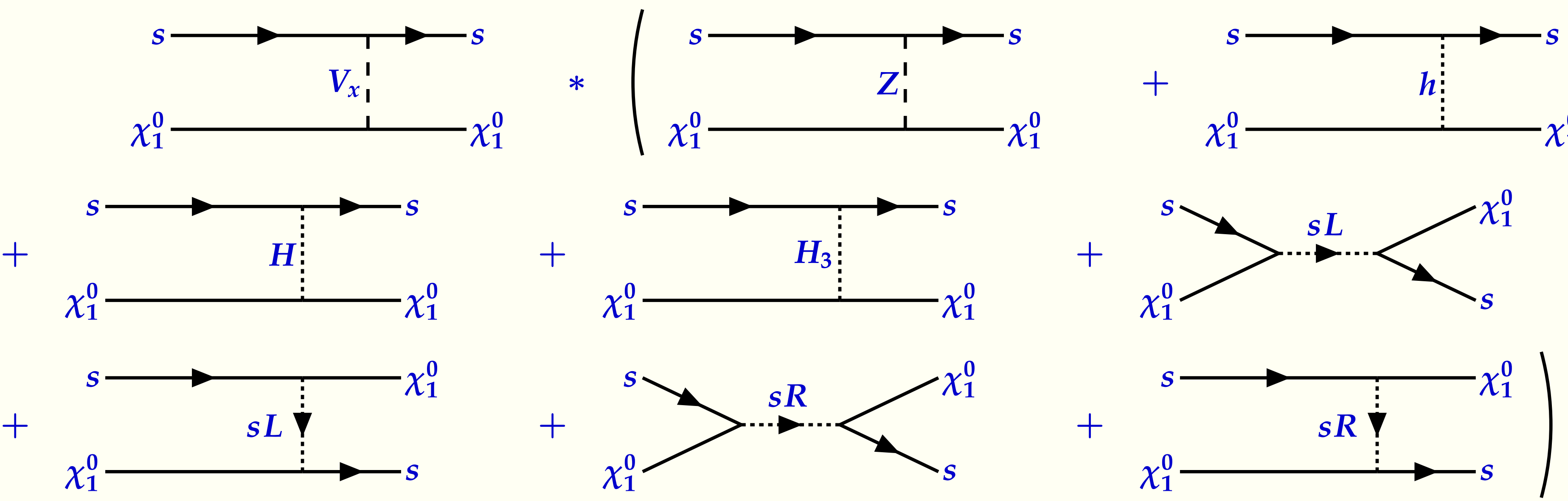
So, for **DM**-nucleon cross sections we have to know operator expansion of **DM**-quark matrix element and nucleon form factors for the following currents:

even: $\overline{\psi}_q \psi_q$, $\overline{\psi}_q \gamma_5 \gamma_\mu \psi_q$

odd : $\overline{\psi}_q \gamma_\mu \psi_q$, $\overline{\psi}_q \sigma^{\mu\nu} \psi_q$

Operator expansion in micrOMEGAs

Traditionally the coefficients at this operator are evaluated symbolically using **Fiertz** ***identities. Instead*** **micrOMEGAs** ***creates an auxiliary models with addition vertices which corresponds to operators presented above. After that micrOMEAs calculates squared diagrams which contains in one side the auxiliary vertex, and in another side diagrams of physical matrix element.***



Nucleon form factors of light quarks

Even sector scalar form factors are known from hadron spectroscopy and πN scattering. In proton we use by default:

	d	u	s
scalar	0.033	0.023	0.26(0.12) $\pm$
vector	-0.427	0.842	-0.085

The main uncertainty comes from **s-quark** scalar FF.

For **odd** sector

	d	u	s
scalar	1	2	0
vector	-0.231	0.839	-0.046

Here scalar part is known for sure, but σ contribution comes from lattice calculations.

We have included routine **setProtonFF(scalar,vector, sigma)** which allows user to improve form factors.

Nucleon form factors of heavy quarks and other heavy color pa

They come from energy-momentum tensor trace anomaly:

$$M_N < N|N >=< N| \sum_{q=u,d,s} M_q \bar{\psi}_q \psi_q (1+2\gamma) + (\frac{\beta}{2\alpha^2}) \alpha G_{\mu\nu} G^{\mu\nu} |N >$$

It allows to evaluate gluon component in nucleon in LO

$$M_N < N|N >=< N| \sum_{q=u,d,s} M_q \bar{\psi}_q \psi_q - \frac{9}{8\pi} \alpha G_{\mu\nu} G^{\mu\nu} |N > \quad (1)$$

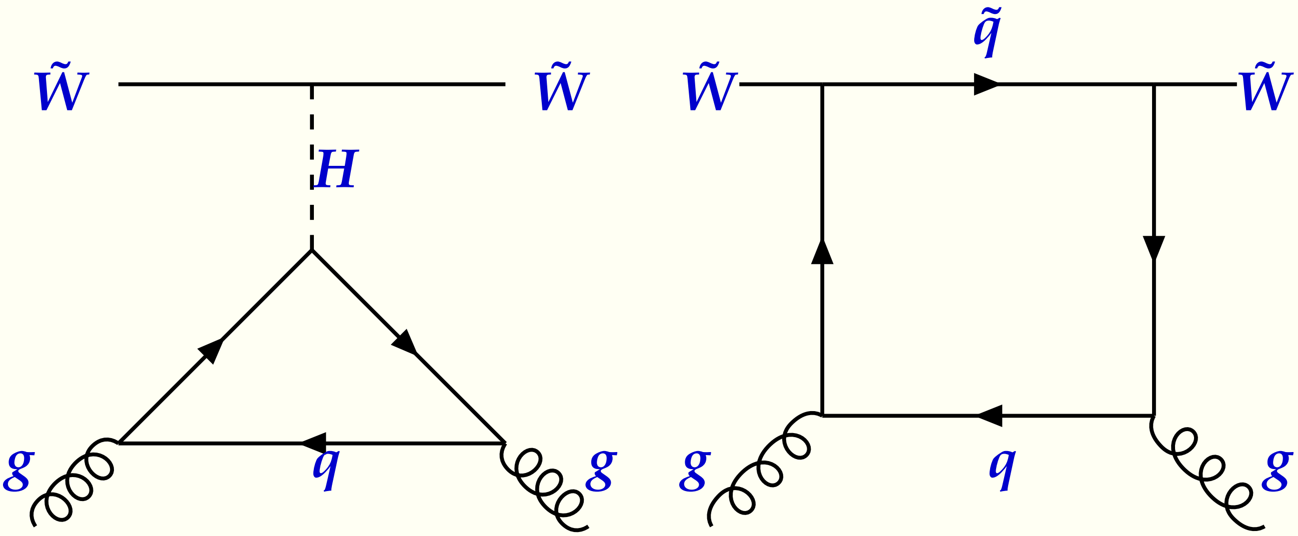
If gluon component is known one can evaluate heavy quarks condensate in nucleon. Formula (??) allows us to guess the result

$$< N|M_Q \bar{\psi}_Q \psi_Q |N >= -\frac{\Delta\beta}{2\alpha^2(1+2\gamma)} < N|\alpha G_{\mu\nu} G^{\mu\nu} |N > \quad (2)$$

Up to NLO term (QCD corrections)

$$< N|M_Q \bar{\psi}_Q \psi_Q |N >= -\frac{1}{12\pi}(1+\frac{11\alpha(M_Q)}{4\pi}) < N|\alpha G_{\mu\nu} G^{\mu\nu} |N > \quad (3)$$

For Higgs diagrams this approach is perfect, but for s-quark exchange it has a precision about $M_Q^2/(MSQ^2 - M_\chi^2)$.



It is 100% essential for t-quark whose contribution is suppressed. And in principle it can be noticeable for b-quark. In SUGRA such correction gives only about 2%.

Default micrOMEGAs works at tree level approximation nucleusRecoil(...,box=0,..). But for the models like MSSM where loop corrections are known one can substitute box=qbox_(). This routine calculate box diagrams according to Drees&Nojiri-1993.

Twist-2 operators

They are the so-called twist-2 operators containing field derivatives which also contribute to scalar amplitude at rest. In principle each operator should be treated separately because it has its own nucleon form factor. For simplicity we do not distinguish between twist-zero and twist-2 operators since typically contribution of twist-2 operators less than 1%. A complete treatment of twist-2 operators in neutralino nucleon elastic scattering in the MSSM was first presented in Drees&Nojiri-1993.

Comparison against DarkSuSy and Isajet.

For the **SD** amplitudes we have:

$$A^{SD}_{micrO} = A^{SD}(Z) + A^{SD}(\tilde{q})$$
$$A^{SD}_{Isajet} = A^{SD}(Z) - A^{SD}(\tilde{q}) \quad (4)$$
$$A^{SD}_{DarkSusy} = A^{SD}(Z) + 0.5A^{SD}(\tilde{q}) \quad (5)$$

DarkSuSy and Isajet have not implemented QCD and SUSY-QCD corrections. The first one typically increases $A^{SI}(H\bar{q}_b q_b)$ in **20%**, the second on change $A^{SI}(H\bar{q}_d d_d) \approx$ **20%** at large **tb**. Ignoring these correction we have found

$$A^{SI}_{micrO}(H\bar{q}q) = A^{SD}_{Isajet}(H\bar{q}q))$$
$$A^{SI}_{micrO}(\tilde{q}) \neq A^{SD}_{Isajet}(\tilde{q}) \quad (6)$$

Will be improved in next Isajet release.

$$A^{SI}_{micrO}(H\bar{q}_l q_l) = A^{SD}_{DarkSusy}(H\bar{q}_l q_l))$$
$$(Mq_{run}/Mq_{pole})A^{SI}_{micrO}(H\bar{q}_h q_h) = A^{SD}_{DarkSusy}(H\bar{q}_h q_h)) \quad (7)$$