Computation of direct detection using MADGRAPH5

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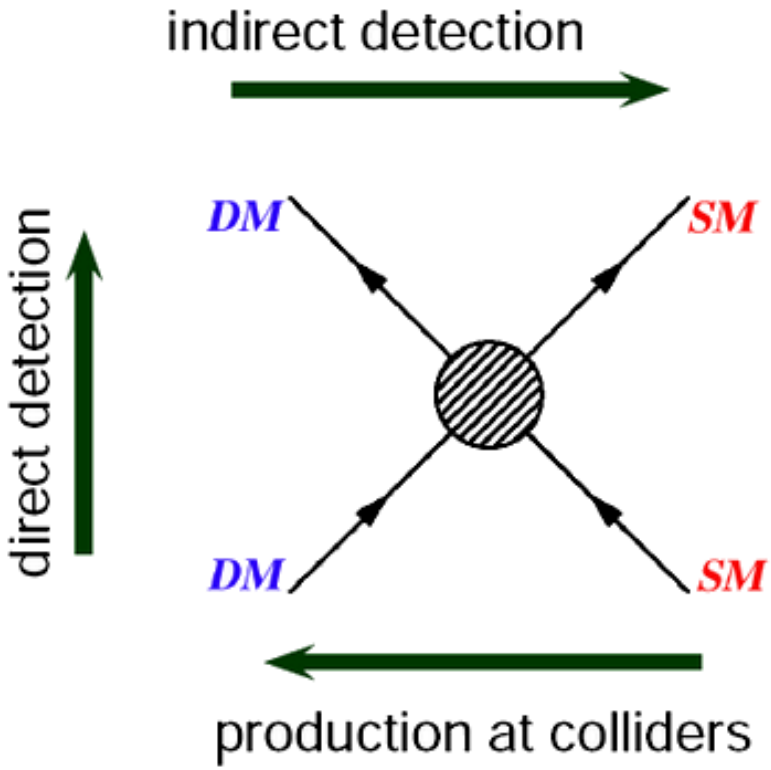
DM detection opportunities

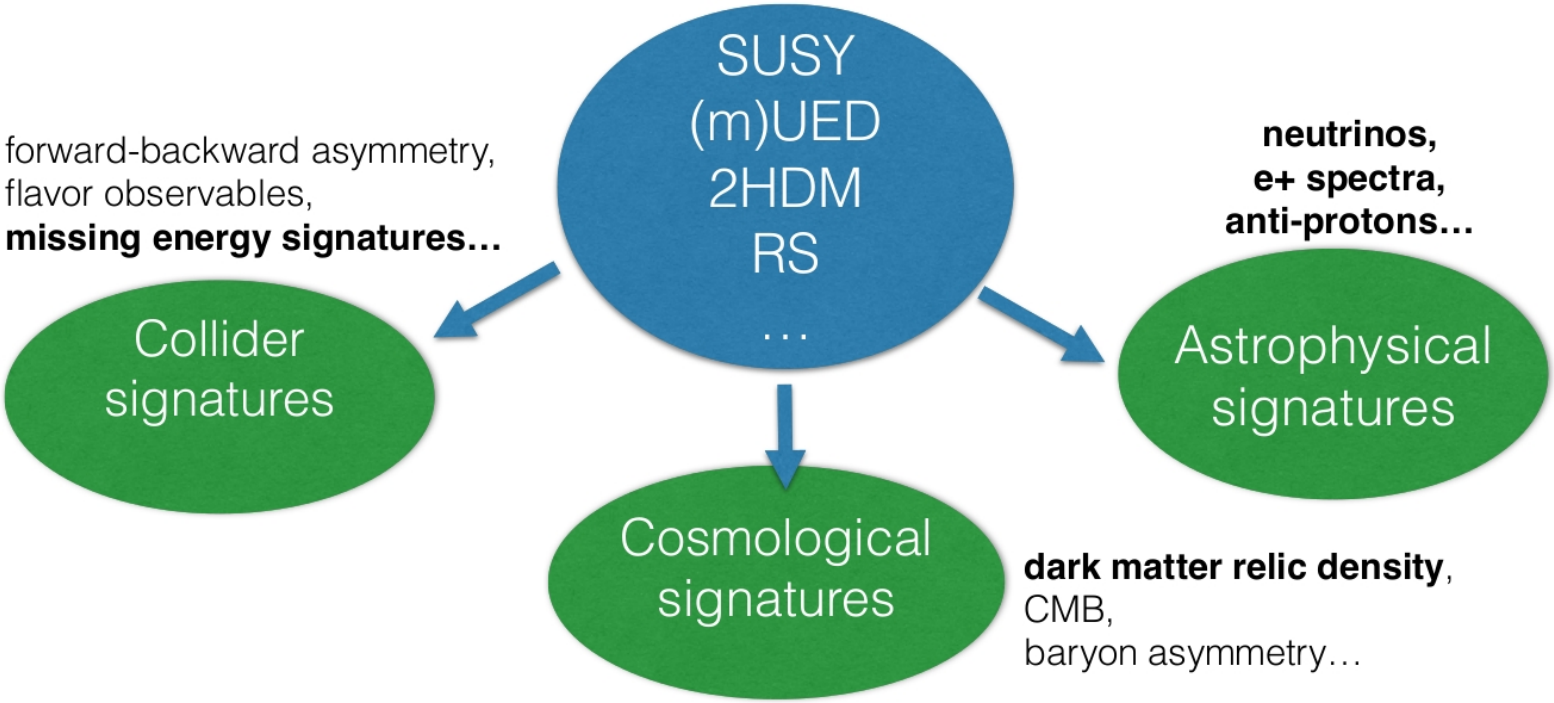
Three possibilities

- Indirect detection: FERMI-LAT, AMS-02.
- Direct detection: XENON100, LUX, CDMS.
- Production at collider: LHC.

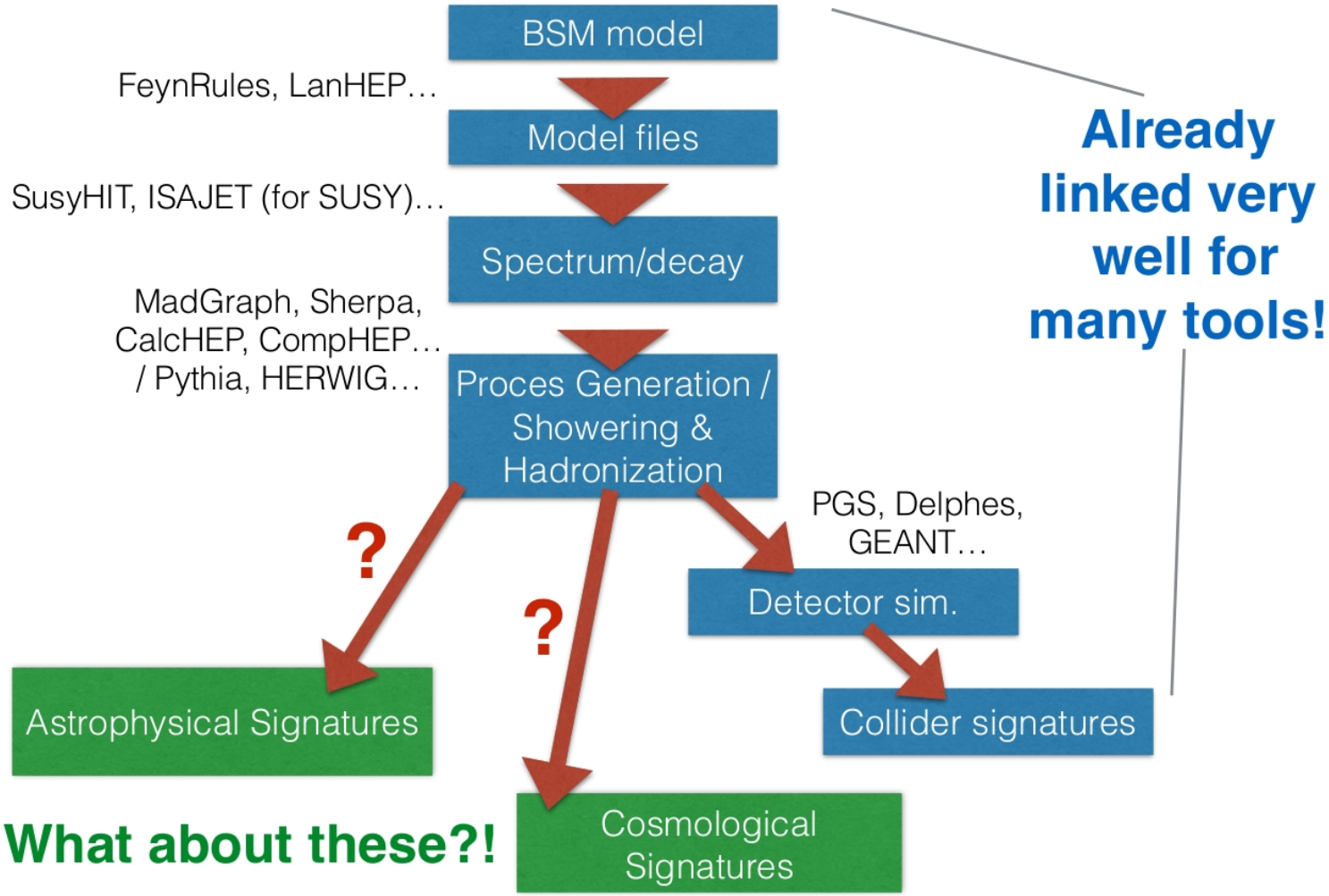


BSM Physics in the LHC era

- Models of new physics grew complex - Many fields, many parameters, many signatures.
- Much relies on the numerical tools nowadays.

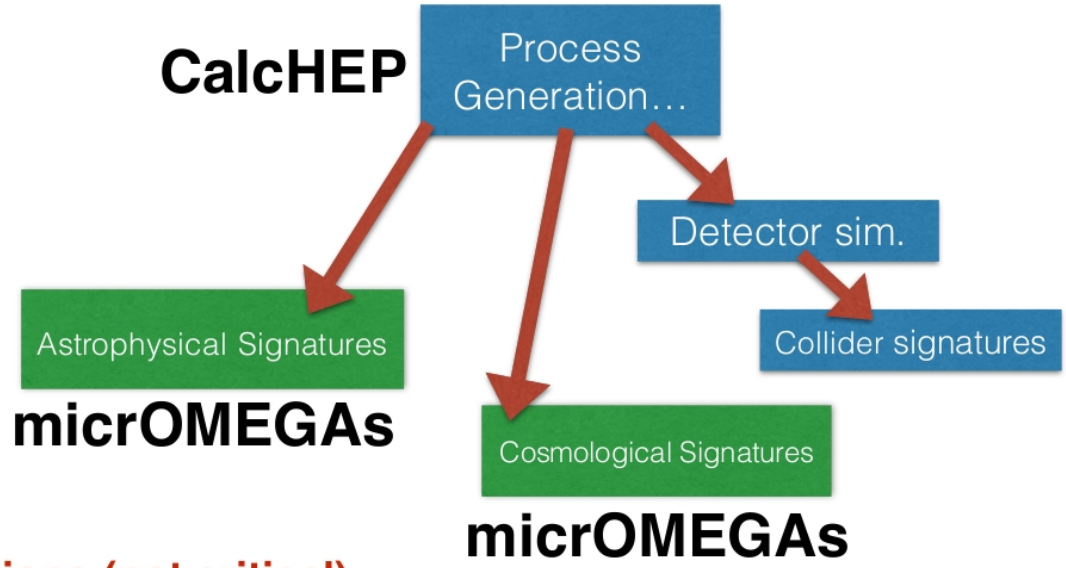


BSM Tools in the LHC era



DM Tools in the LHC era

Currently **CalcHEP/micrOMEGAs** (Comput.Phys.Commun. 149 (2002) 103-120) is the only tool available which can calculate Collider + Astrophyiscal + Cosmological signatures in a **generic model**.



Some limitations (not critical):

- 4 point interaction in SU(3) needs a special treatment. FeynRules does not generate correct model files for CalcHEP/micrOmegas.

- Practically limited by the fact that CalcHEP takes a long time to calculate collider processes beyond 4-6 final state particles.

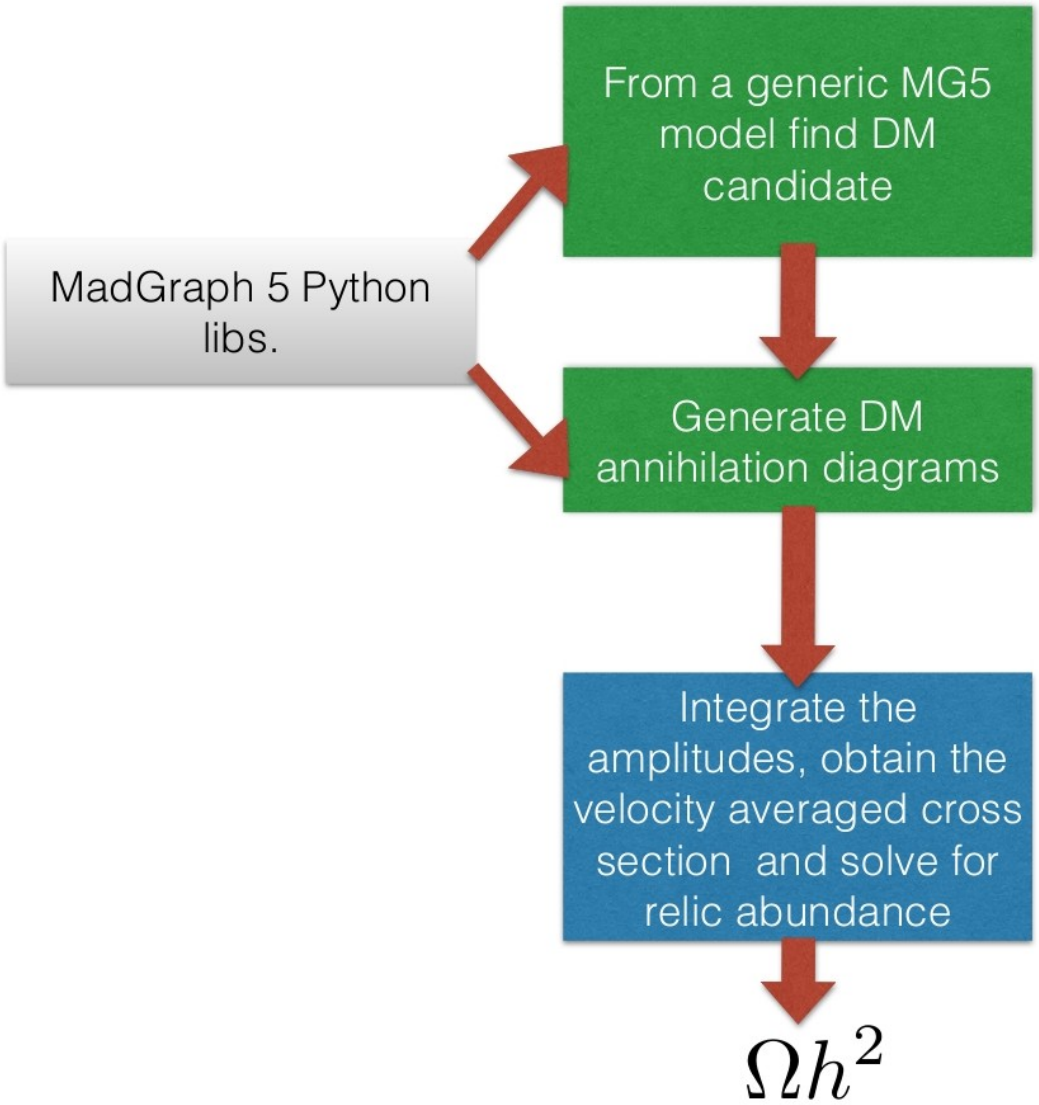
MadDM

- First step to extend MadGraph5 capabilities to dark matter phenomenology
- Built on top of existing MadGraph5 architecture - inherits all of the existing MadGraph structure.

Why MadGraph5?

- Popular among experimentalists.
- Novel Python libraries make add-ons easy.
- MadGraph5_aMC@NLO is an NLO generator (future loop-induced processes).

MadDM structure



Python module
(darkmatter class)

FORTRAN module

MadDM: Direct detection (New)

Matrix element $\langle \bar{q} q \rangle$ of quarks in a nucleon state :

$$\langle \bar{q} q \rangle = \frac{m_{p,n}}{m_q} f_q^{p,n} \text{ (light quarks)}; \ \langle \bar{q} q \rangle = \frac{2}{27} \frac{m_{p,n}}{m_q} f_G^{p,n} \text{ (heavy quarks)}$$

DM-nucleon couplings:

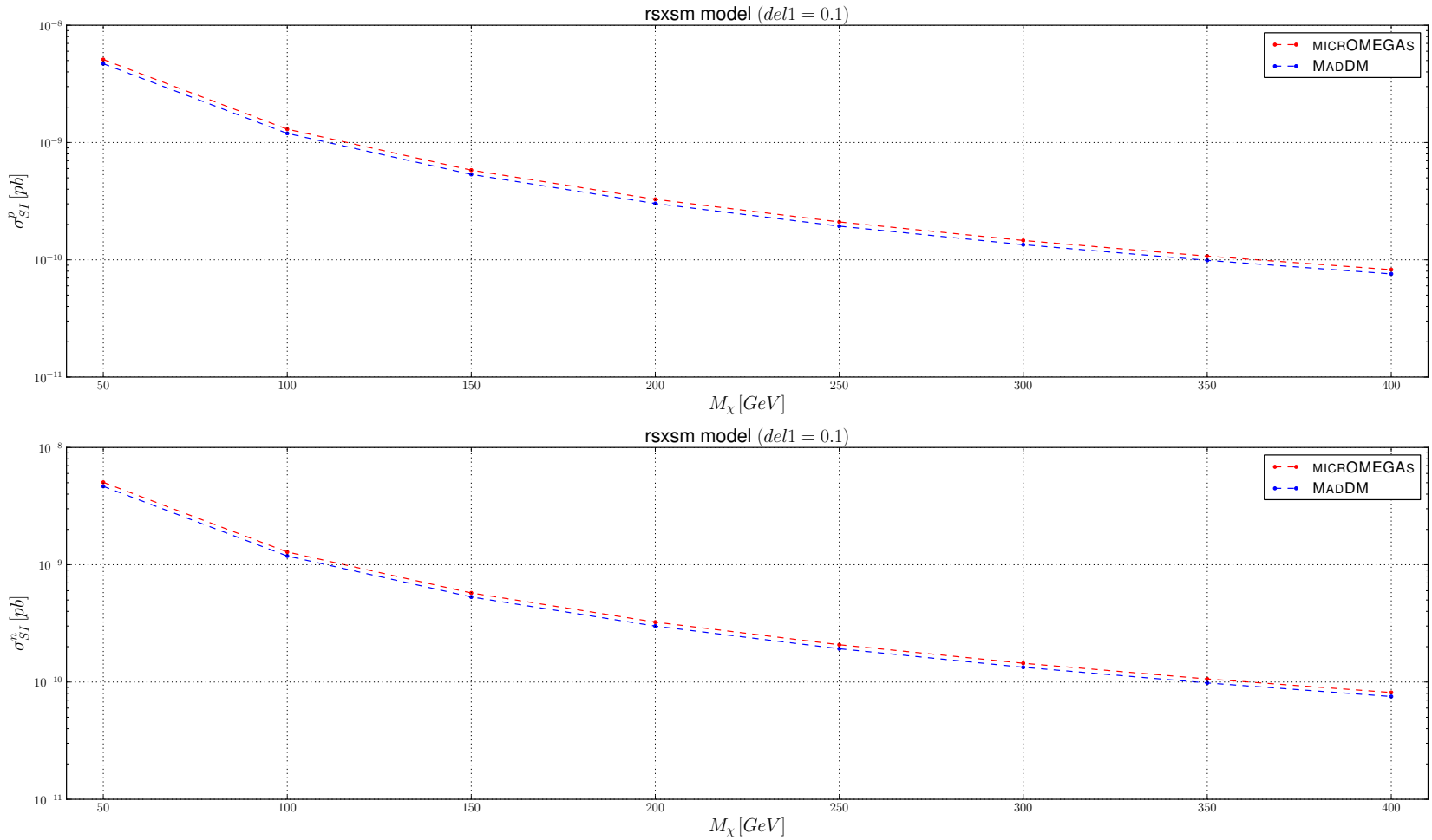
$$f_{p,n}^{\chi} = m_{p,n} \sum_{q=u,d,s} \frac{\mathcal{C}_q}{m_q} f_q^{p,n} + \frac{2}{27} m_{p,n} f_G^{p,n} \sum_{q=c,b,t} \frac{\mathcal{C}_q}{m_q}$$

where $\mathcal{C}_q$ comes from the projection operator method (and $\langle \mathcal{M} \rangle = \mathcal{C}_q \langle \bar{q} q \rangle$).
Finally, you can compute the cross-section DM-nucleus (SI interactions),

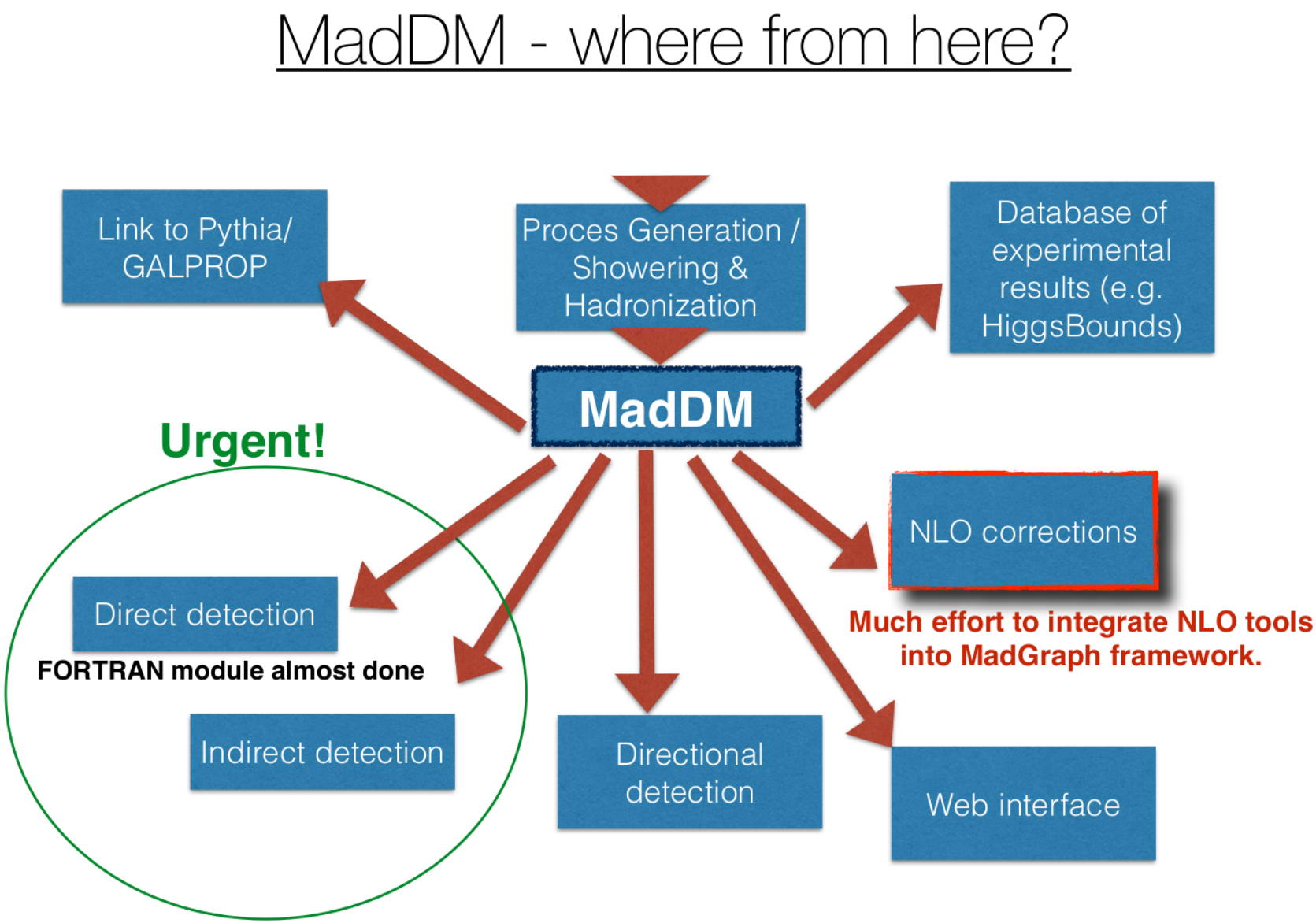
$$\sigma = \frac{4 m_N^2 m_\chi^2}{\pi \left(M_\chi + m_N \right)^2} \cdot \left(A f_p^{\chi} + (A - Z) f_n^{\chi} \right)^2$$

$\Rightarrow$ Already implemented in MadDM !

MadDM validations - rsxSM



Future of MadDM



Thanks !

Tutorial : `http://susy.phsx.ku.edu/~mihailo/tutorial.html`

MadDM : Direct detection (NEW)

We implement an effective Lagrangian ($\mathcal{L}_{eff}$) including all the effective operators available for DM-quarks interactions for a specific DM spin and for SI (or SD) (similar as micrOMEGAs, arXiv:0803.2360) :

	DM spin	Even	Odd
SI	0	$2M_\chi \Phi_\chi \Phi_\chi^* \bar{\psi}_q \psi_q$	$i\left(\partial_\mu \Phi_\chi \Phi_\chi^* - \Phi_\chi \partial_\mu \Phi_\chi^*\right) \bar{\psi}_q \gamma^\mu \psi_q$
	$\frac{1}{2}$	$\bar{\psi}_\chi \psi_\chi \bar{\psi}_q \psi_q$	$\bar{\psi}_q \gamma_\mu \psi_\chi \bar{\psi}_q \gamma^\mu \psi_q$
	1	$2M_\chi A^*_{\chi\mu} A^\mu_\chi \bar{\psi}_q \psi_q$	$i\lambda_{q,o}\left(A^{*\alpha}_\chi \partial_\mu A_{\chi,\alpha} - A^\alpha_\chi \partial_\mu A^*_{\chi\alpha}\right) \bar{\psi}_q \gamma_\mu \psi_q$
SD	$\frac{1}{2}$	$\bar{\psi}_\chi \gamma_\mu \gamma_5 \psi_\chi \bar{\psi}_q \gamma^\mu \gamma^5 \psi_q$	$-\frac{1}{2} \bar{\psi}_\chi \sigma_{\mu\nu} \psi_\chi \bar{\psi}_q \sigma^{\mu\nu} \psi_q$
	1	$\sqrt{6}\left(\partial_\alpha A^*_{\chi\beta} A_{\chi\nu} - A^*_{\chi\beta} \partial_\alpha A_{\chi\nu}\right)$	$i\frac{\sqrt{3}}{2}\left(A_{\chi\mu} A^*_{\chi\nu} - A^*_{\chi\mu} A_{\chi\nu}\right) \bar{\psi}_q \sigma^{\mu\nu} \psi_q$
		$\varepsilon^{\alpha\beta\nu\mu} \bar{\psi}_q \gamma_5 \gamma_\mu \psi_q$	

Then the trick is to combine $\mathcal{L}_{eff}$ to the input model (related to $\mathcal{L}_{input}$) to get the interference term between the two models :

$$\left|\mathcal{M}_{eff+input}\right|^2 = \left|\mathcal{M}_{input}\right|^2 + \left|\mathcal{M}_{eff}\right|^2 + 2\left|\mathcal{M}_{eff} \cdot \mathcal{M}^*_{input}\right|$$

$\Rightarrow$ the interference term gives us the right contribution !