MadDM

V.2.0

Dark Matter Phenomenology in the MG5_aMC@NLO framework

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with
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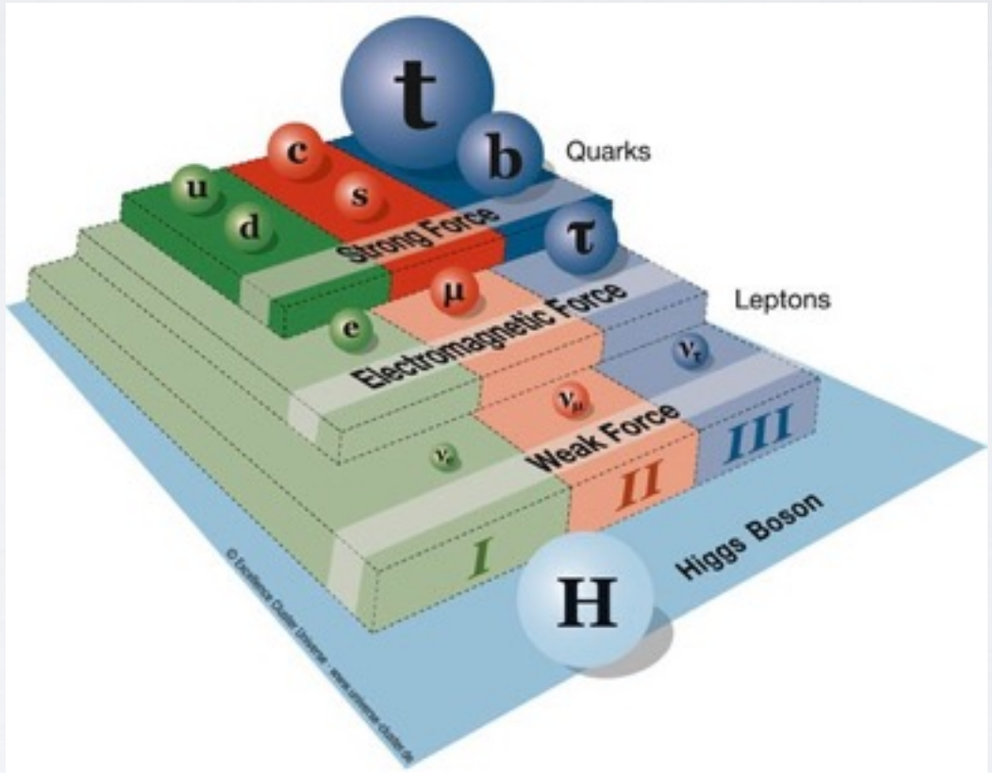
arXiv:1505.04190

BSM Physics in LHC era

- Standard Model has been very successful in explaining observed particle physics phenomena.

Some deficiencies:

- ★ Baryogenesis.
- ★ Leptogenesis.
- ★ Neutrino Masses.
- ★ Dark Matter.
- ★ Dark Energy.



- DM is very well motivated for New Physics beyond SM.

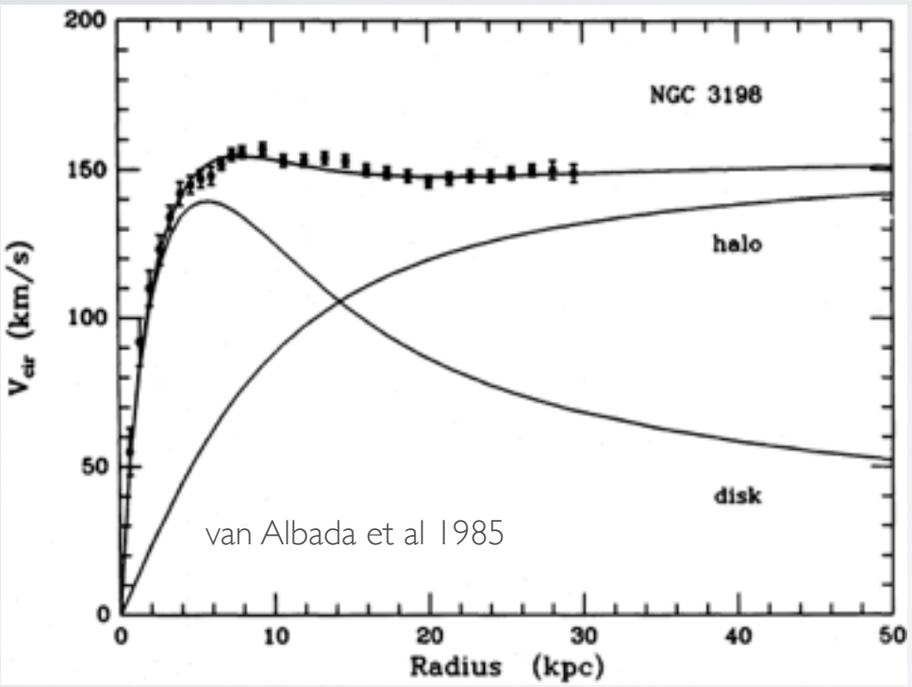
Why?

Many intriguing and undeniable hints that DM exists

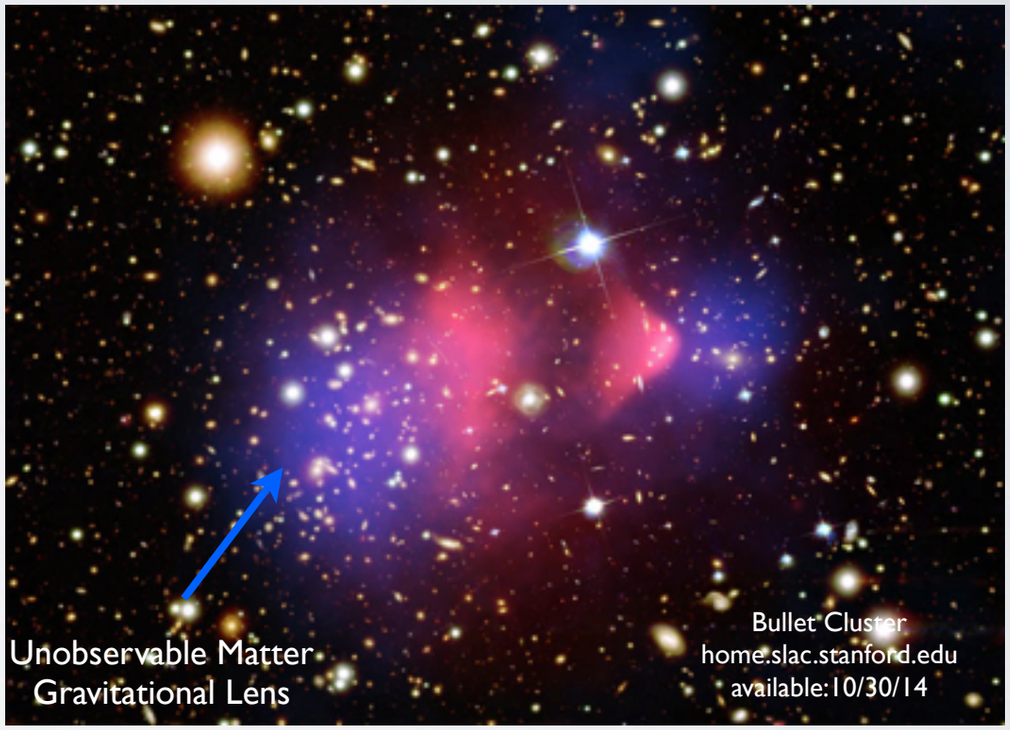
DARK MATTER

Evidence From Astrophysics and Cosmology

Rotational velocities of spiral galaxies

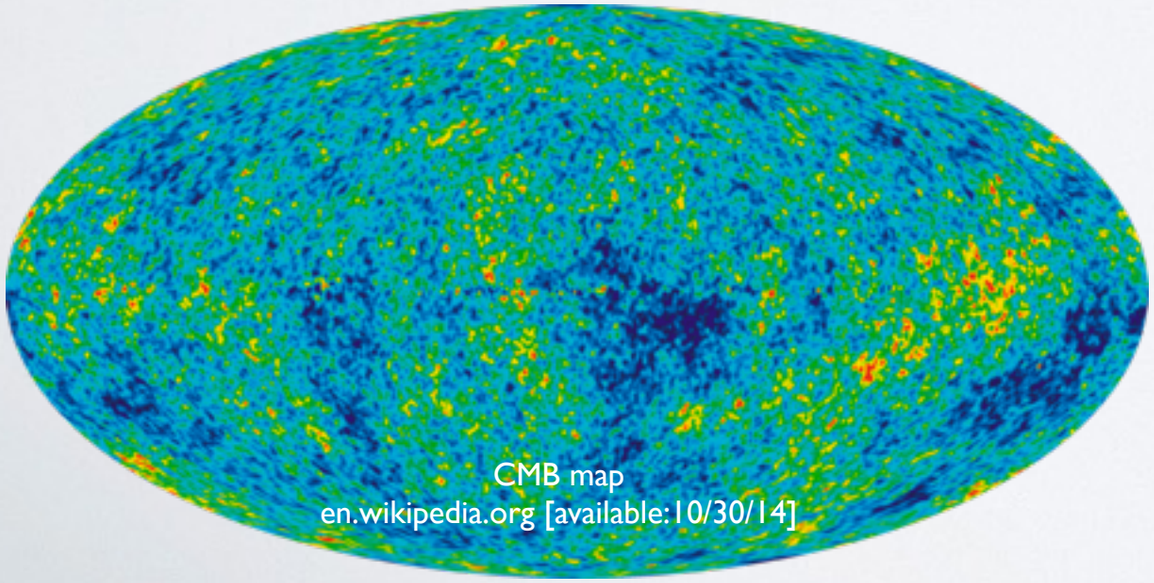


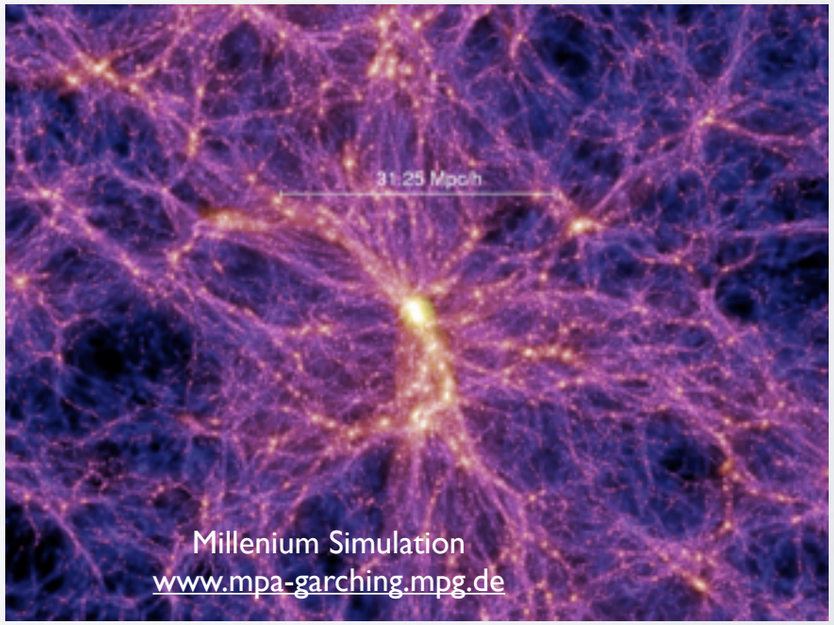
van Albada et al 1985



Gravitational Lensing

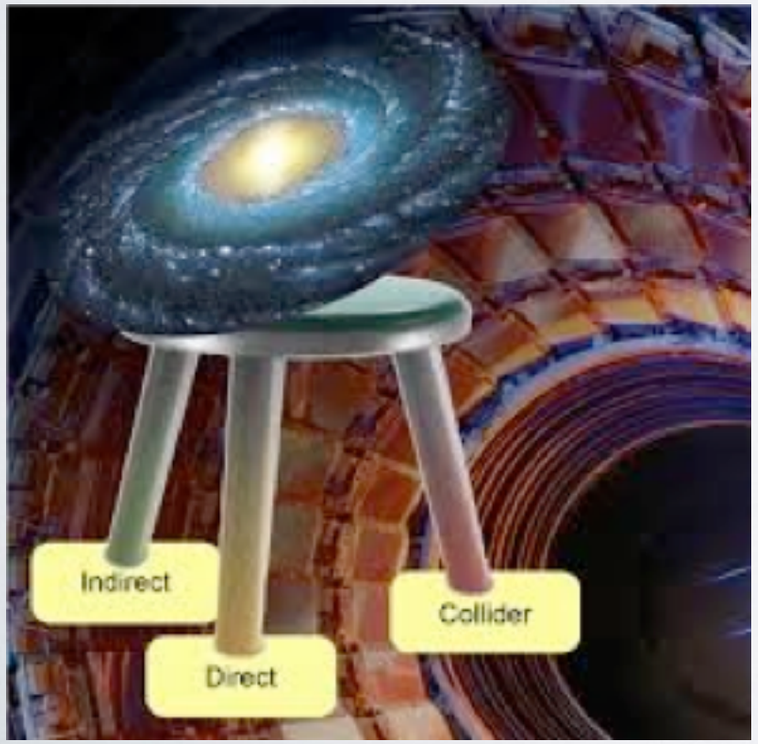
Velocity dispersions, CMB maps, N-body simulations

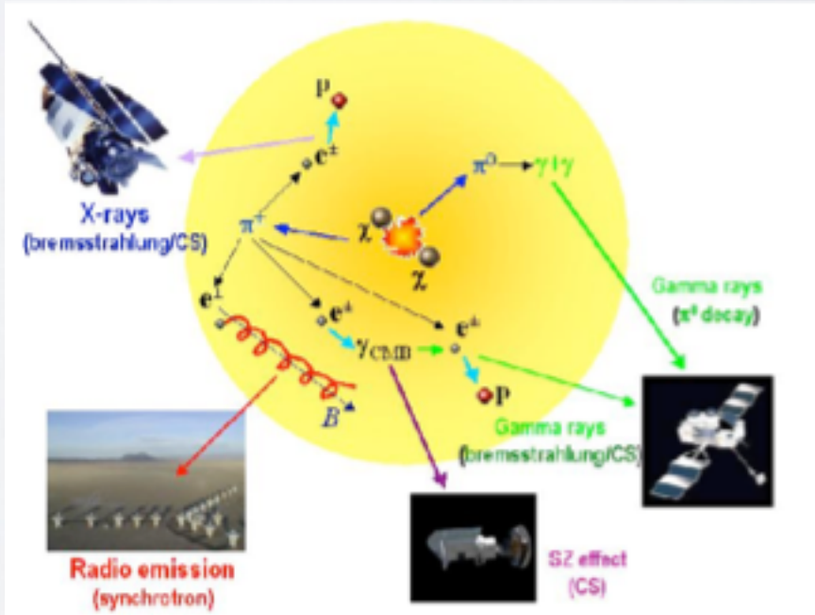




- Nature of DM **remains unknown**.
- Physicists devised strategies to find DM.
  - Astrophysical and Cosmological information.
  - Indirect detection
  - Direct detection
  - Collider signatures

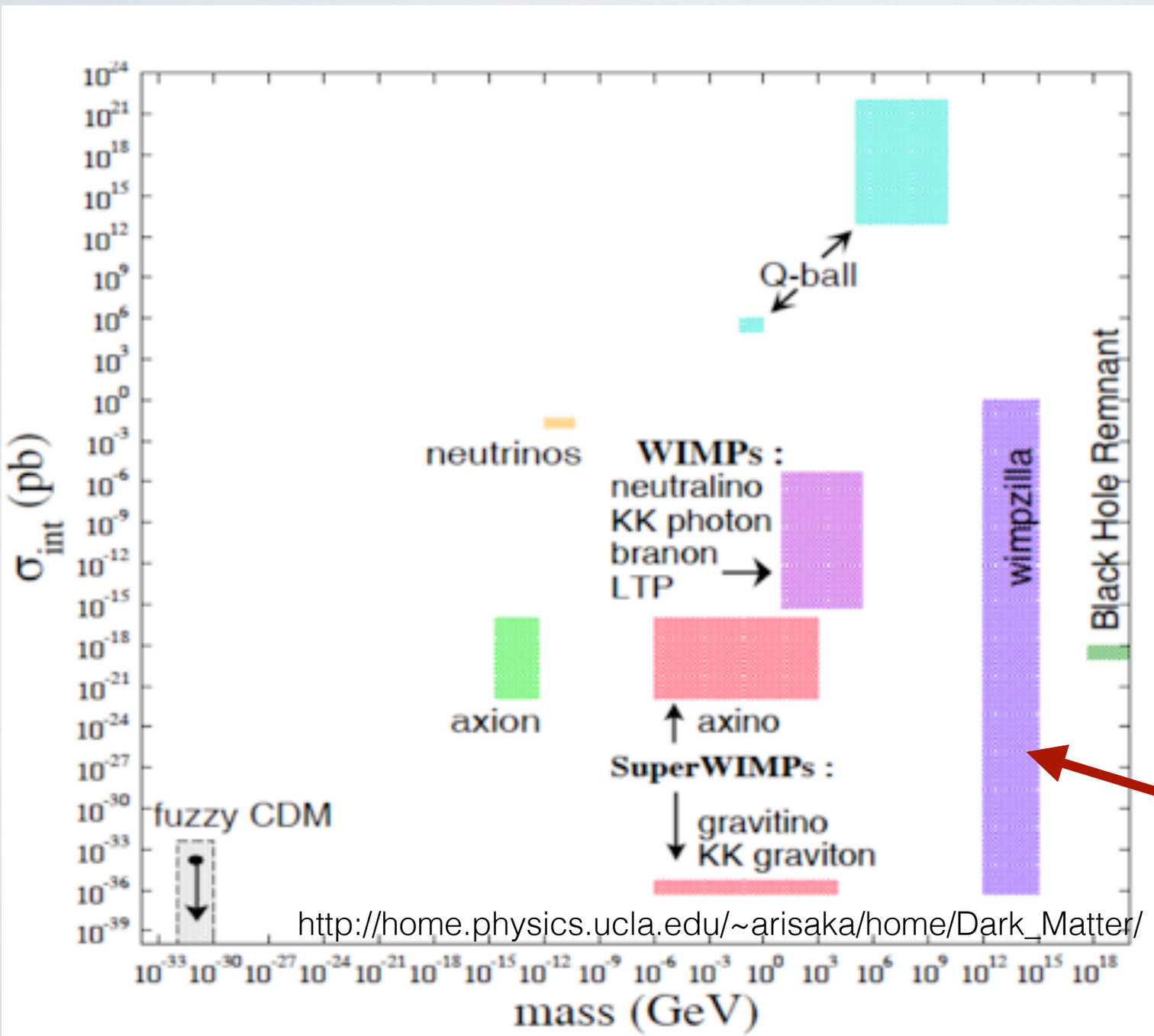
All Complementary

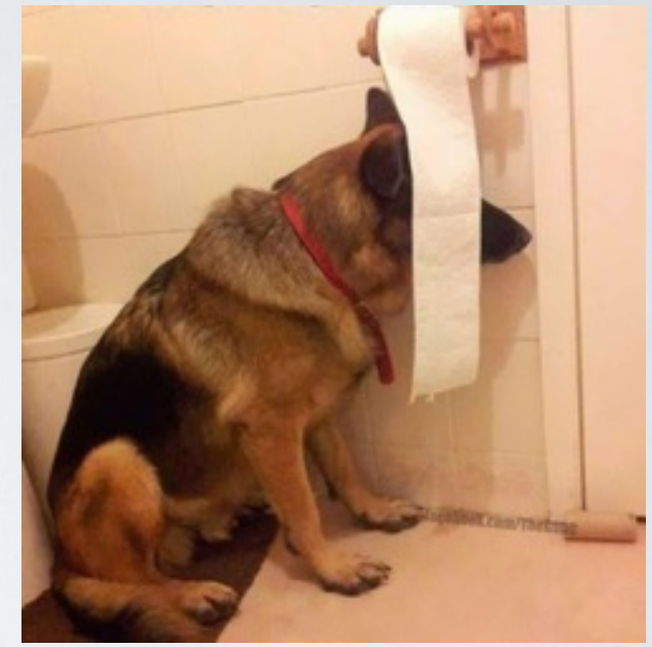




Dark Matter Complementarity

- We have no sense of where new physics is hiding



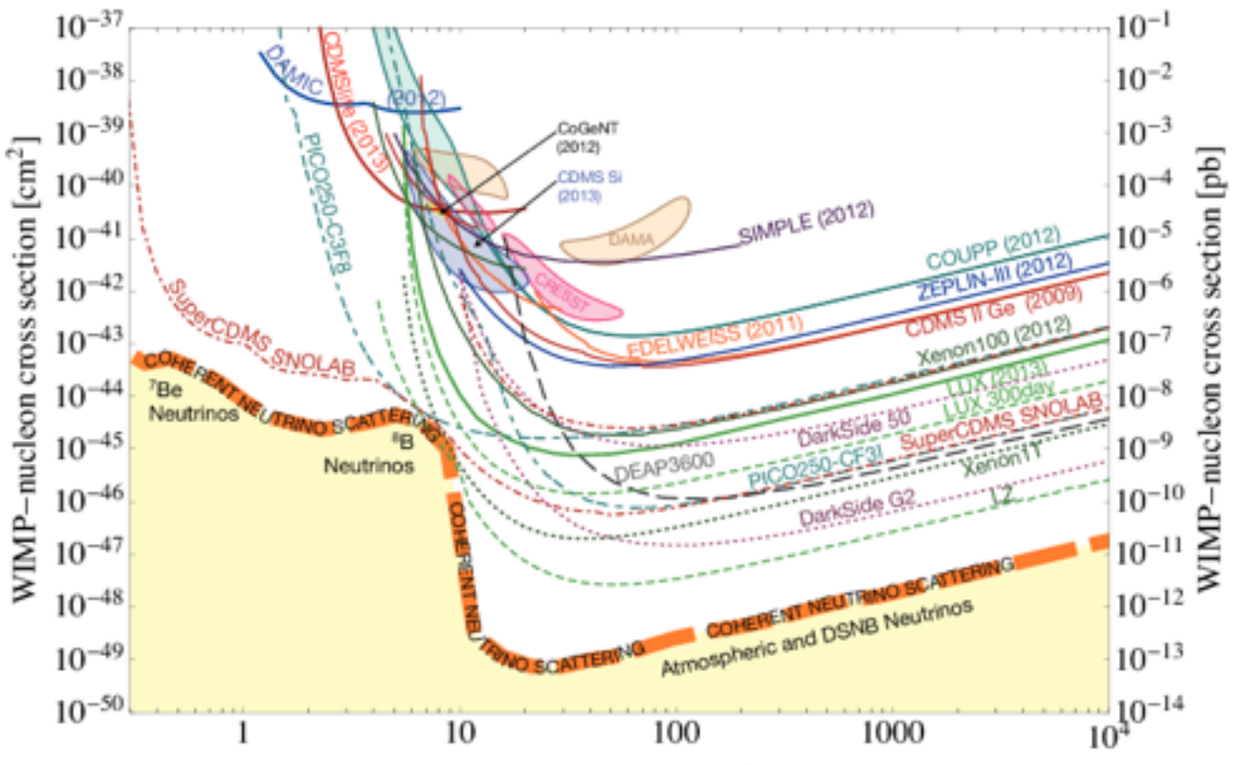


DM models alone span many orders of magnitude in energy scales

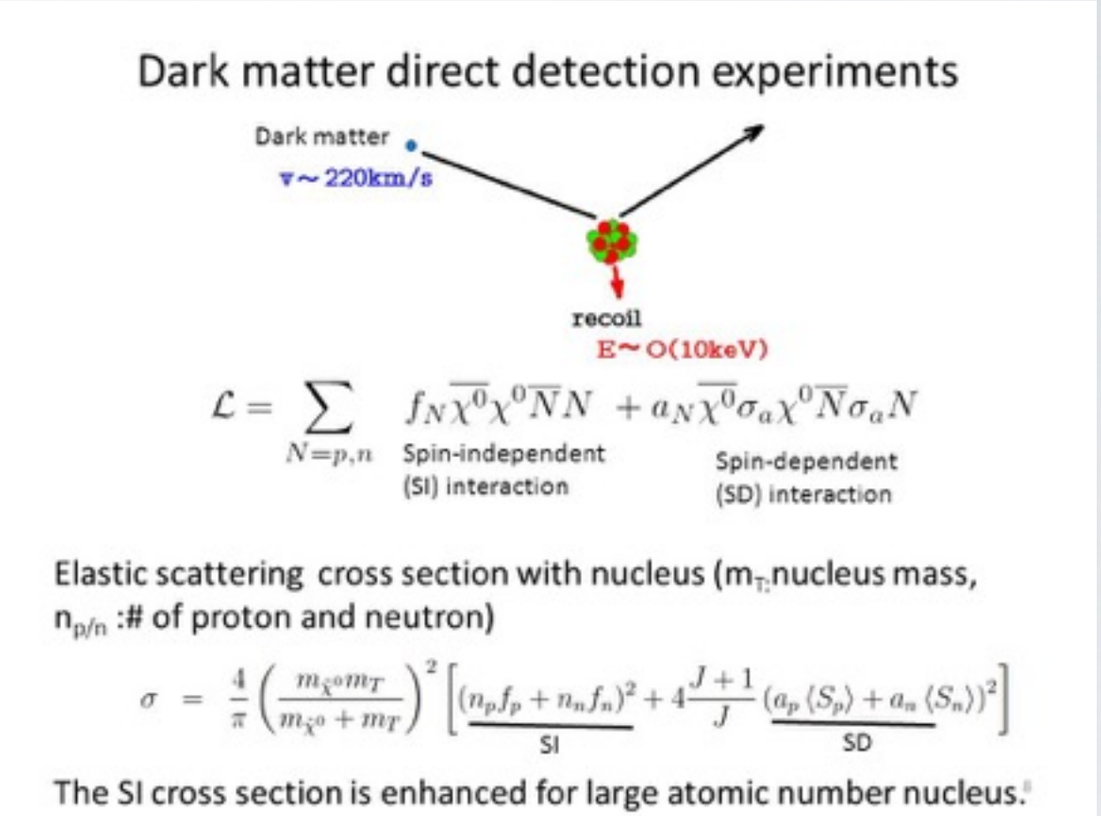
Dark Matter Complementarity

- Direct detection experiments have placed constraints on DM scattering off nuclei.

Mostly sensitive to EW scale



Phys.Dark Univ. 4 (2014) 92-97



Based on arXiv: 1504.00915v1

- LHC experiments can probe different scales.

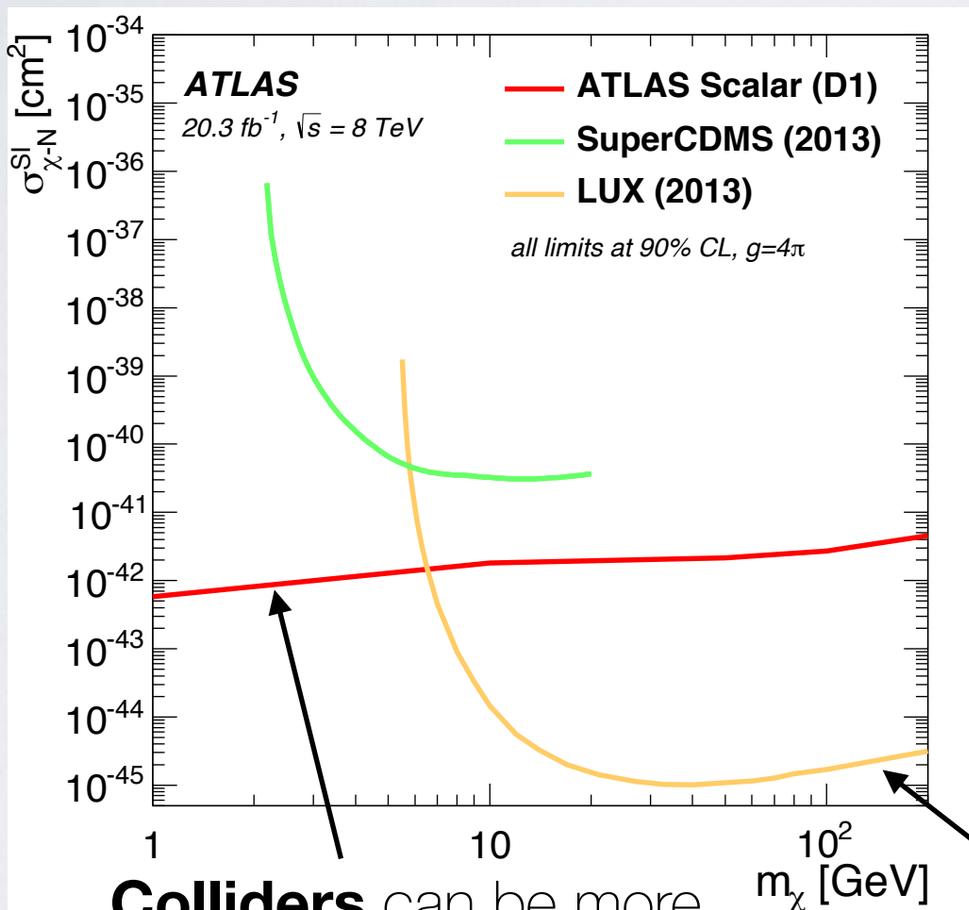
Dark Matter Complementarity

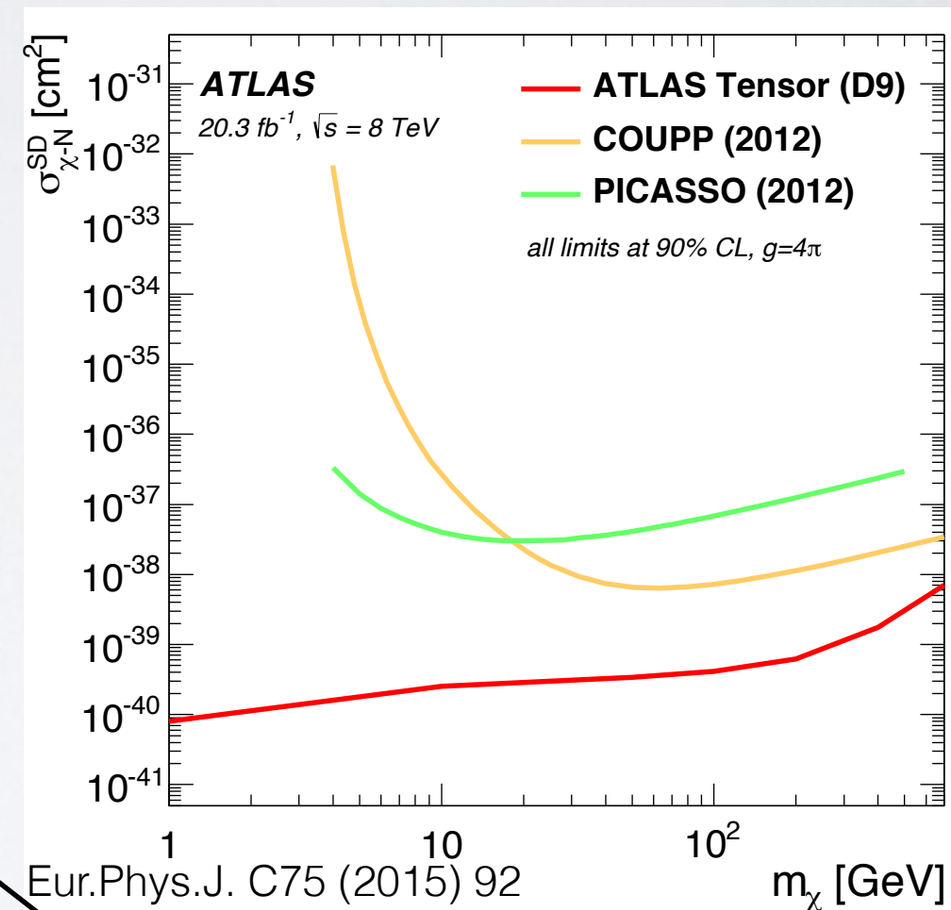
- Recently LHC Analysis provided complementary information to underground experiments.

ATLAS DM searches in effective theory approach

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

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





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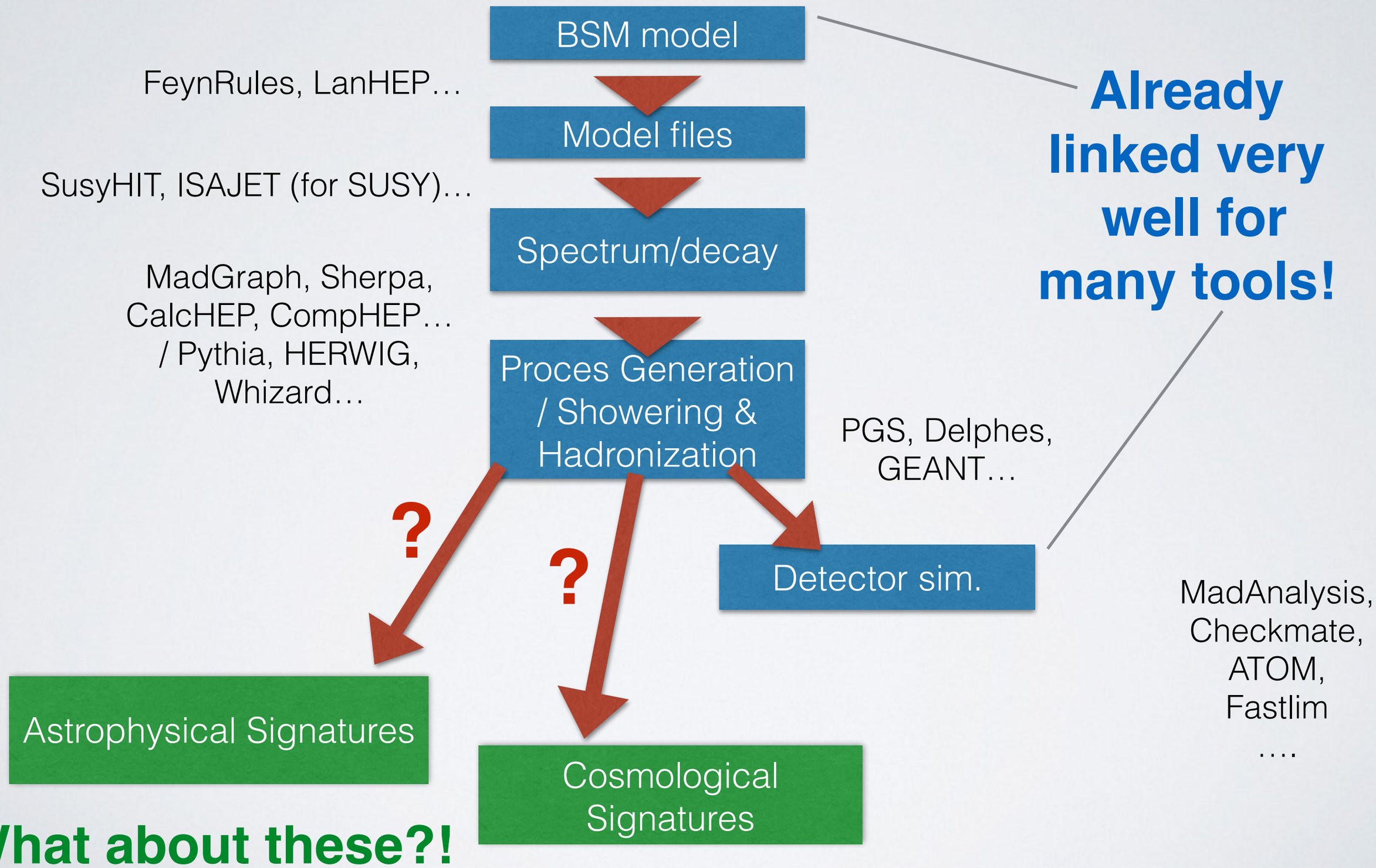
Colliders can be more sensitive to low mass DM

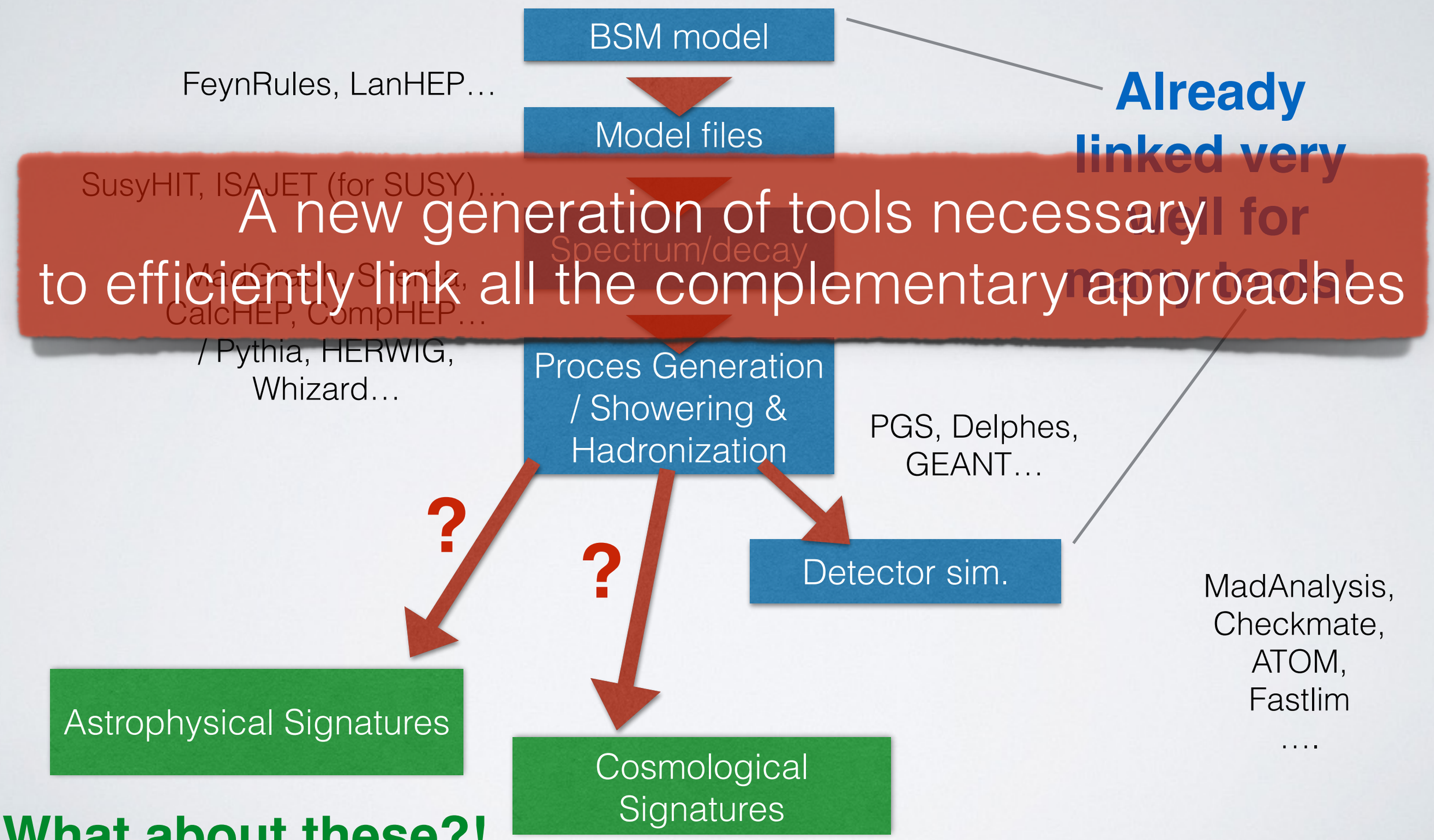
Direct detection provides better limit in "high mass" regime

Complementarity studies require powerful simulation tools

BSM tools in LHC era



BSM tools in LHC era



MadDM

MadDM emerged as an effort to link:

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

Goal is to allow both **Experimentalists** and **Theorists** to calculate signatures of DM models at all interfaces with click of a button.

User friendly architecture of **MadGraph_aMC@NLO** provides ideal framework for MadDM development.

MadDM

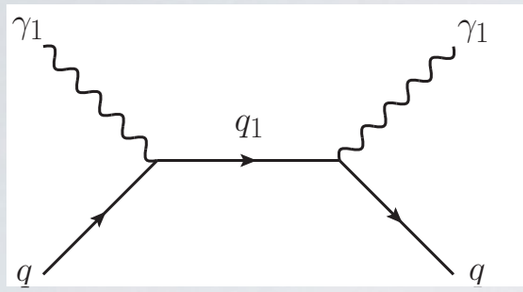
MadDM emerged as an effort to link:

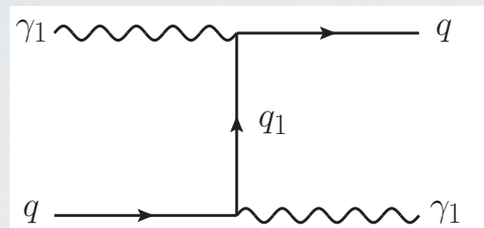
- **DM collider searches**, with
- **early cosmology** signatures (relic density) and
- **direct/indirect detection**.

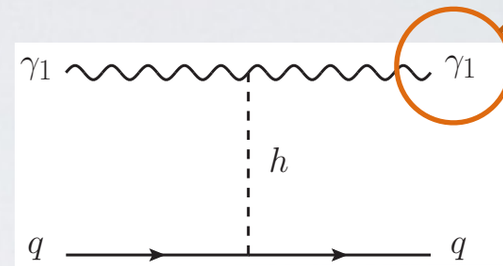
Version 1.0 of MadDM focused on calculations of **DM relic density** (in a generic UFO model).

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

Validations (mUED):



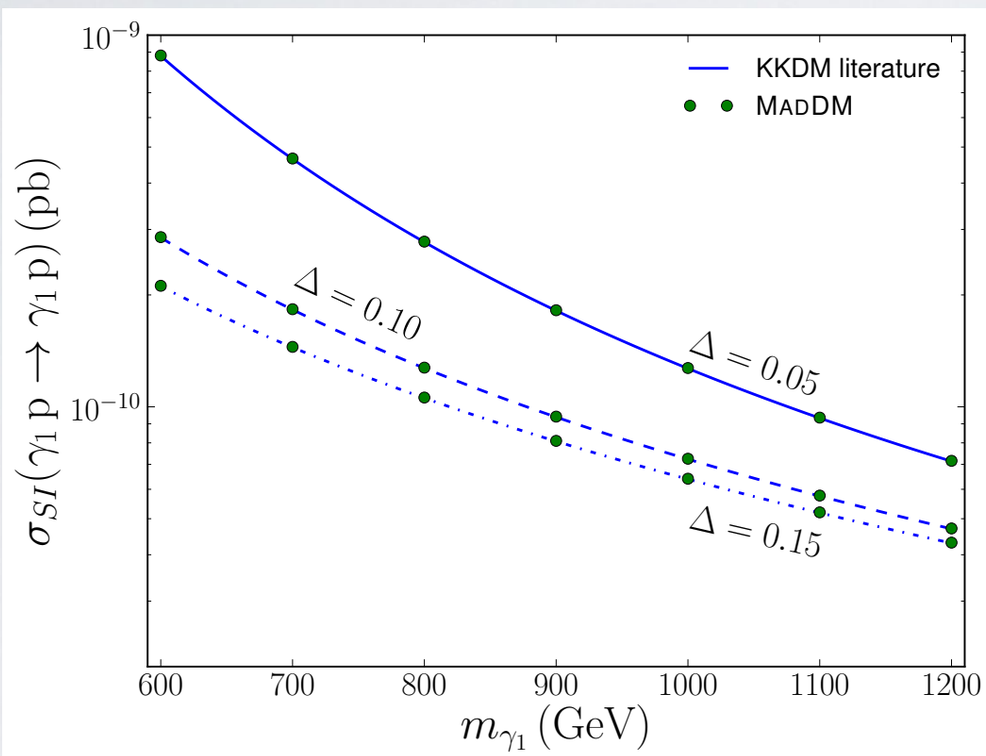


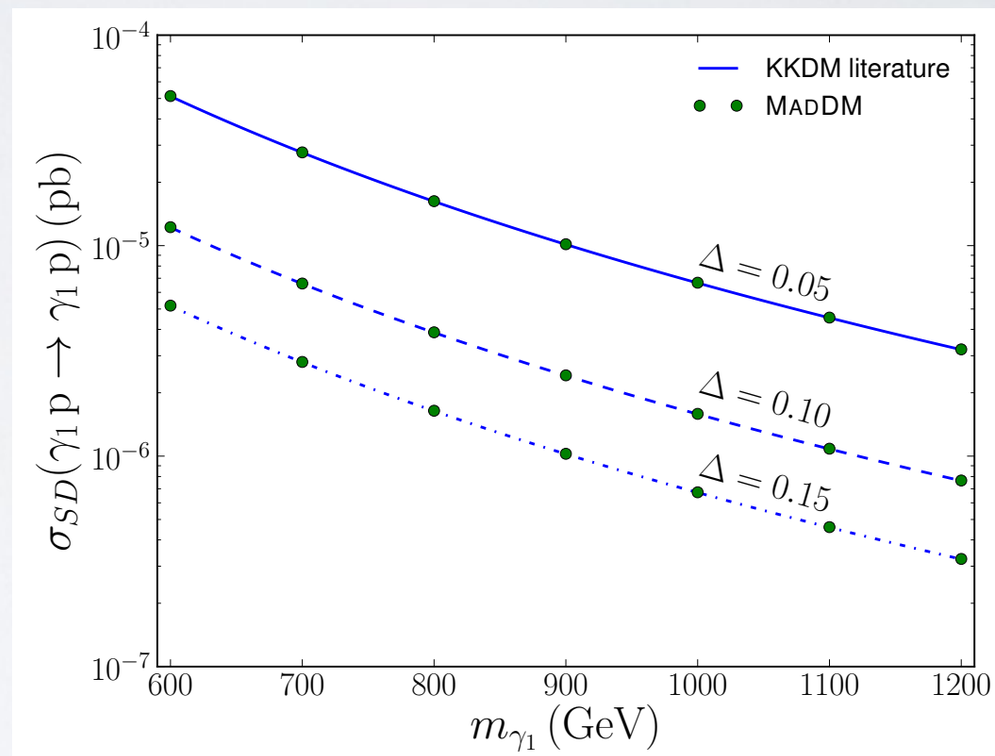


KK photon

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

Arrenberg et al, arXiv:1307.6581



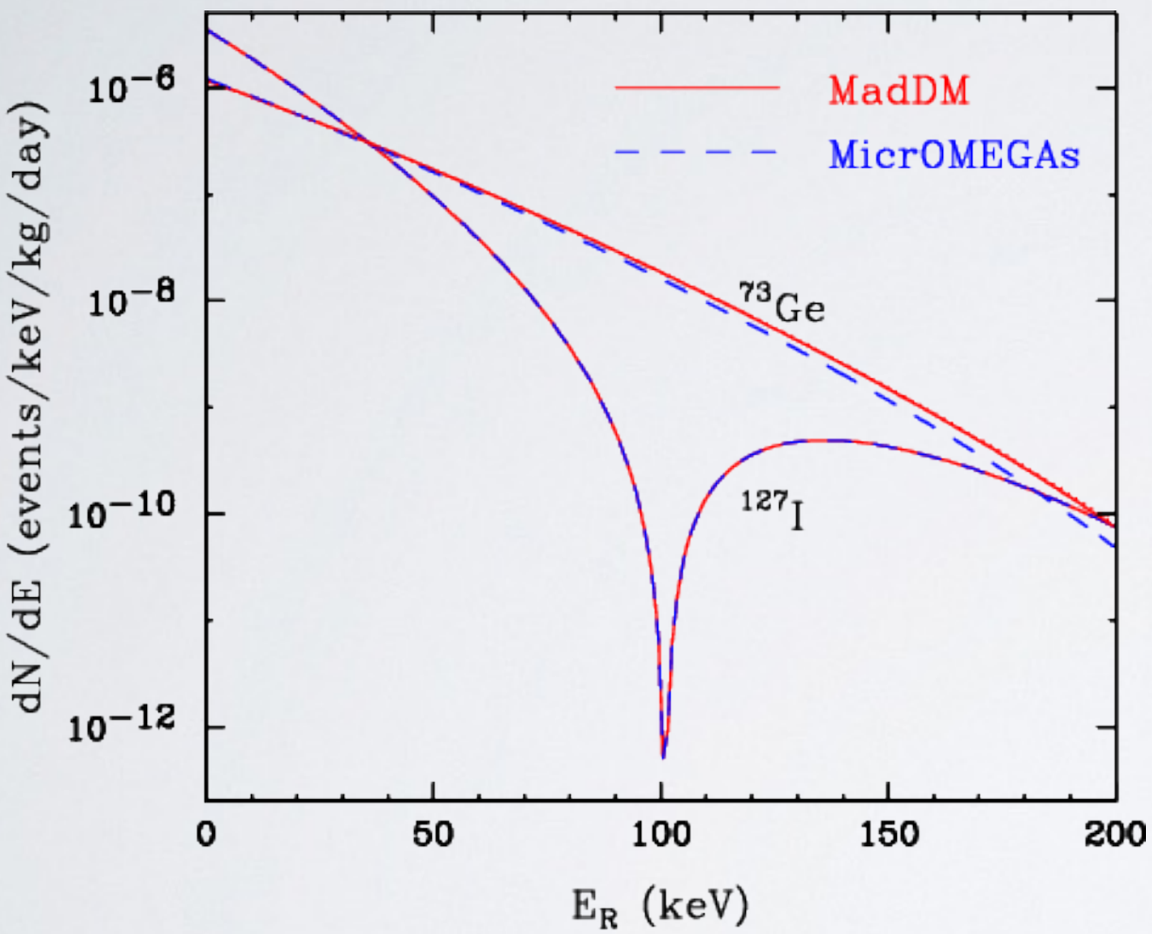


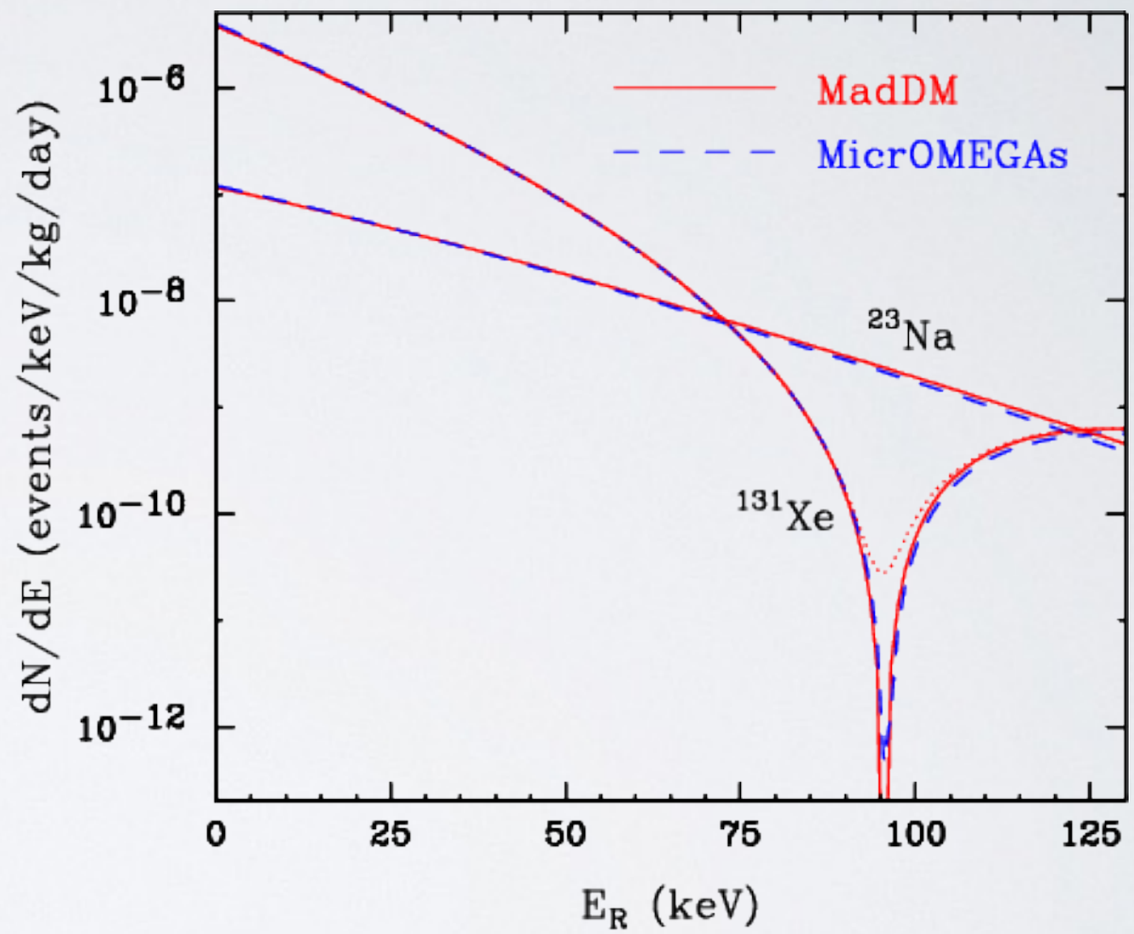
Excellent agreement between MadDM and literature!

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

Validations (Higgs portal, scalar DM)

We find good agreement in recoil rates with micrOMEGAs.





Assuming a 1pb DM-nucleon scattering cross section

Testing of model points

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
-----------------------------------------------------
```

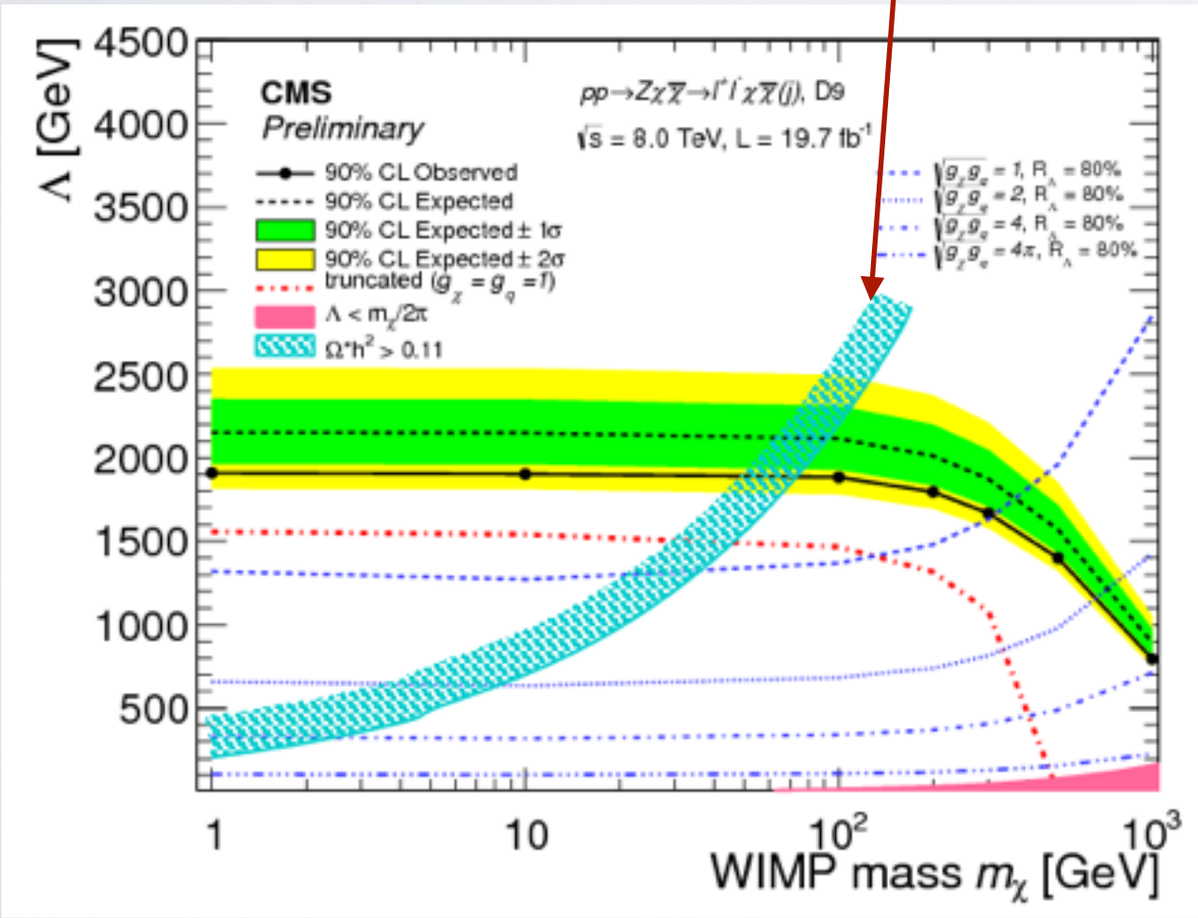
The ultimate goal is to **confront DM models** with collider, astro physical and cosmological constraints in a fully automated framework!

i.e. we would like to have **Collider bounds** together with **Astrophysical** and **Cosmological** signatures.

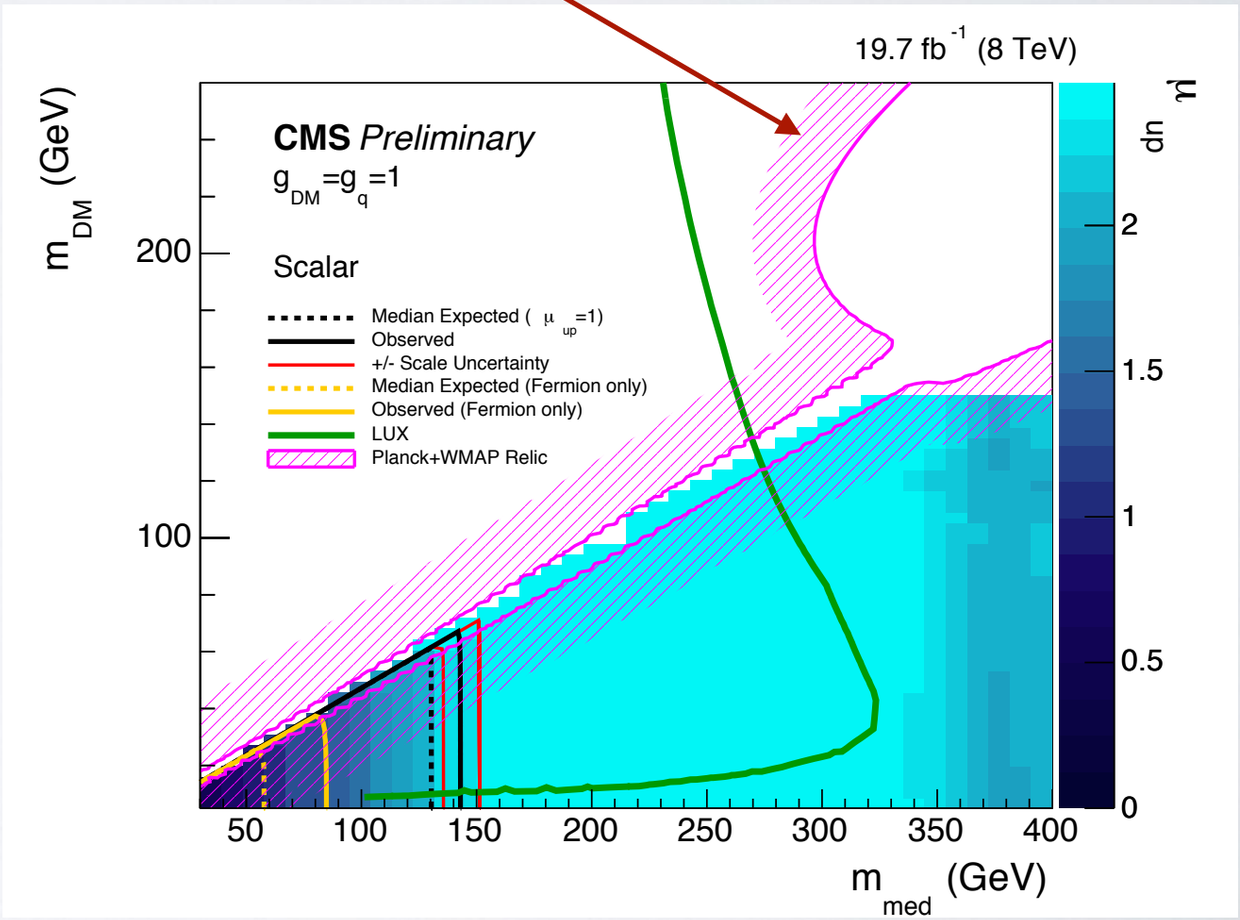
- MadDM has already been used by the CMS experiment,

  in the search for DM EFT's in Mono-jet/Z analyses

Relic Density using MadDM



CMS collaboration 2015: CMS-PAS-EXO-12-054



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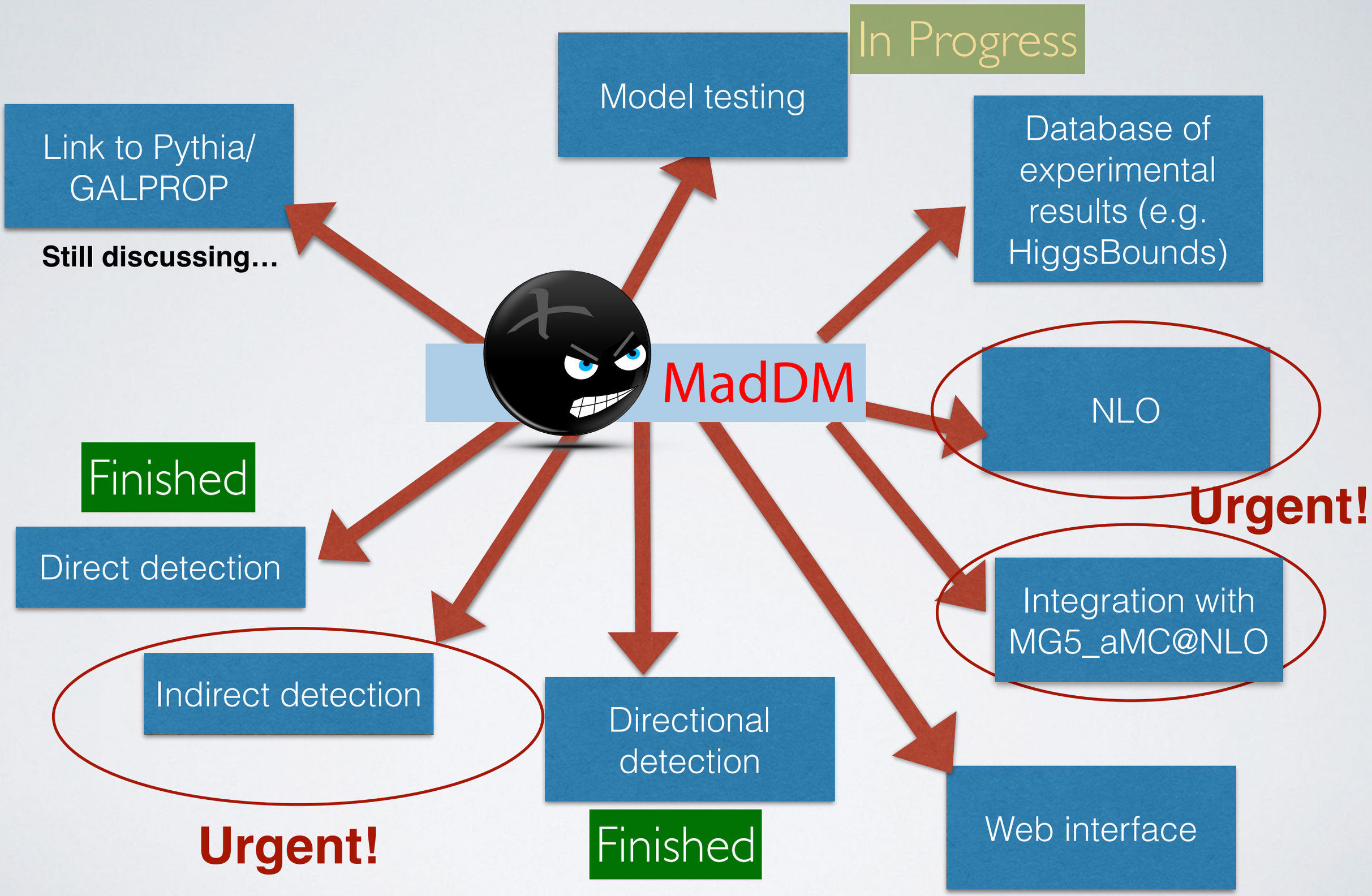
MadDM Status



MadDM V3.0

- 2->N annihilation, linking to MadEvent.
- Gamma-ray, positron fluxes, DM density profiles.
- Galactic propagation (link to Pythia/Galprop) & halo models
- Loop induced DM annihilations to photons/electrons/neutrinos.
- Loops for collider and direct detection studies.

  eg. Higgs Portal models
- Multicomponent DM: Semi annihilations, Assisted Freeze-out.
- Output in html form just as in current MG5.

Indirect detection

Link to MG5_aMC @NLO

MadDM V3.0

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Indirect detection

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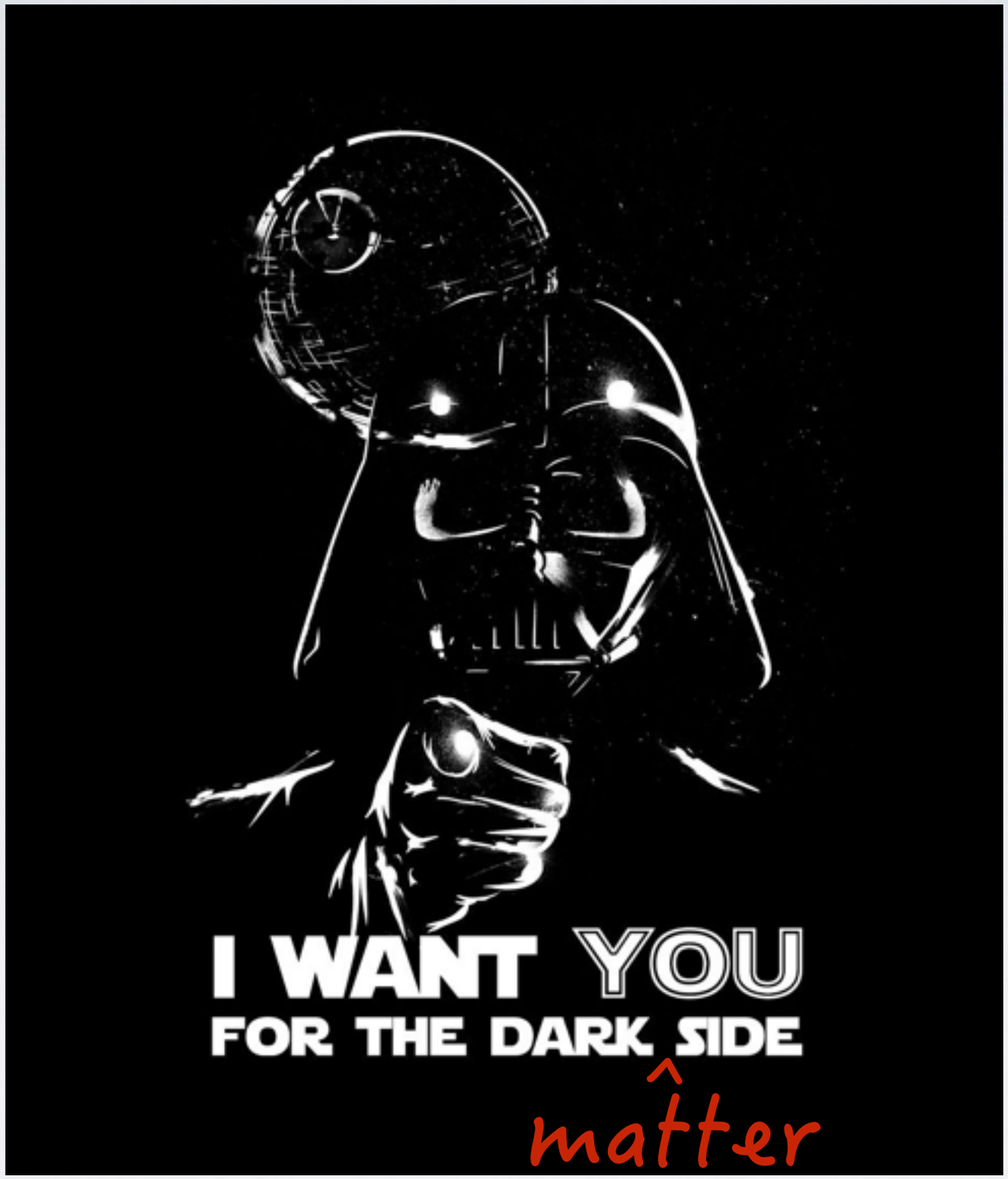


Help us build the best DM phenomenology tool!

Not convinced yet?

How about now?!

MadDM

susy.phsx.ku.edu/~mihailo/

Thank you!

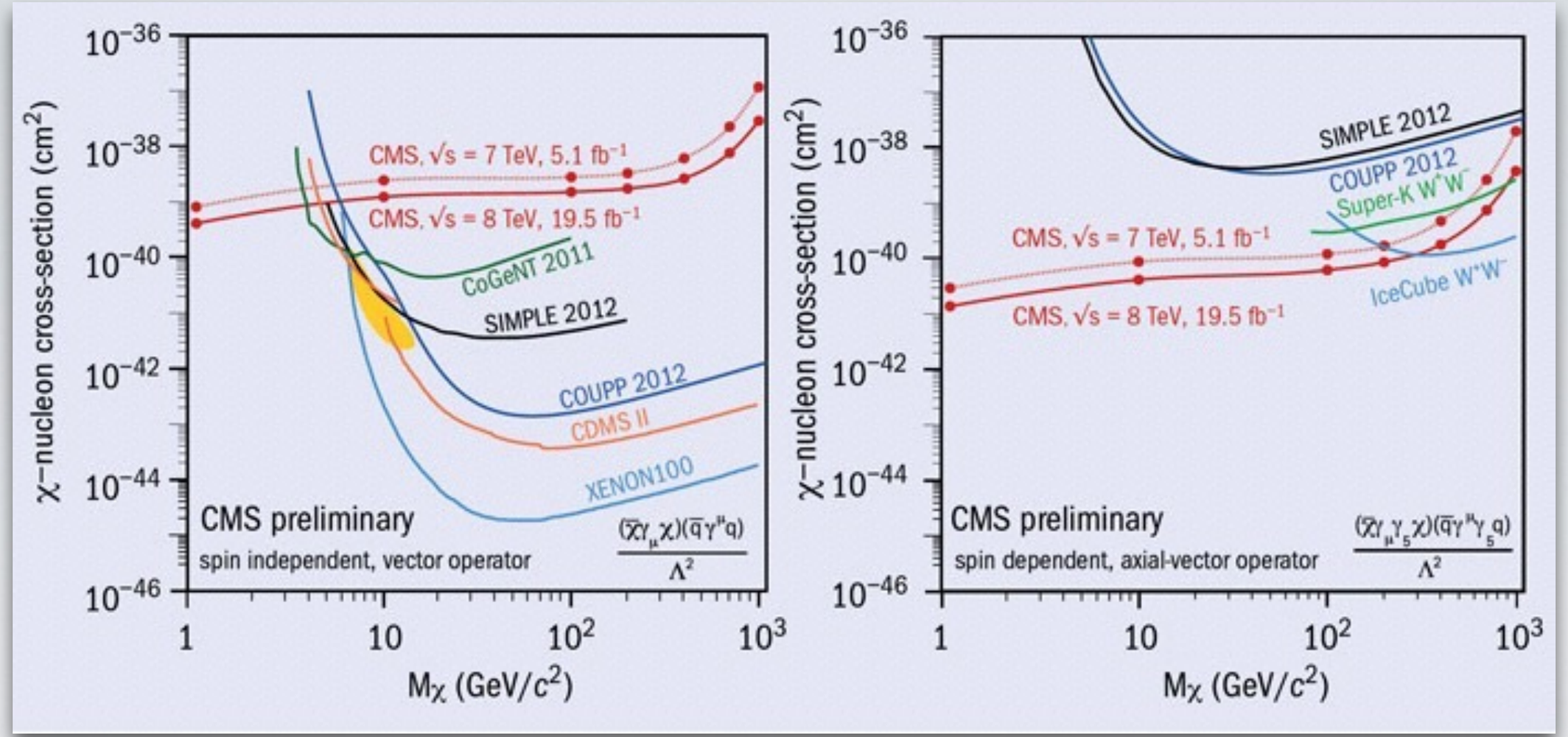
Any (**constructive**) suggestions, comments,
and criticisms are welcome!

A beta version of MadDM available for download at:

launchpad.net/maddm

BACK UP

From CMS

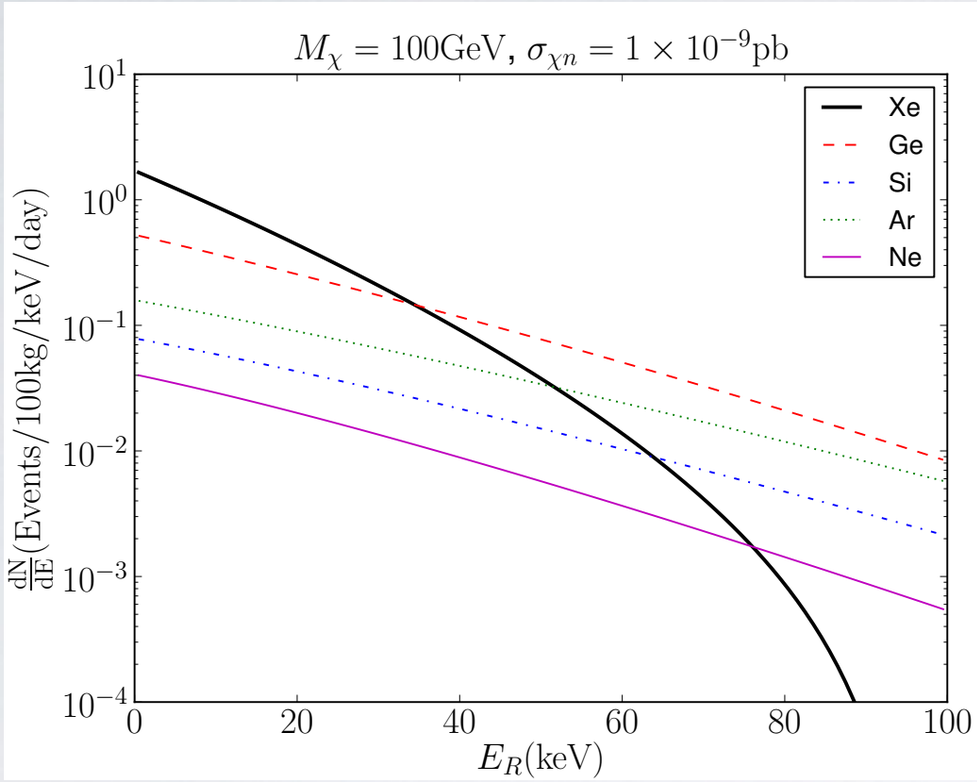


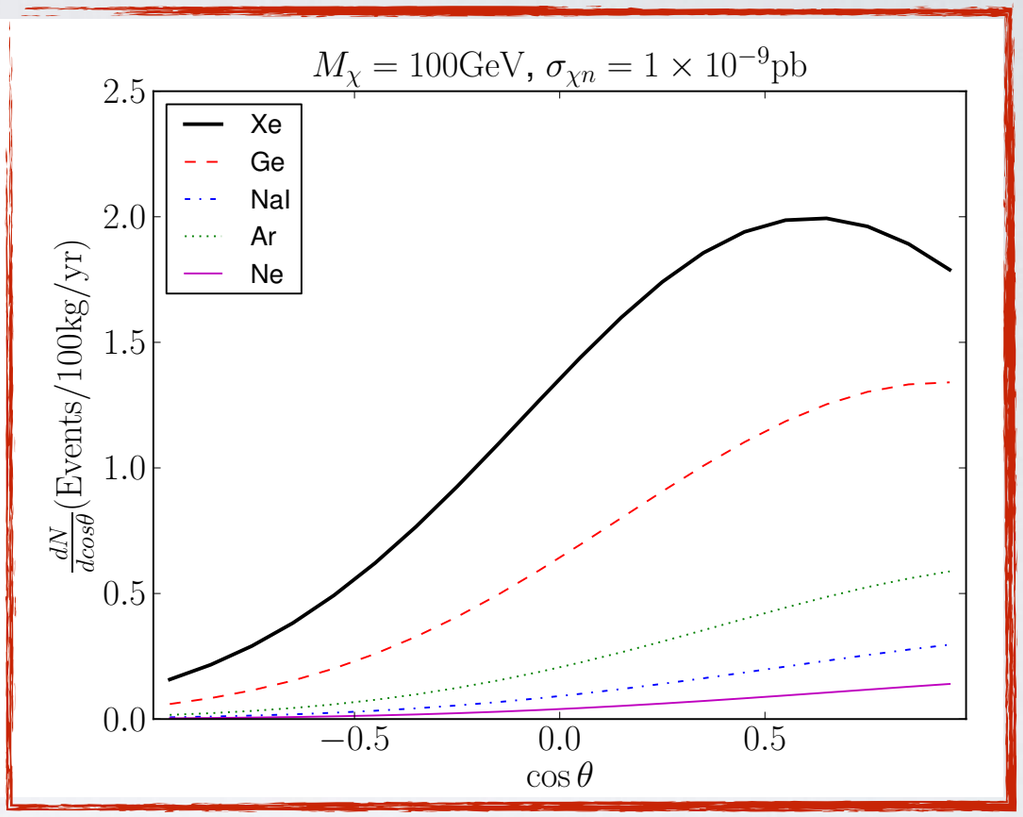
CMS-PAS-EXO-12-048

- Searching for DM at interface of collider physics, astroparticle physics and cosmology might be best path to discovery and distinguishing DM scenarios.

- Requires large amount of computational power and relevant simulation tools.

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!

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**)