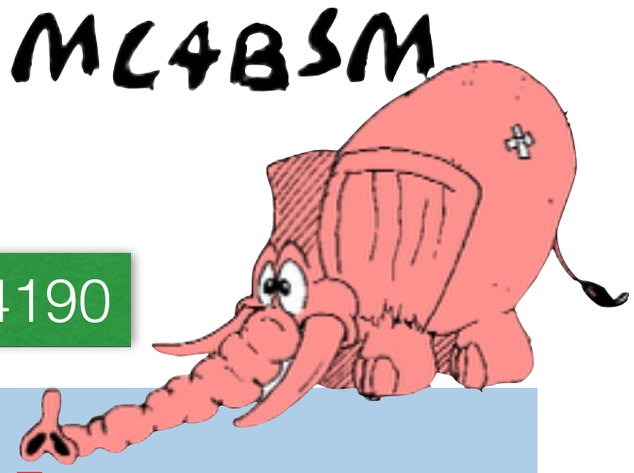

arXiv:1505.04190

MadDM

Dark Matter Direct Detection in the MG5_aMC@NLO framework

Mihailo Backovic (UCL-CP3), , K.C. Kong (KU), Olivier Mattelaer (Durham), Antony Martini (UCL-CP3), Gopolang Mohlabeng (KU).

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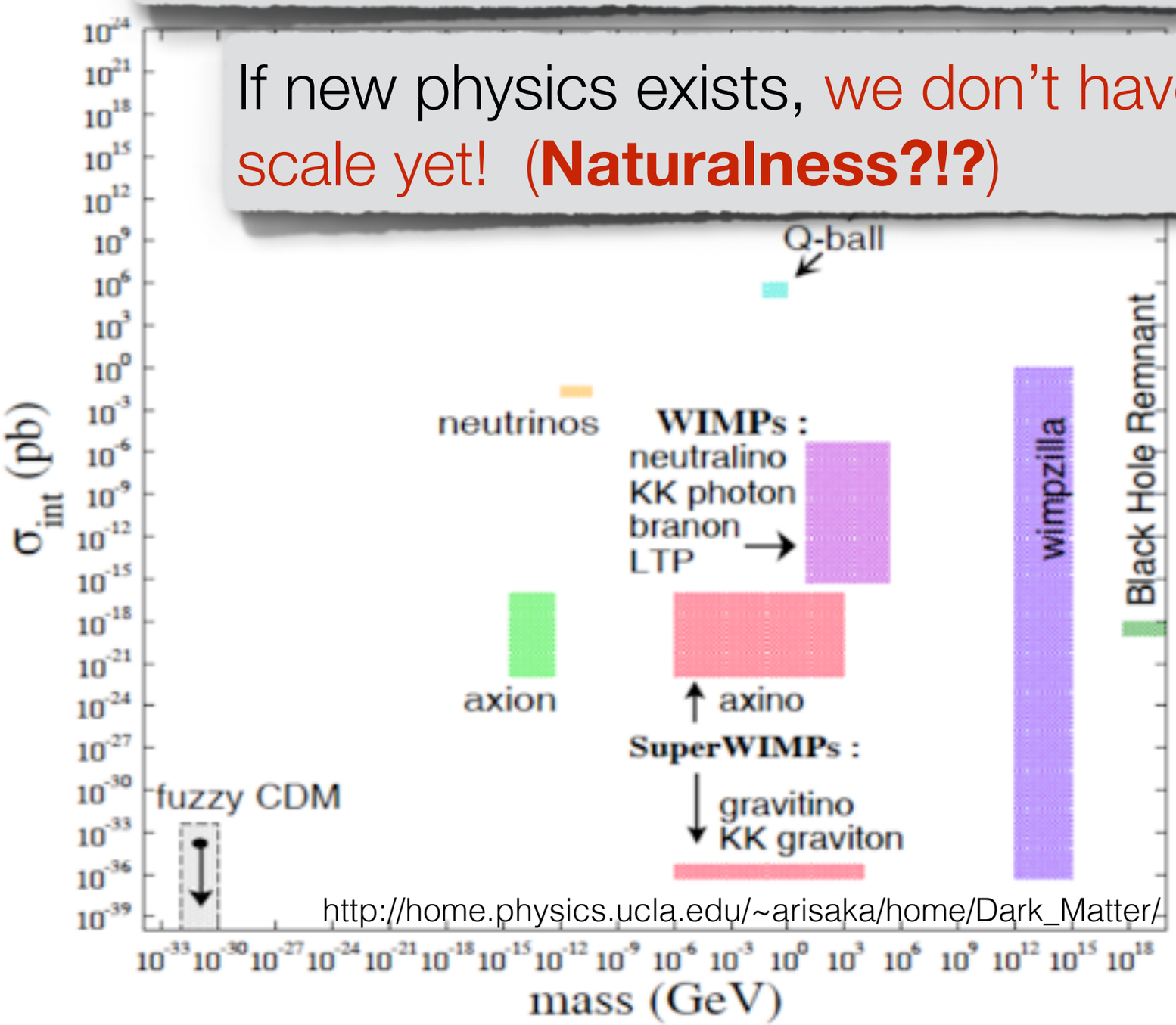
BSM Physics in the LHC era

We have “hints” that there is BSM physics out there
- **dark matter is a good example!**

If new physics exists, we don’t have a good sense of the scale yet! (**Naturalness?!?**)



http://home.physics.ucla.edu/~arisaka/home/Dark_Matter/

Models of DM alone span many orders of magnitude in energy scales.

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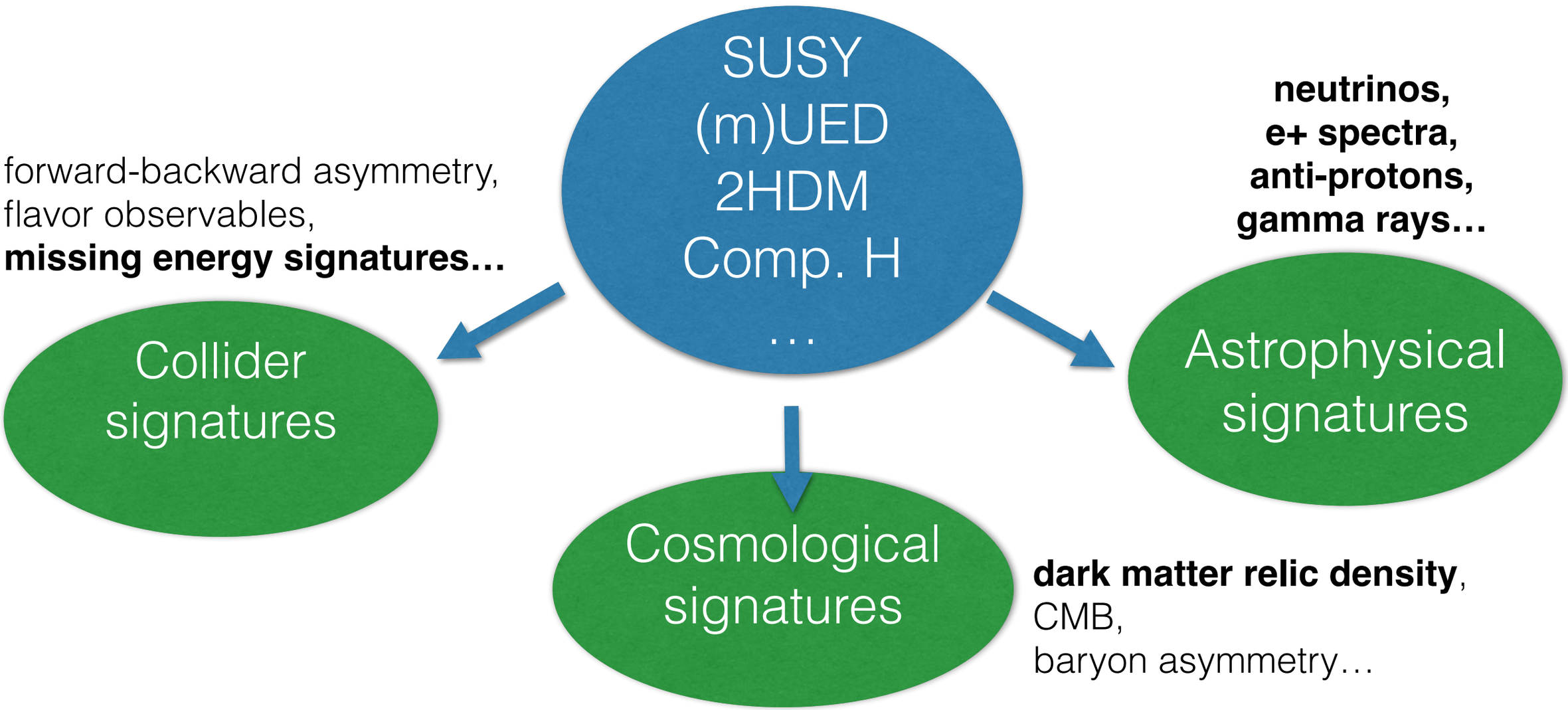
BSM Physics in the LHC era

We have a **vast number of NP models** and **many approaches** to try and discover NP.



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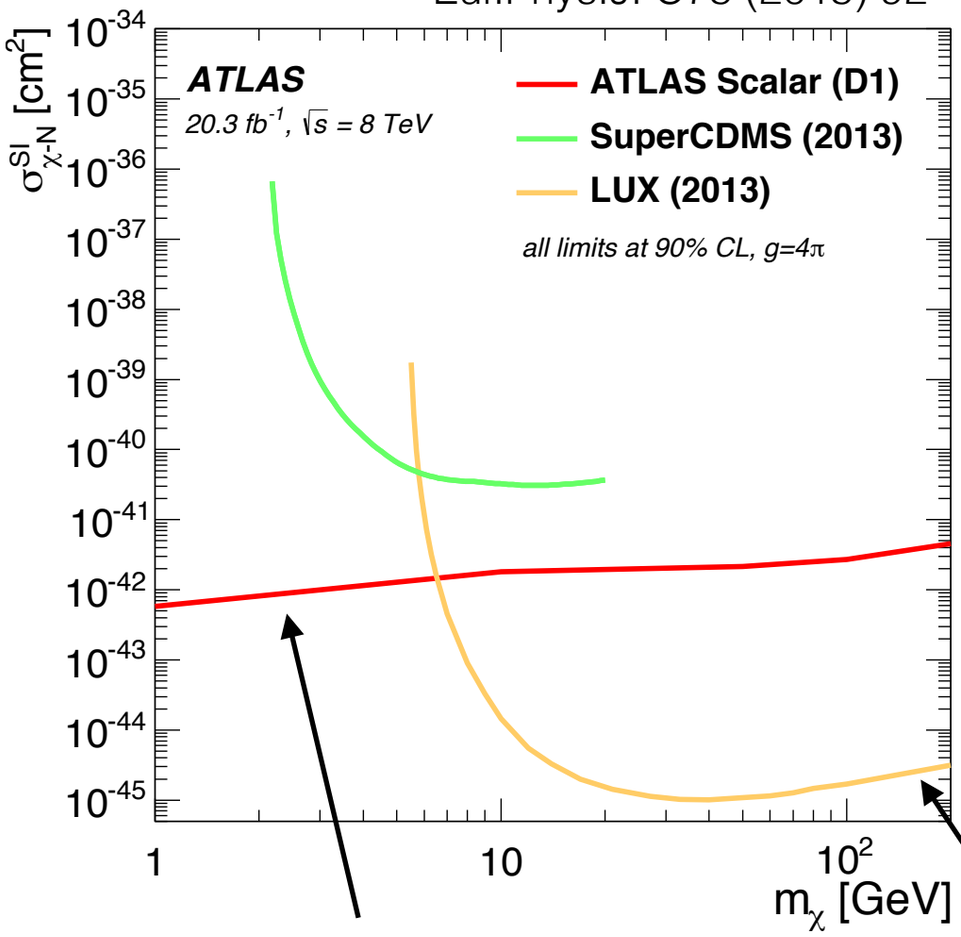
Complementarity of DM searches

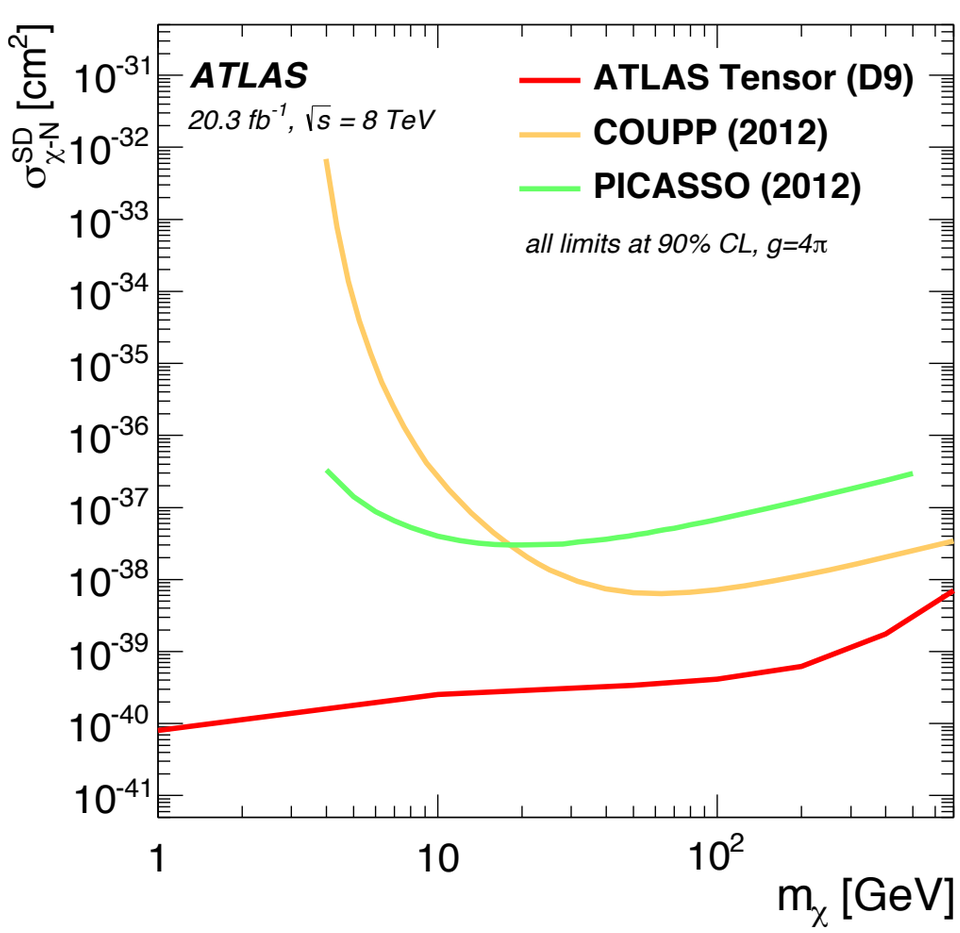
ATLAS DM searches in effective theory approach

$$\mathcal{O}_{\text{scalar}} = \sum_q \frac{m_q}{M_*^N} \bar{q} q \bar{\chi} \chi \quad \text{(D1)}$$

$$\mathcal{O}_{\text{tensor}} = \sum_q \frac{1}{M_*^2} \bar{\chi} \sigma^{\mu\nu} \chi \bar{q} \sigma_{\mu\nu} q. \quad \text{(D9)}$$

Eur.Phys.J. C75 (2015) 92



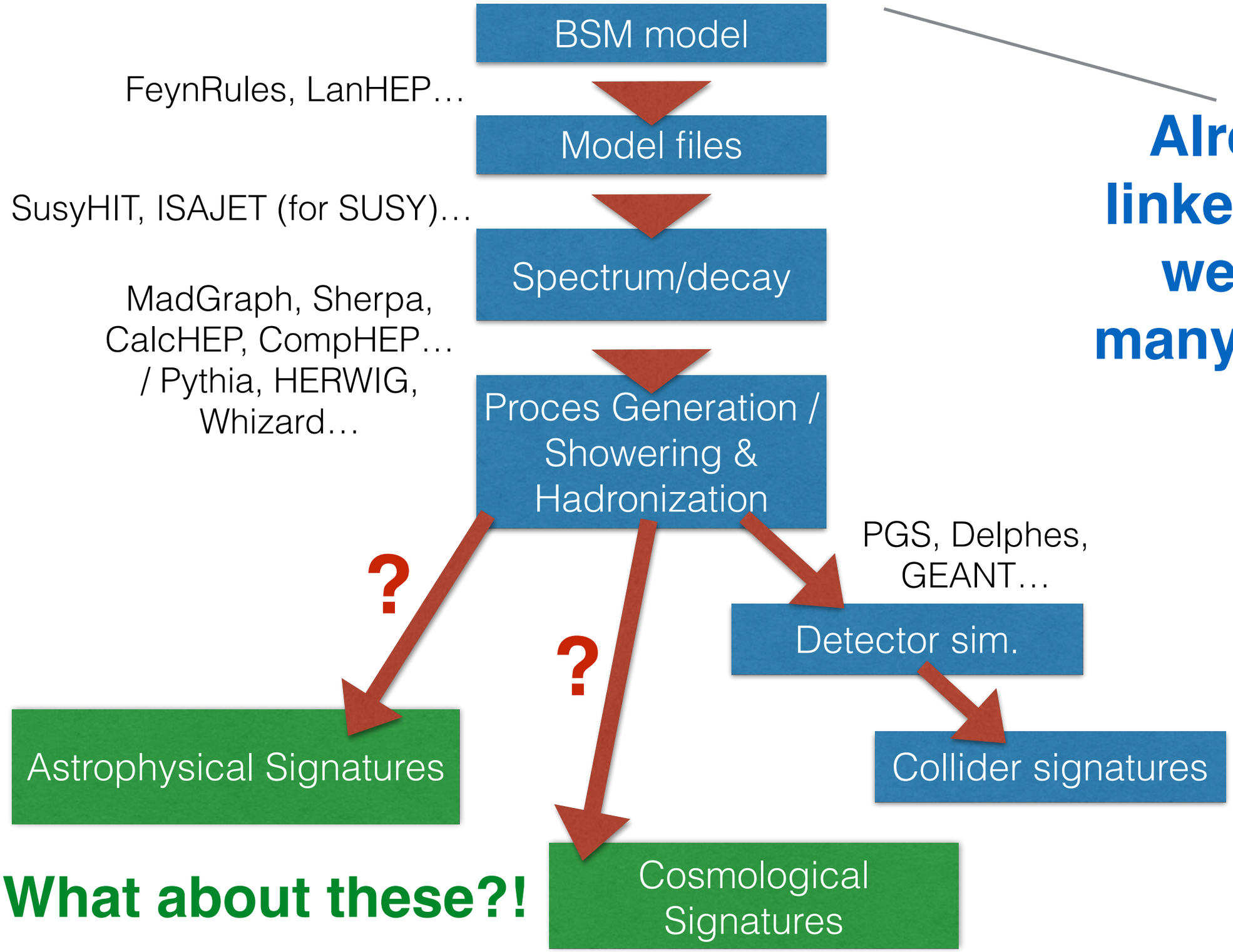


Colliders can be more sensitive to low mass DM

Direct detection provides better limit in “high mass” regime

Note: Complementarity of DM searches is model dependent!

BSM Tools in the LHC era



Already linked very well for many tools!

MadAnalysis, Checkmate, ATOM, Fastlim ….

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BSM Tools in the LHC era

BSM model

FeynRules, LanHEP…

Model files

SusyHIT, ISAJET (for SUSY)…

Spectrum/Decay

MadGraph, Sherpa, CalcHEP, CompHEP… / Pythia, HERWIG, Whizard…

Proces Generation / Showering & Hadronization

?

?

PGS, Delphes, GEANT…

Detector sim.

Collider signatures

MadAnalysis, Checkmate, ATOM, Fastlim ….

Astrophysical Signatures

Cosmological Signatures

What about these?!

Already linked very well for many tools!

A new generation of tools necessary to efficiently link all the complementary approaches

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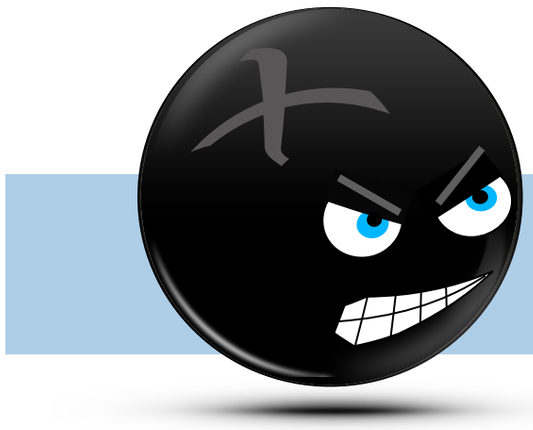
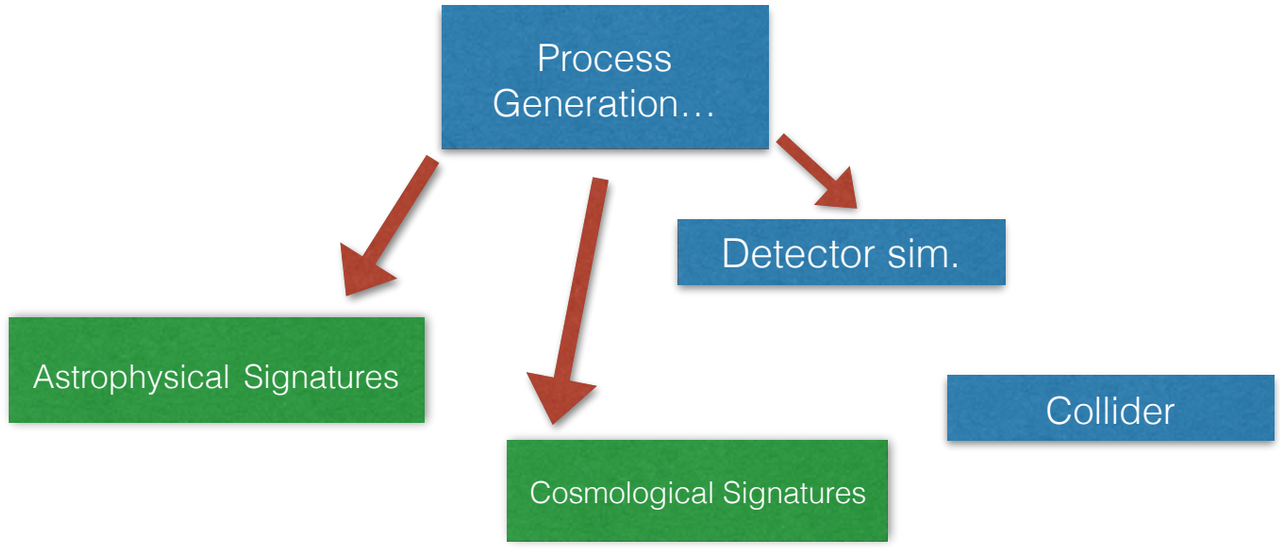


MadDM



MadDM emerged as an effort to link:

- **DM collider searches**, with
- **early cosmology** signatures (relic density) and
- **direct/indirect detection**.

Version 1.0 of MadDM focused on calculations of **DM relic density** (in a generic UFO model).

Version 2.0 of MadDM extends the functionality to **DM direct detection.**

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MadDM - DM-nucleon cross section

- We consider both the SI and SD cross sections:

$$\sigma_0^{SI} = \frac{4\mu_\chi^2}{\pi}\left(\lambda_p Z + \lambda_n (A-Z)\right)^2 \qquad \sigma_0^{SD} = \frac{16\mu_\chi^2}{\pi}\frac{J_A+1}{J_A}\left(\xi_p S_p^A + \xi_n S_n^A\right)^2$$

Nucleon form factor
(typically extracted from data)

$$\lambda_{p,n} \sim \sum_q f_q C_q \frac{m_{p,n}}{m_q}$$ Nucleon amplitude

$$\langle M_{\chi q \to \chi q}\rangle = C_q \langle \bar{q} q\rangle$$

Need to extract the coefficient C_q !

- Calculation of C_q **simple analytically, but tricky numerically**.

- Took a long time to implement. New model merging features of MadGraph were crucial! (thank you MG guys!)

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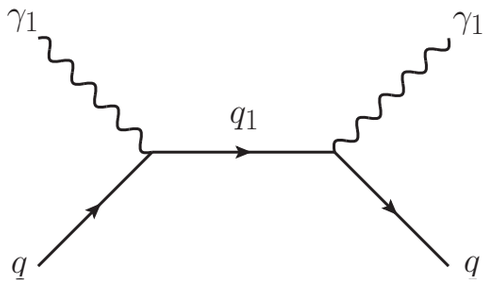
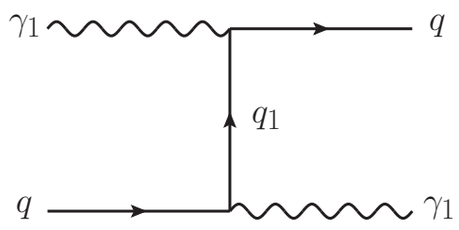
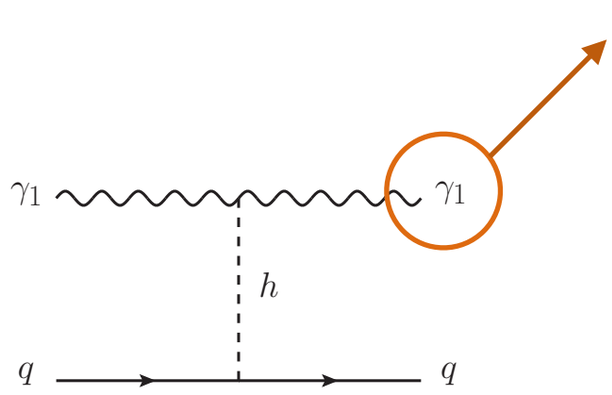
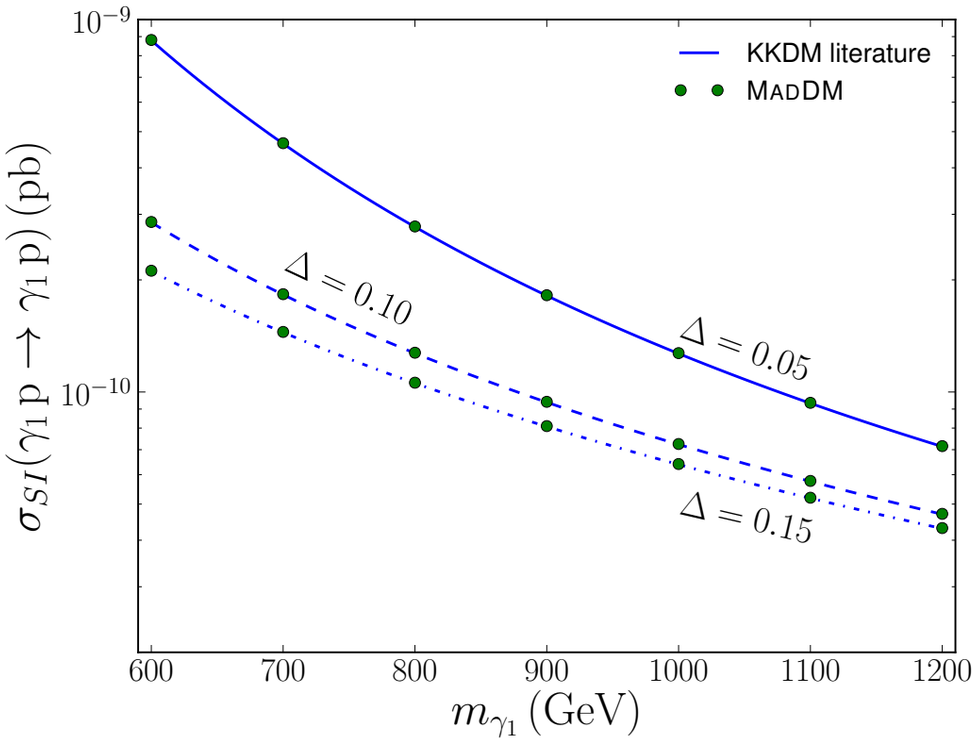
Validations (mUED):

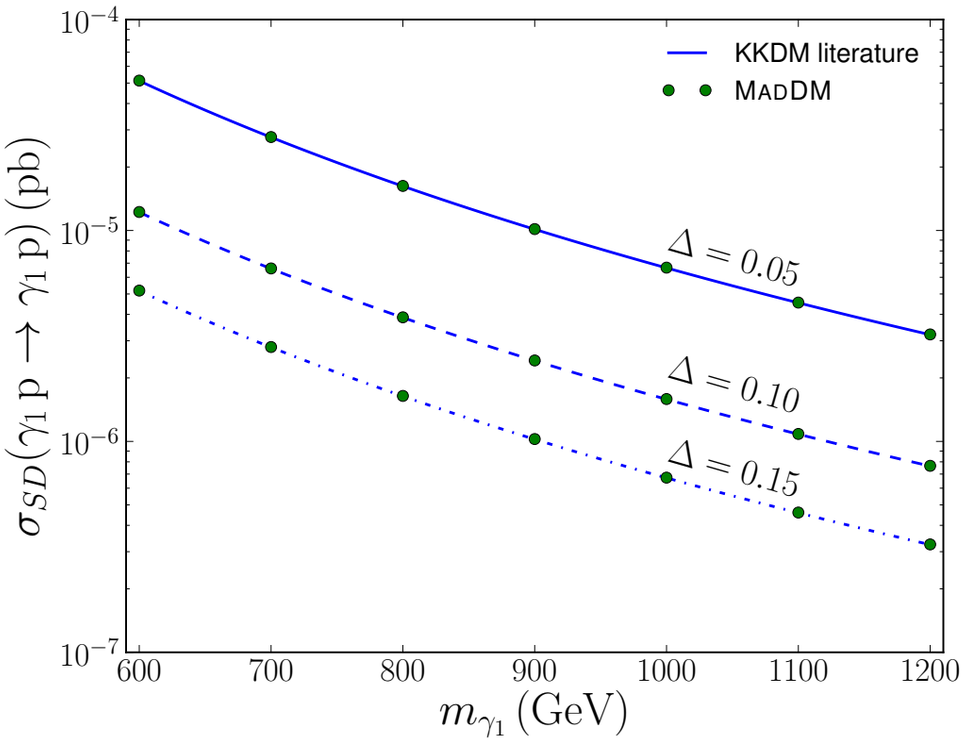






$$\Delta = \frac{m_{q_1} - m_{\gamma_1}}{m_{\gamma_1}}$$





Excellent agreement between MadDM and literature!

We also validated the calculation of SI and SD cross sections in a wide range of simplified models and MSSM (SPS1a).

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MadDM - **Nucleus Recoil Rates**

Local DM density

Velocity distribution

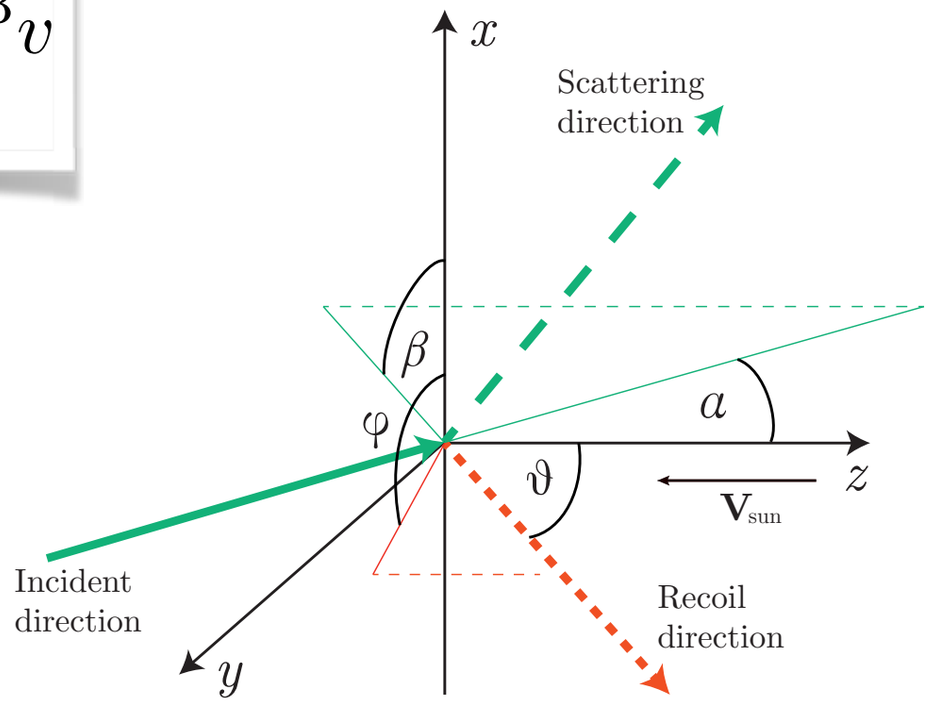
$$\frac{d^2R}{dE_R d\Omega_{(\theta,\phi)}} = \frac{2\,\rho_0}{m_\chi}\int \frac{d\sigma}{dq^2 d\Omega_{(\theta,\phi)}} v f(\mathbf{v}) d^3v$$

Differential DM-**nucleus** cross section

DM-**nucleon** cross section

$$\frac{d\sigma}{dq^2 d\Omega_{(\theta,\phi)}} = \frac{\sigma_{\chi N}}{8\pi\mu^2 v} F^2(q)\delta\left(v\cos\theta - \frac{q}{2\mu}\right)$$

Nuclear form factor



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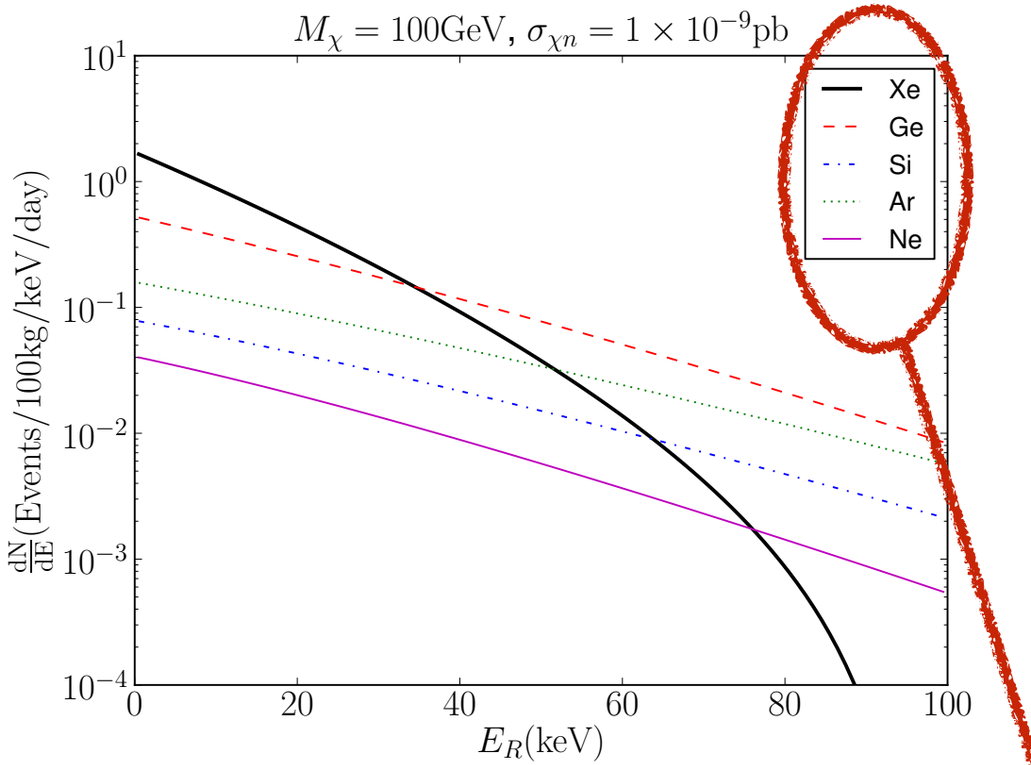
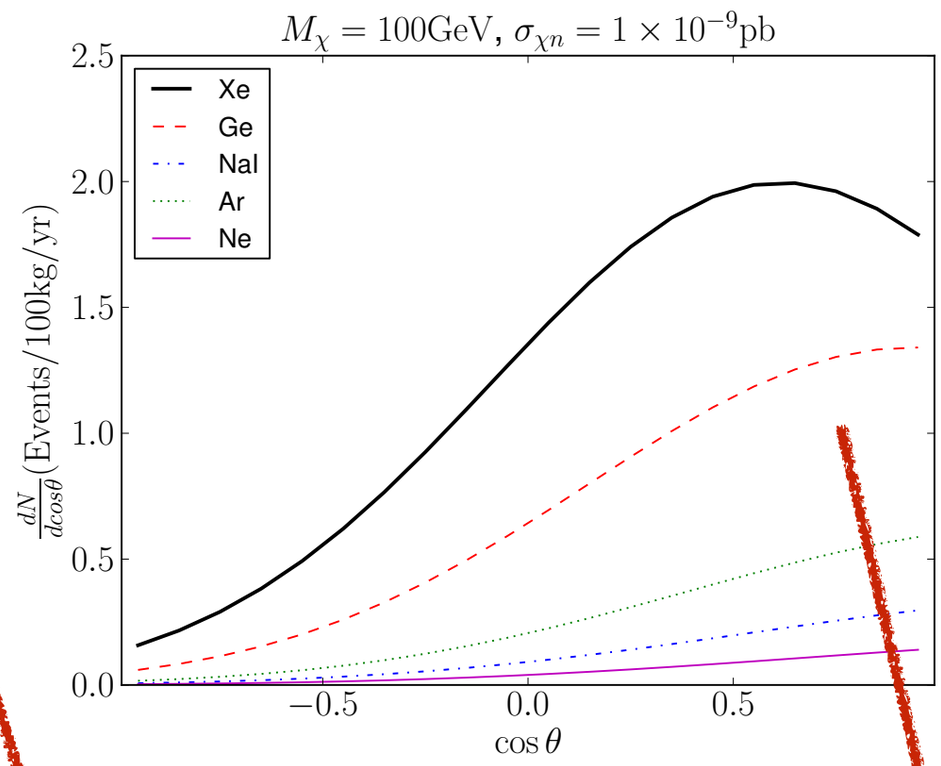
Example **recoil distributions**





Target Material	S_{ij}	$\langle S_n \rangle$	$\langle S_p \rangle$	J
Xenon	Ref. [39]	-0.272	-0.009	$\frac{3}{2}$
Germanium	Ref. [40]	0.378	0.030	$\frac{9}{2}$
Silicon	Ref. [41]	0.13	-0.002	$\frac{1}{2}$
Neon	Refs. [26, 41]	0.294	0.02	$\frac{1}{2}^*$
Argon	Ref. [26]	0*	0*	$\frac{1}{2}^*$
Sodium	Ref. [39]	0.0199	0.2477	$\frac{3}{2}$
Iodine	Ref. [39]	0.075	0.309	$\frac{5}{2}$
Carbon	Ref. [26]	-0.172	-0.009	$\frac{1}{2}$
Fluorine	Refs. [41, 42]	-0.0087	0.4751	$\frac{1}{2}$
Sulphur	Ref. [26]	0*	0*	$\frac{1}{2}^*$

we implemented a wide range of target materials!

(**also, composites: NaI and CF**)

Nuclear recoil due to DM has preferred direction

(**due to DM "wind"**)

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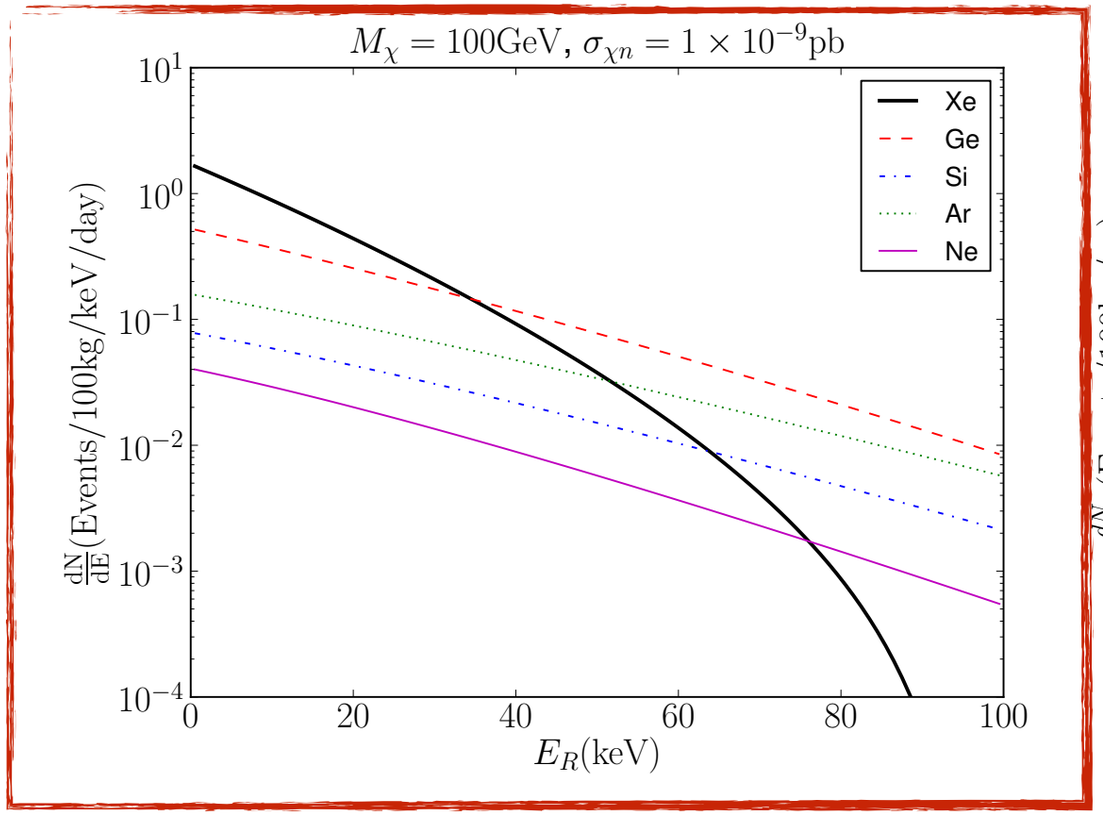
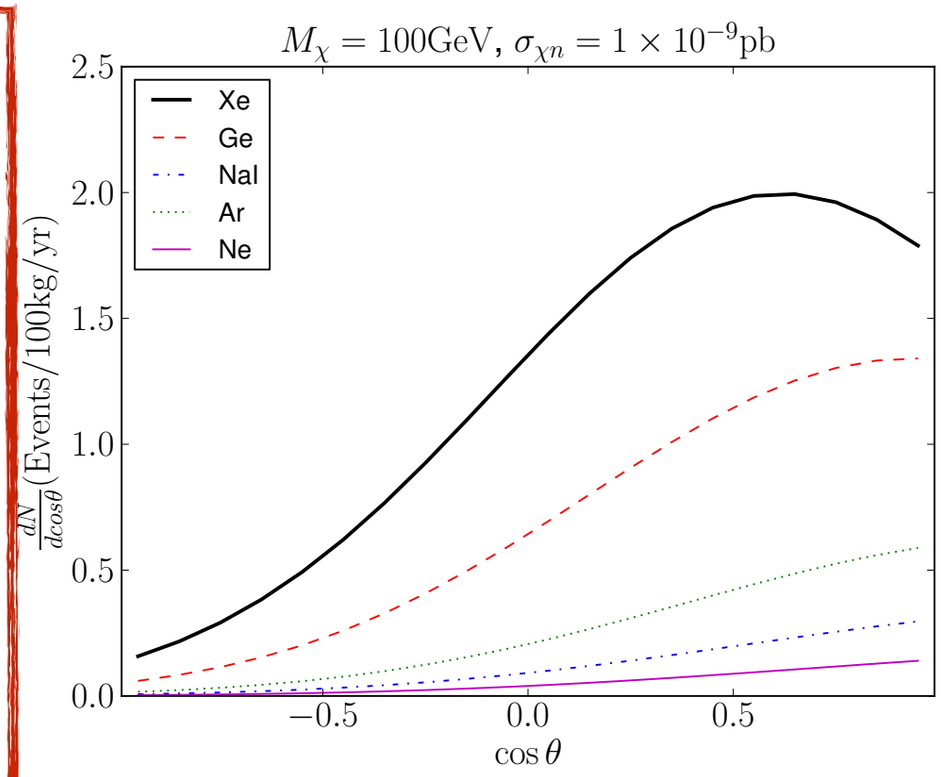
Example **recoil distributions**





People typically calculate dR/dE because this is the quantity dir. detection experiments can measure…

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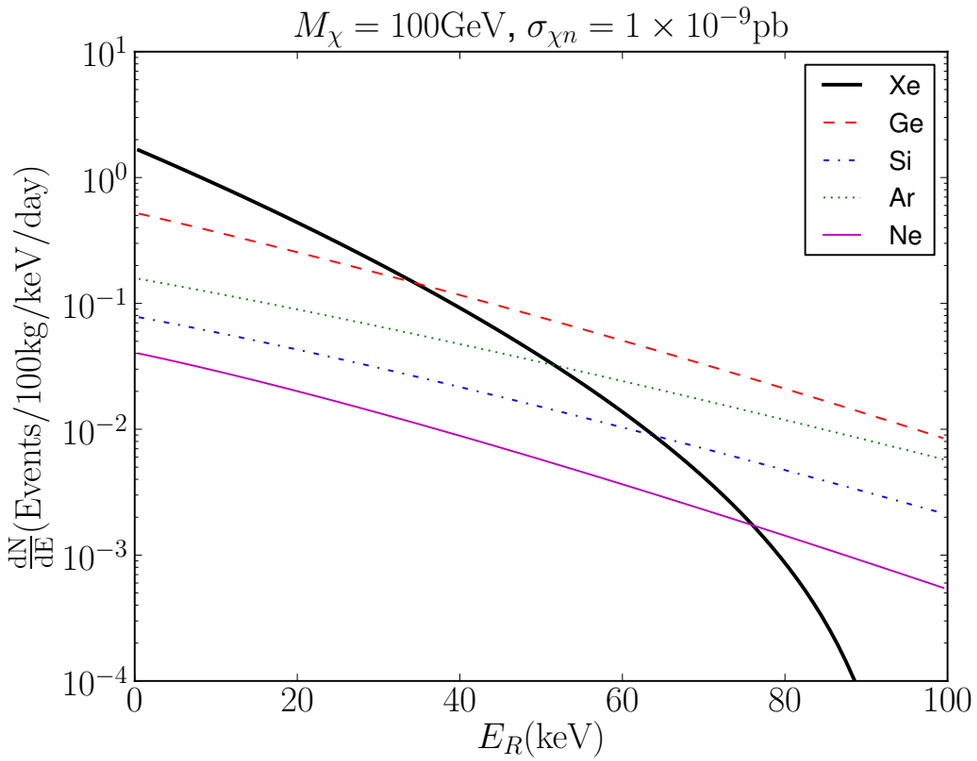
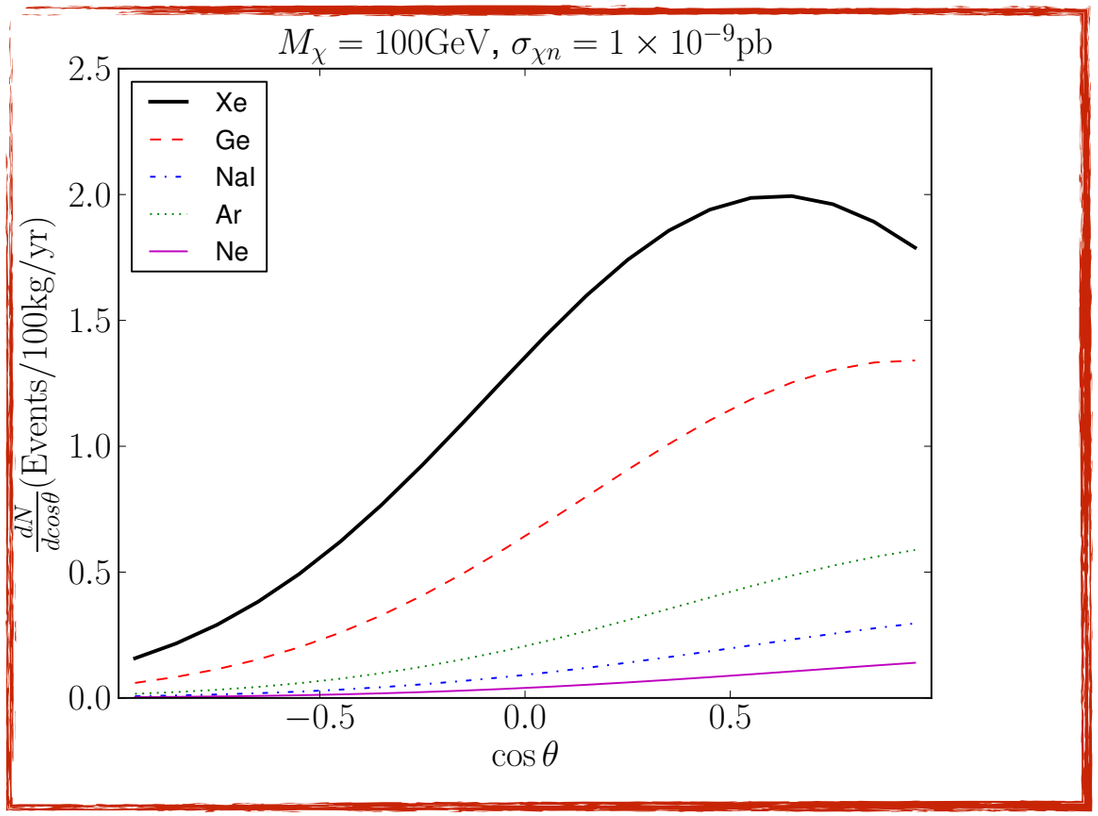
Example **recoil distributions**





People typically calculate dR/dE because this is the quantity dir. detection experiments can measure…

…yet, there are **many reasons to consider** $dR/dE\, d\cos(\theta)$

MadDM is the first public code to allow for calculations of angular recoil distributions!

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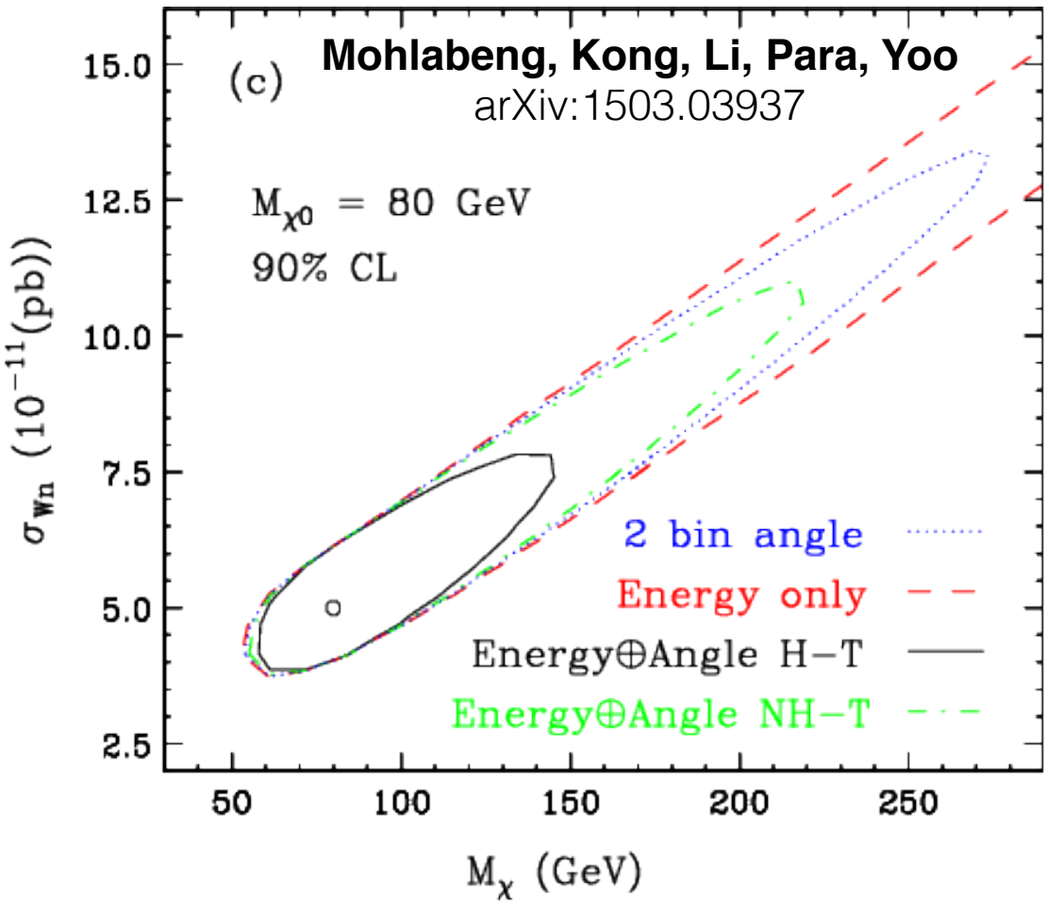
MadDM - **directional detection** of DM

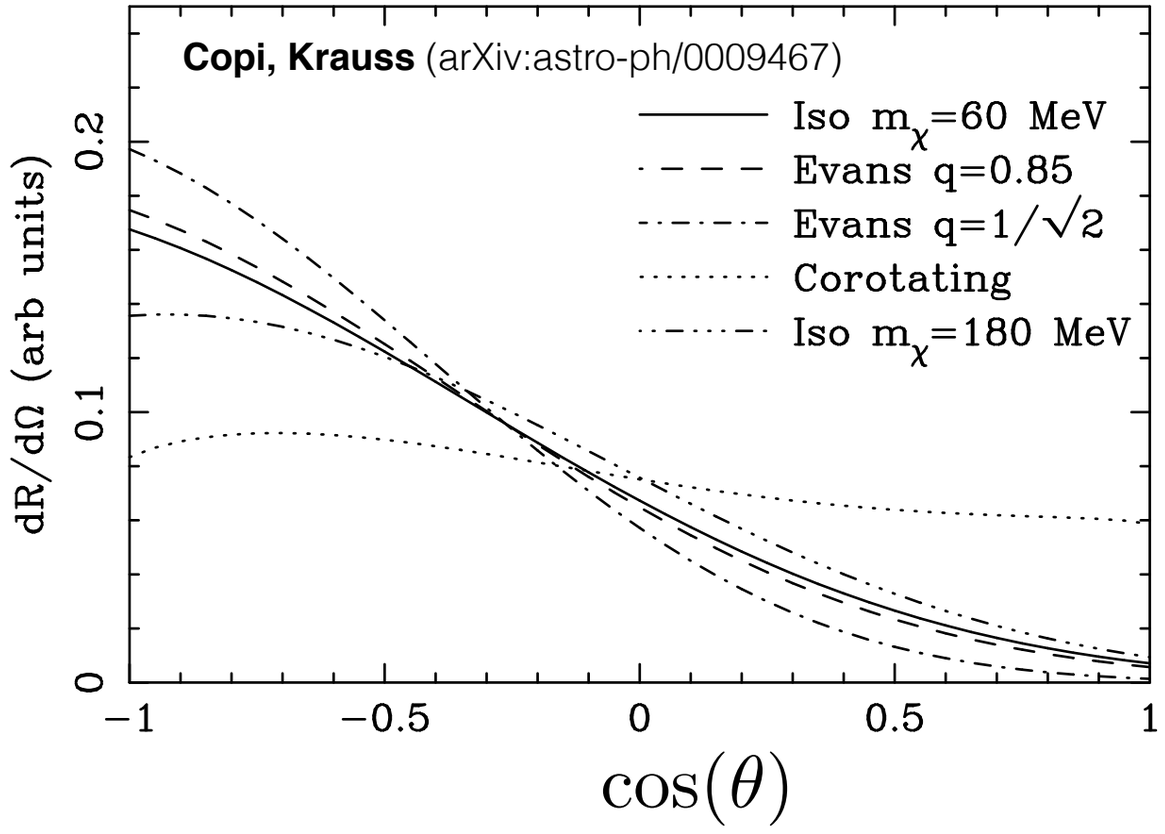
In case DM is discovered - need to measure the **DM and halo properties**. Directional information could be important in this case!

Angular+energy recoil information gives **better mass/cross section measurements**



Directionality can give us **useful info. about the halo models**

Comparison of different halo models



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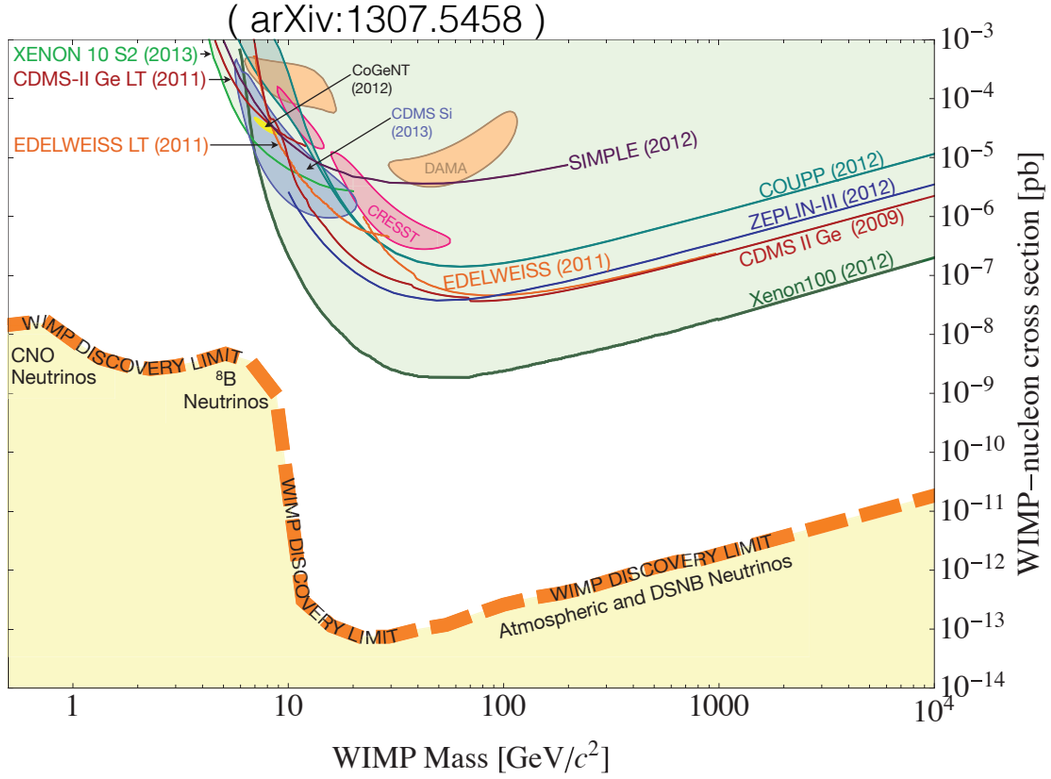
MadDM - **directional detection** of DM

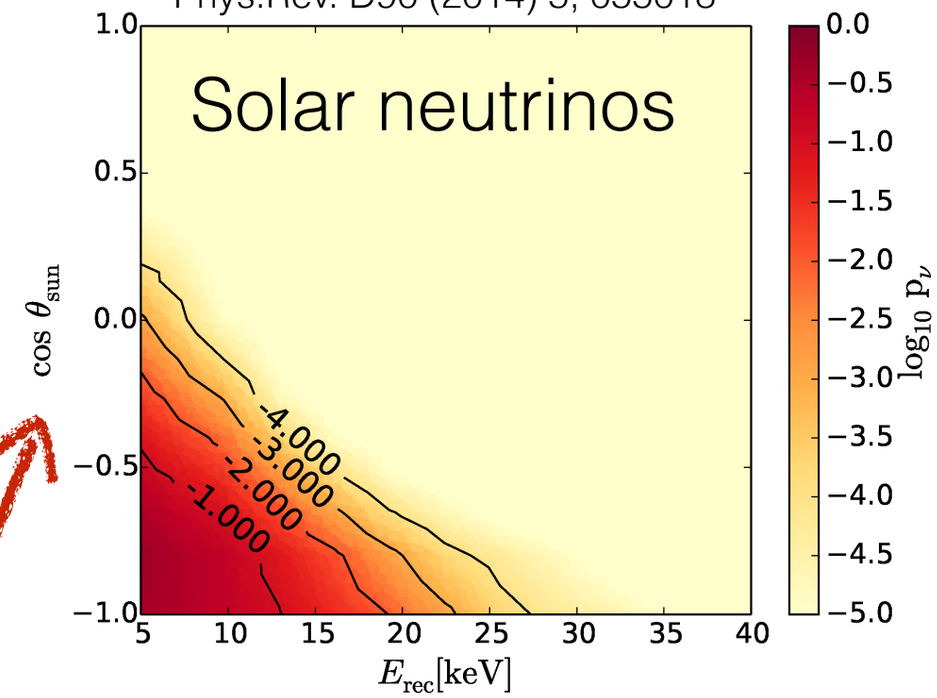
In case DM is not discovered - Neutrinos could become a non-negligible background in the future

Directional information can be used to **discriminate neutrino backgrounds**!

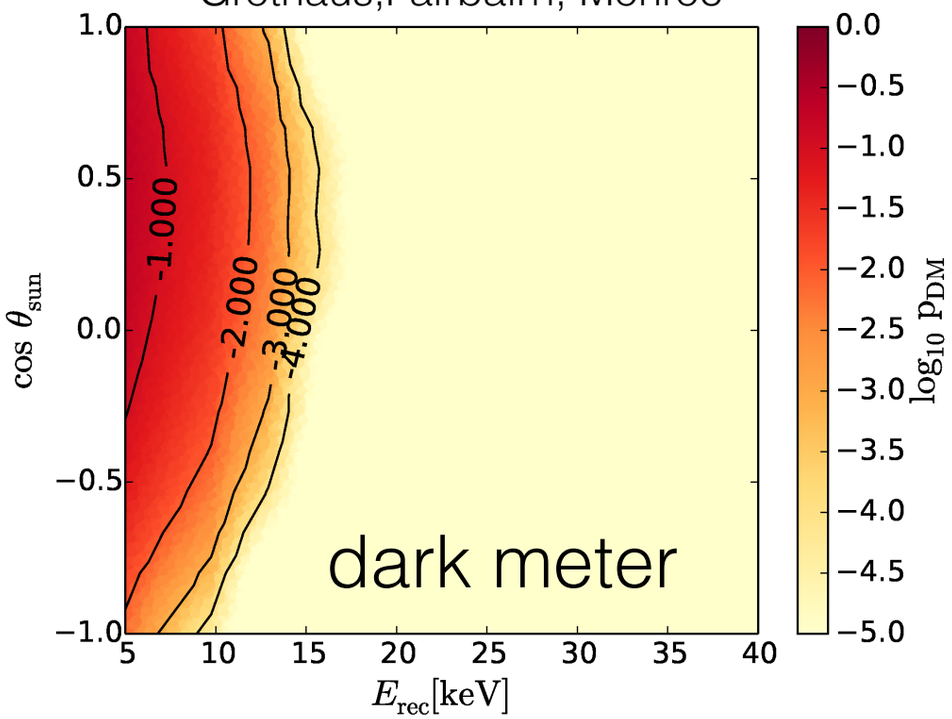
J. Billard, L. Strigari, E. Figueroa-Feliciano
(arXiv:1307.5458)



Phys.Rev. D90 (2014) 5, 055018



Grothaus,Fairbairn, Monroe



θ points from the Sun

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MadDM - **directional detection** of DM

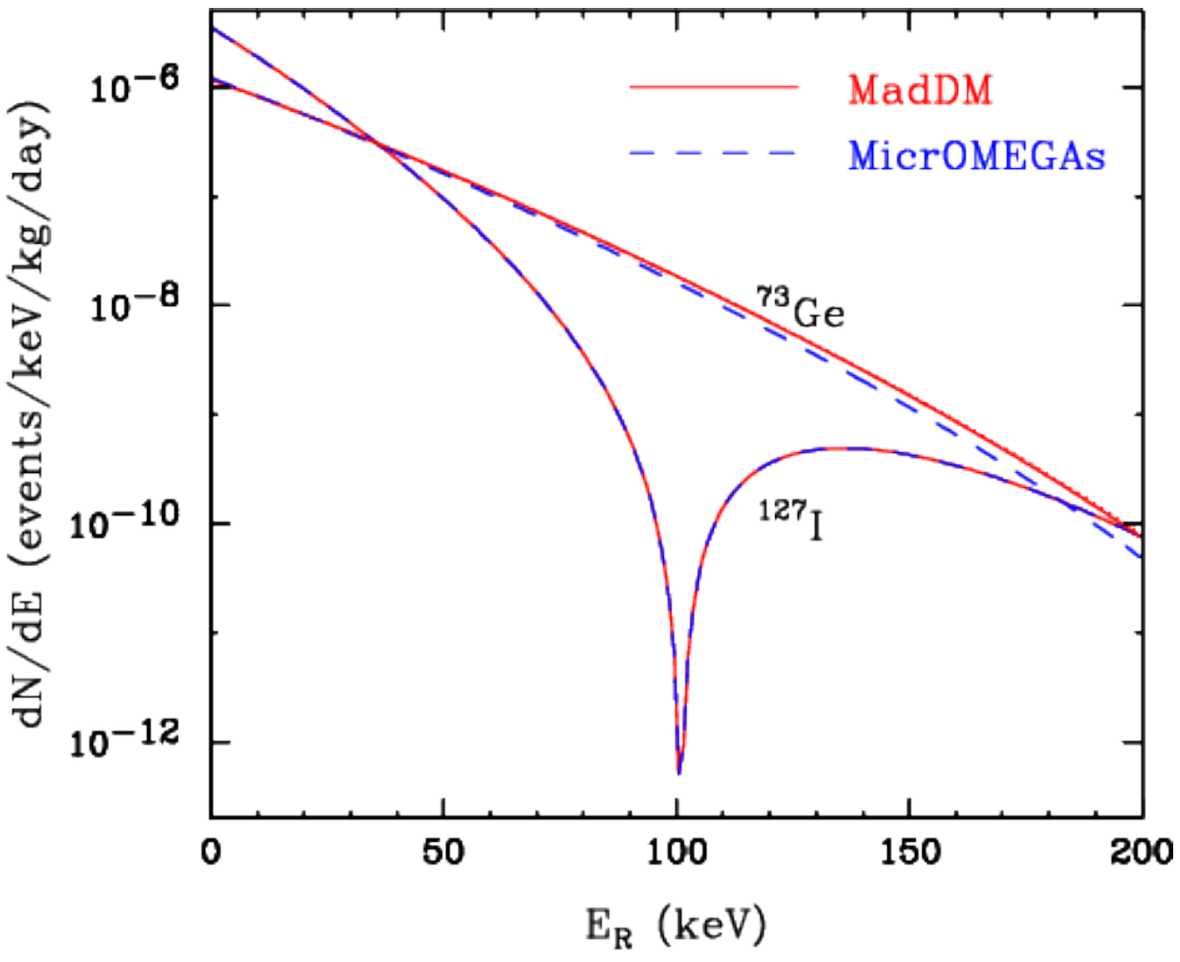
Several small scale experiments have sensitivity
to nuclear recoil directionality, but are **limited by detector volume**
(**DRIFT** (CF4 + CS2), **DM-TPC** (CF4), **MIMAC** (CF4)…)

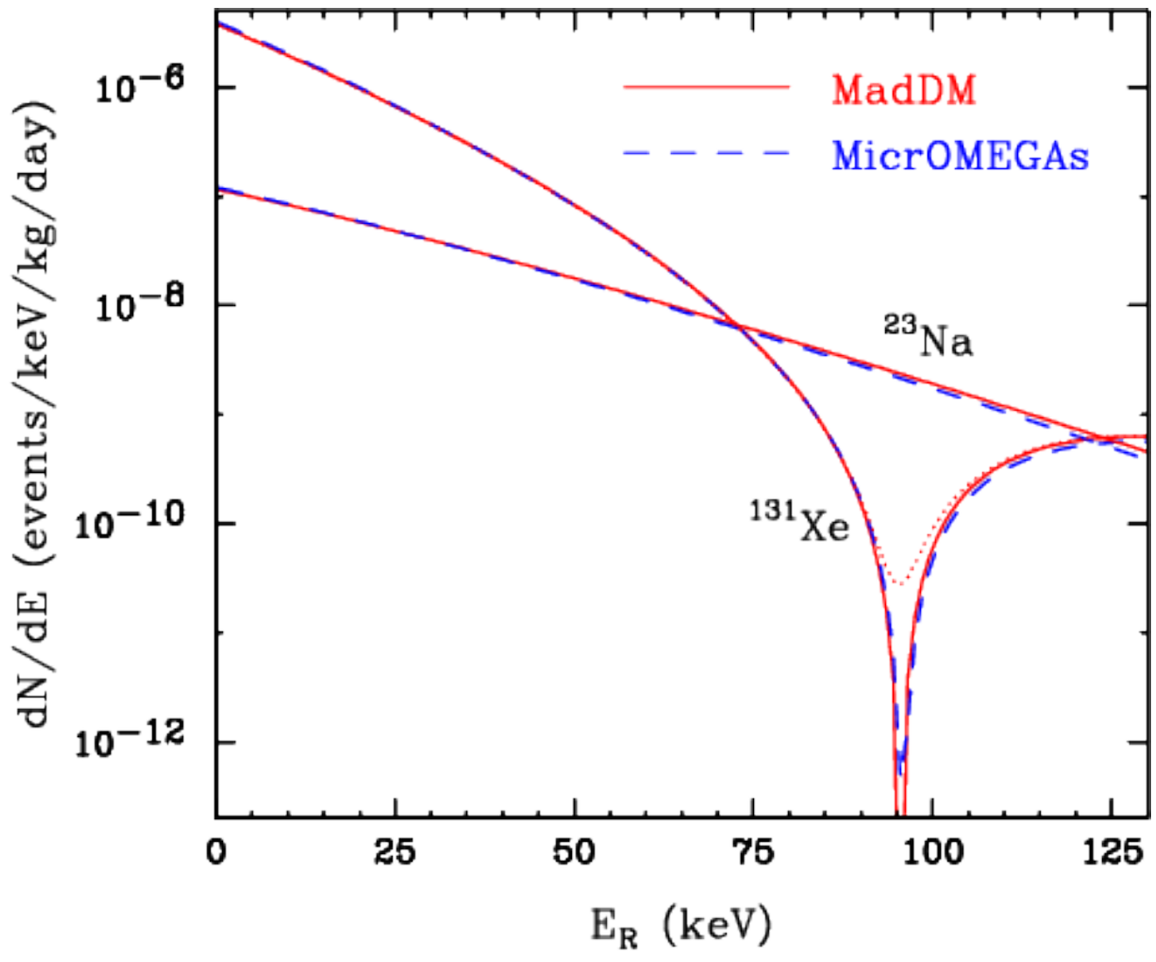
Many proposals for directional detection in the literature:

- G. Mohlabeng, K. Kong, J. Li, A. Para, and J. Yoo, (2015), arXiv:1503.03937 [hep-ph].
- C. J. Copi, J. Heo, and L. M. Krauss, Phys.Lett. B461, 43 (1999), arXiv:hep-ph/9904499 [hep-ph].
- D. Santos, J. Billard, G. Bosson, J. Bouly, O. Bourrion, et al., J.Phys.Conf.Ser. 460, 012007 (2013), arXiv:1304.2255 [physics.ins-det].
- E. Daw, J. Fox, J.-L. Gauvreau, M. Gold, L. Harmon, et al., JINST 9, P07021 (2014), arXiv:1307.5525 [physics.ins-det].
- G. Sciolla et al. (DM-TPC collaboration), (2008), arXiv:0806.2673 [astro-ph].
- D. Nygren, J.Phys.Conf.Ser. 460, 012006 (2013).
- **…. and more**

Validations (Higgs portal, scalar DM):

We find good agreement in recoil rates with micrOMEGAs.





Assuming a 1pb DM-nucleon scattering cross section

Simulation of Detector Effects:

- Given the user defined energy and angular resolution, **MadDM can smear the recoil distributions**

- We assume a Gaussian smearing function (**this can be easily modified by the user**):

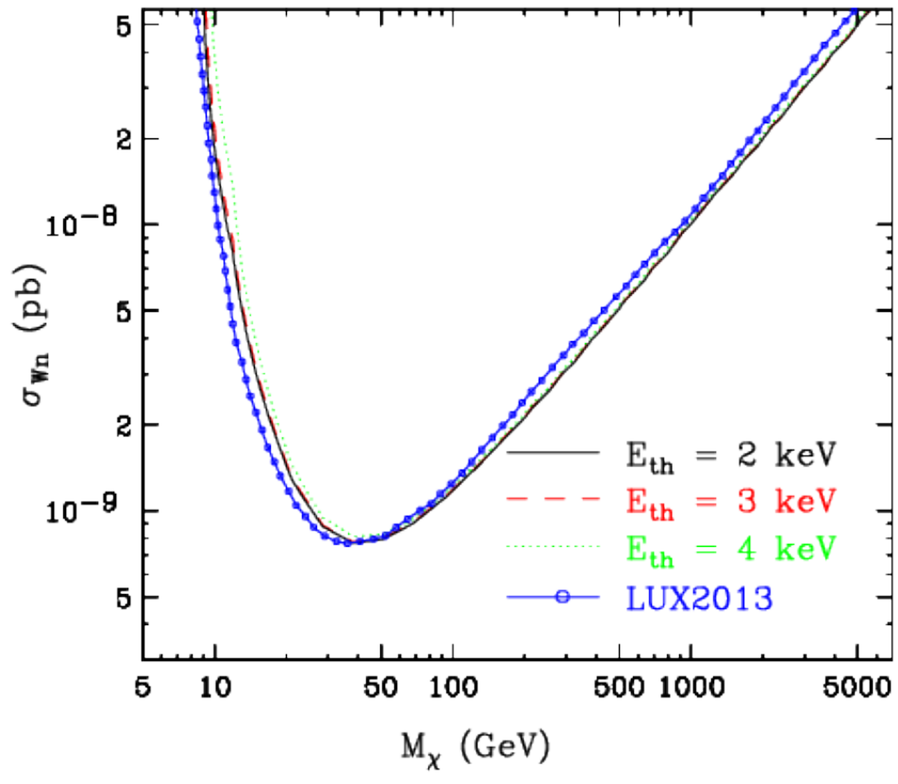
$$F(E,\theta) = \int F(E',\theta') \left(\frac{1}{\sigma_E \sqrt{2\pi}} e^{-\frac{(E-E')^2}{2\sigma_E^2}} \right) \left(\frac{1}{\sigma_\theta \sqrt{2\pi}} e^{-\frac{(\theta-\theta')^2}{2\sigma_\theta^2}} \right) dE' d\theta' \,,$$

Unsmeared distribution

Energy smearing

angular smearing

As a validation we reproduced the LUX exclusion (**calculation fully automated in MadDM**)



Manpower: **MadDM v.1.0**

M. Backovic
(Weizmann)

M. McCaskey

K.C. Kong
(U. of Kansas)

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Manpower: **MadDM v.2.0**

M. Backovic
(Weizmann)

A. Martini
(CP3 - Louvain-la-Neuve)

F. Maltoni
(CP3 - Louvain-la-Neuve)

Also, big thanks to Johan Alwall and Valentin Hirschi!

K.C. Kong
(U. of Kansas)

G. Mohlabang
(U. of Kansas)

Olivier Mattelaer (Durham)

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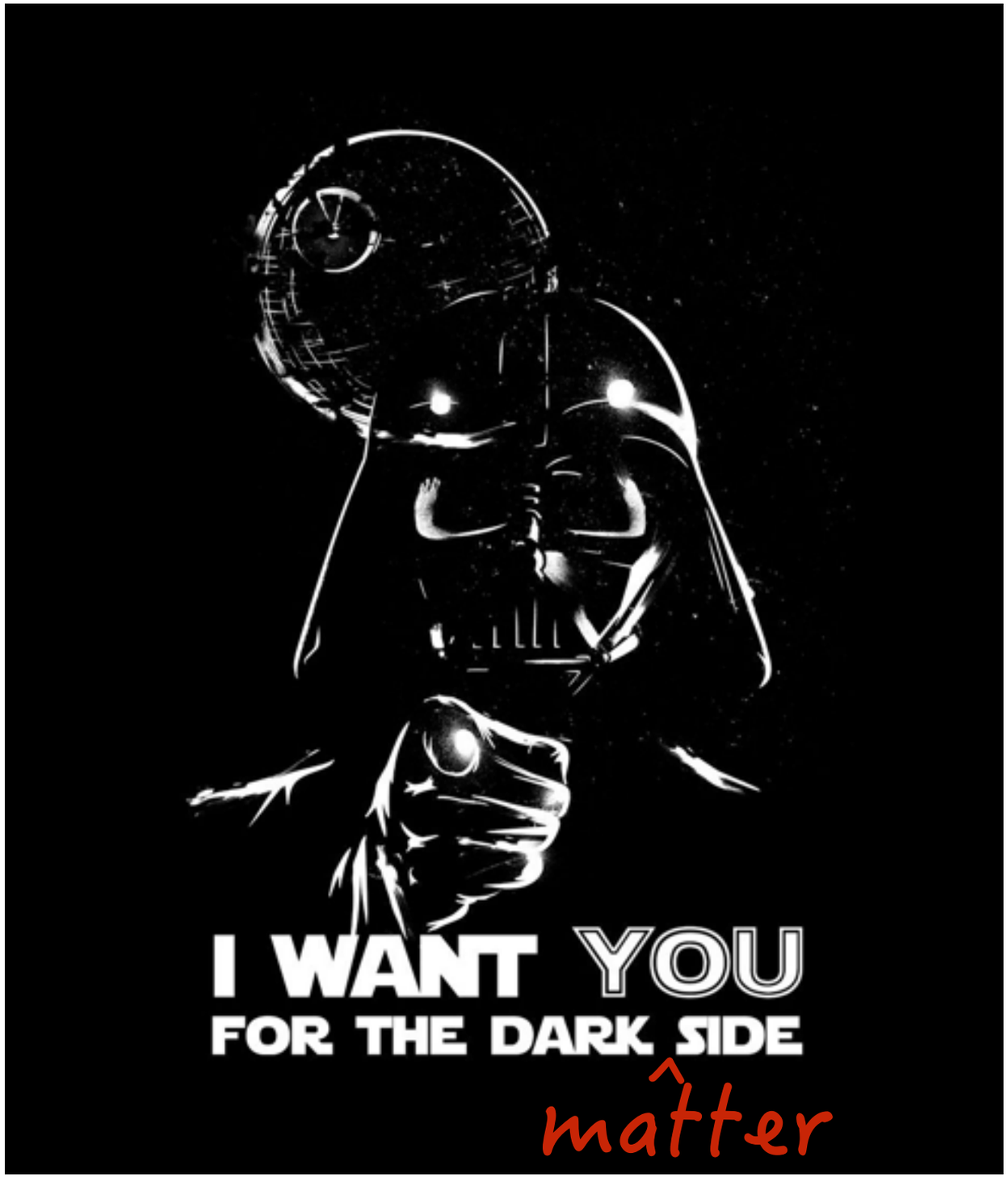
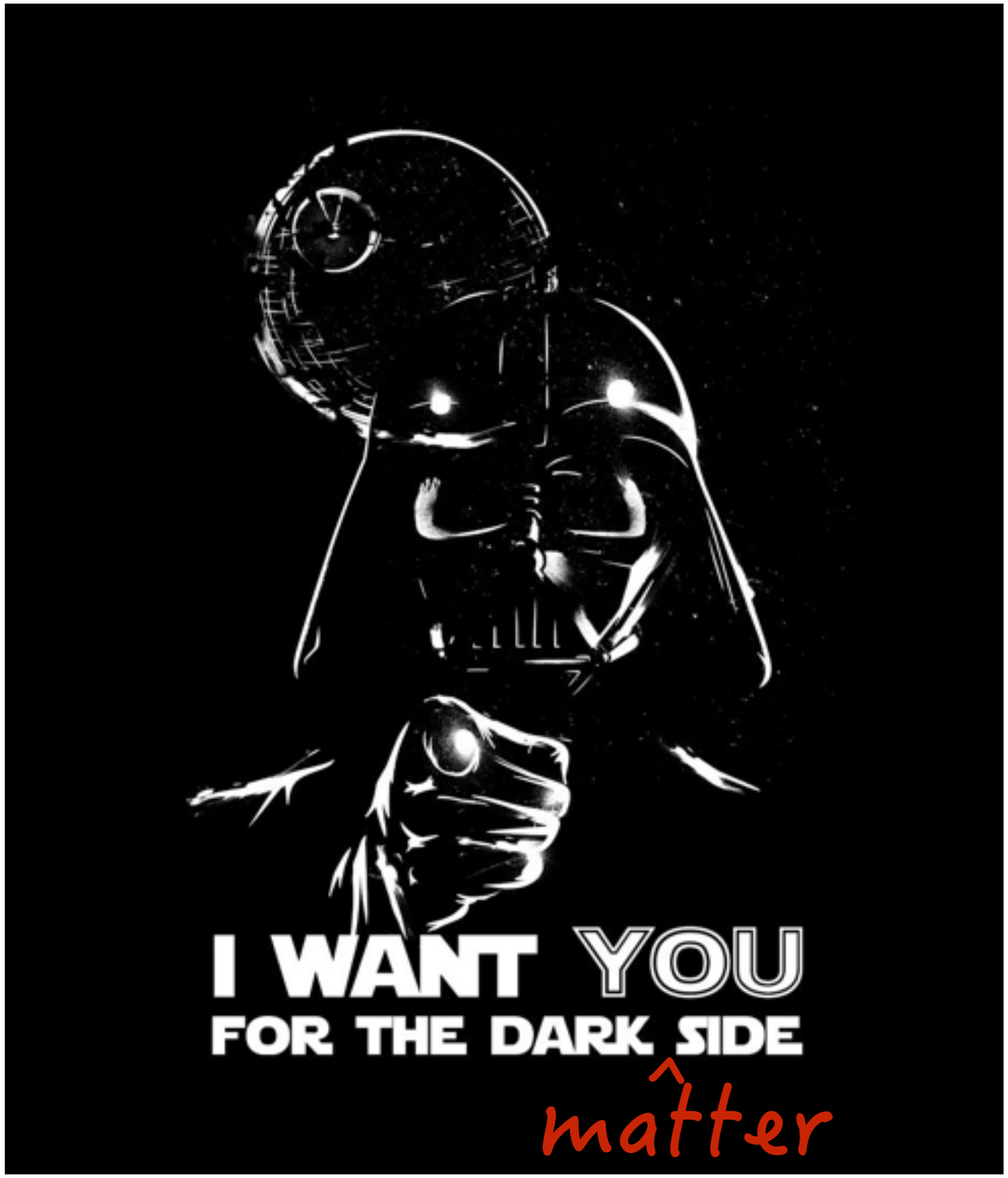


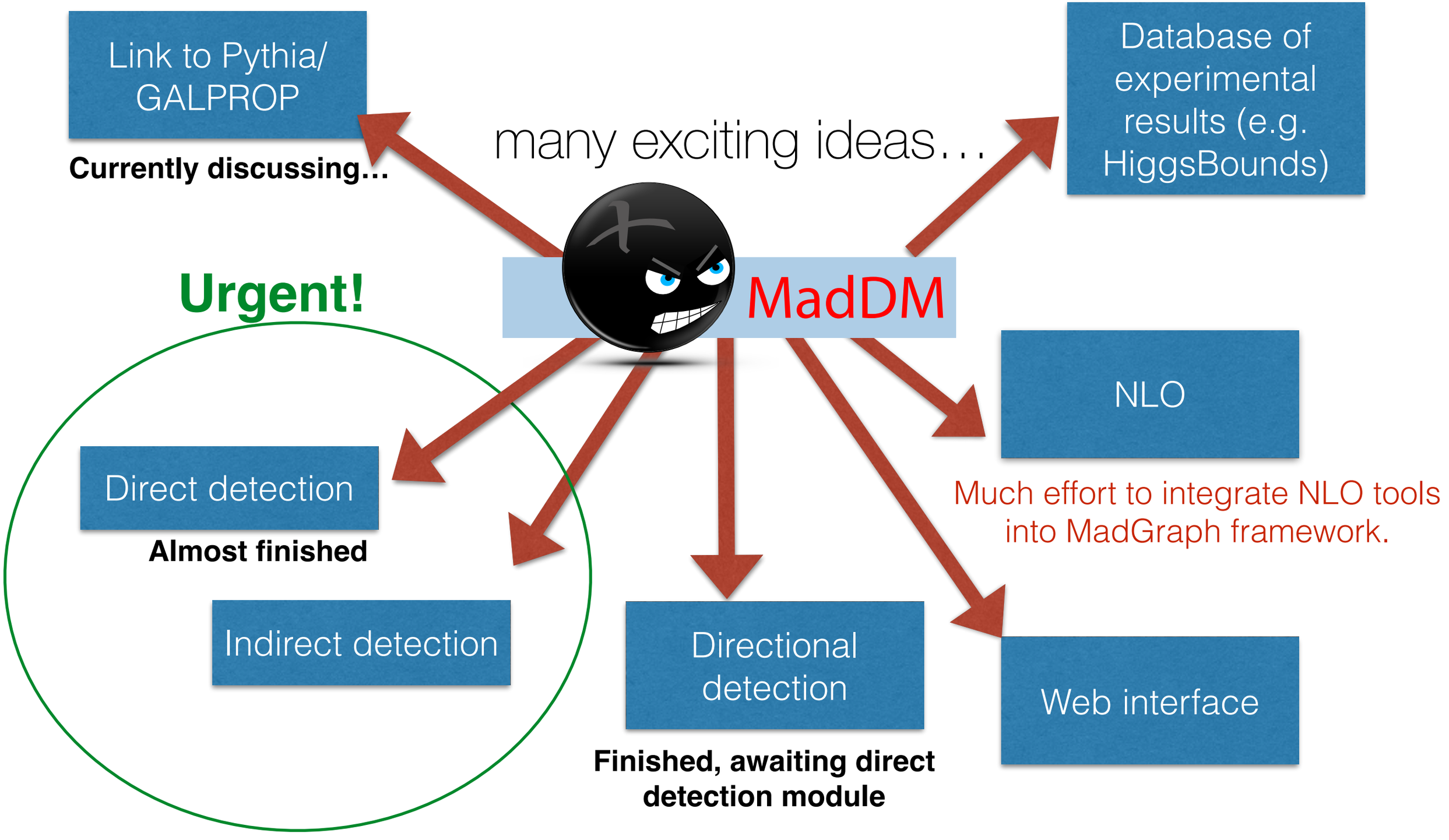
Help us build the best DM phenomenology tool!



Not convinced yet?!

How about now?!

Status exactly 1 year ago:



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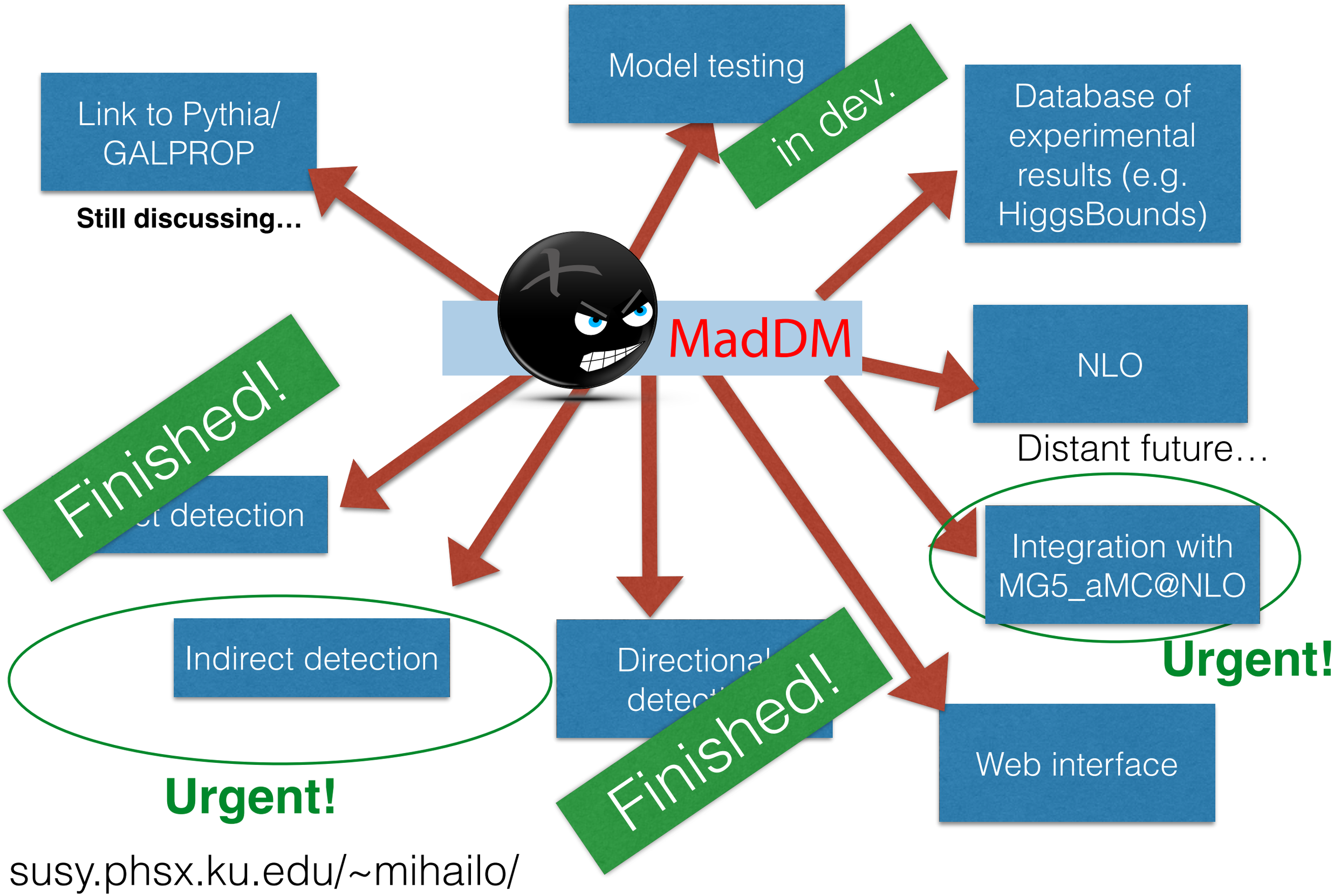
Status Now:



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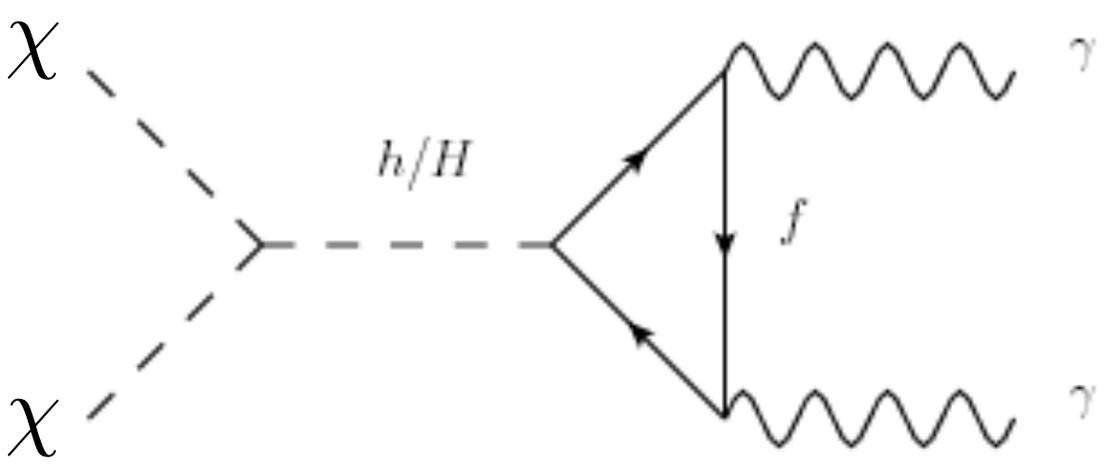
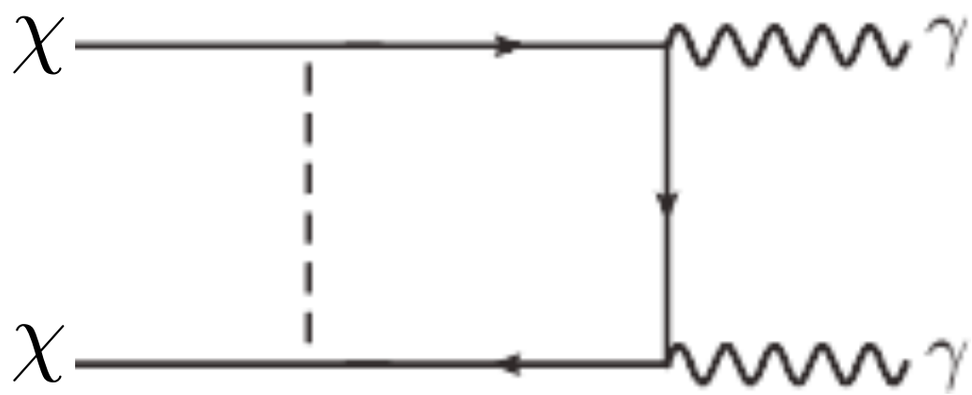
Near future plan: **indirect detection**

MG5_aMC@NLO can calculate amplitudes for loop induced processes.

- We want to exploit this and **build the first publicly available tool which will be able to calculate cosmic ray fluxes in loop induced processes in an arbitrary UFO model.**





Stay tuned!

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Testing of model points (**in development**):

MadDM v.2.0 also incorporates a **simplified model testing functionality**:

The user can **compare the results to existing constraints** (relic density, direct detection cross section etc.)

Example output:

```
-------------------------------------------------------
Running the exclusion analysis on the parameter point...
Considering relic density and bound on SI cross section from LUX

      The parameter point is Excluded.
                Excluded by relic density: True
                Excluded by direct detection: False
-------------------------------------------------------
```

The ultimate goal is to **confront DM models** with collider, astro physical and cosmological constraints in a fully automated framework!

Needs a lot of improvement!
(**maybe integrate with MadAnalysis?!**)

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MadDM

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Thank you!

Any (**constructive**) suggestions, comments,
and criticisms are welcome!

A beta version of MadDM available for download at:

launchpad.net/maddm