Dark Matter Tools
for collider and non-collider experiments

Alexander Belyaev

NExT

Southampton University & Rutherford Appleton LAB

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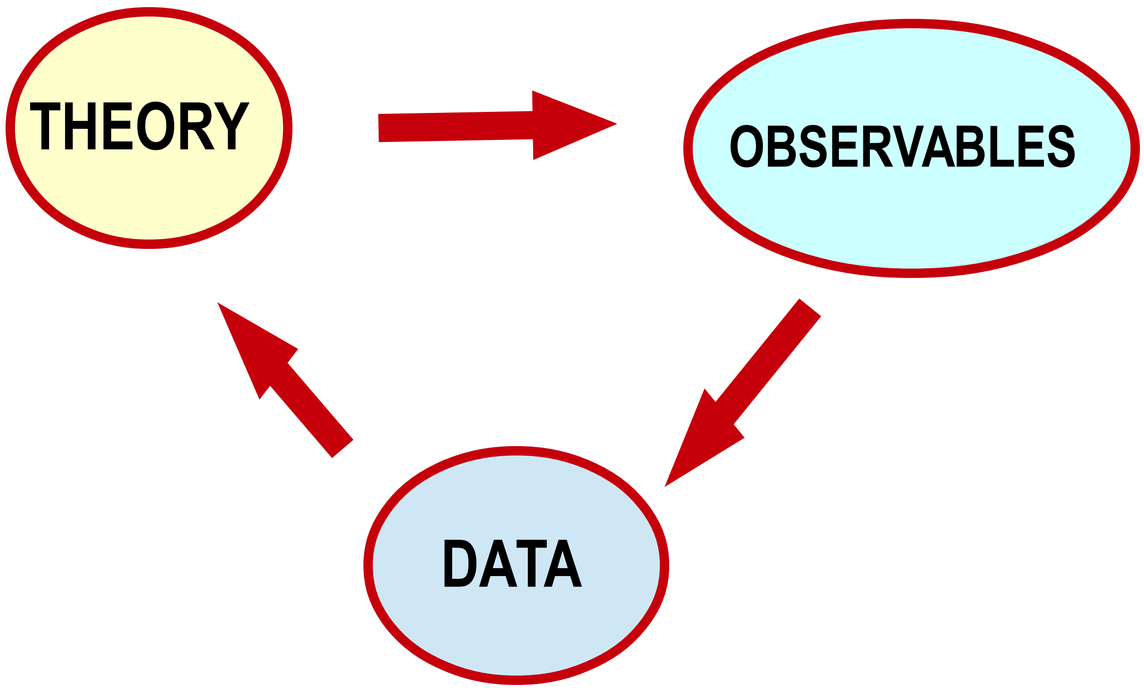
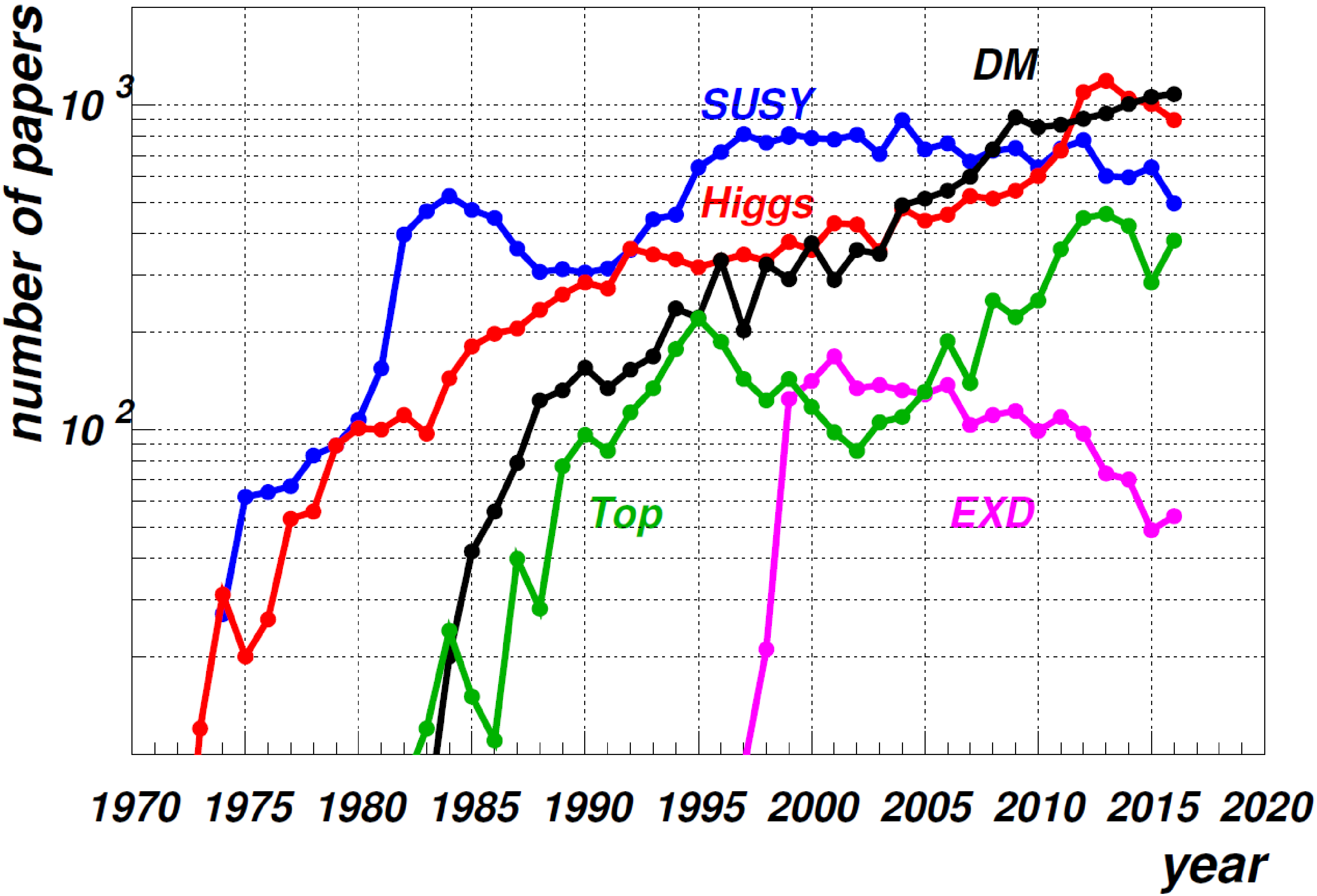
UCI Department of Physics & Astronomy

Outline

- **Theory ↔ Signature link**
  - MicrOMEGAs and MadDM
  - CalcHEP & MadGraph
  - models and repositories
  - Signatures,examples, remarks
- **Signature ↔ Data link**
  - Checkmate, MadAnalysis, Gambit
- **Data → Theory link**
  - The inverse problem of decoding of the underlying theory from signal



Why we are so keen to study DM?



Because the existence of DM is the strongest evidence for BSM, even though we know almost nothing about it!

Spin ?

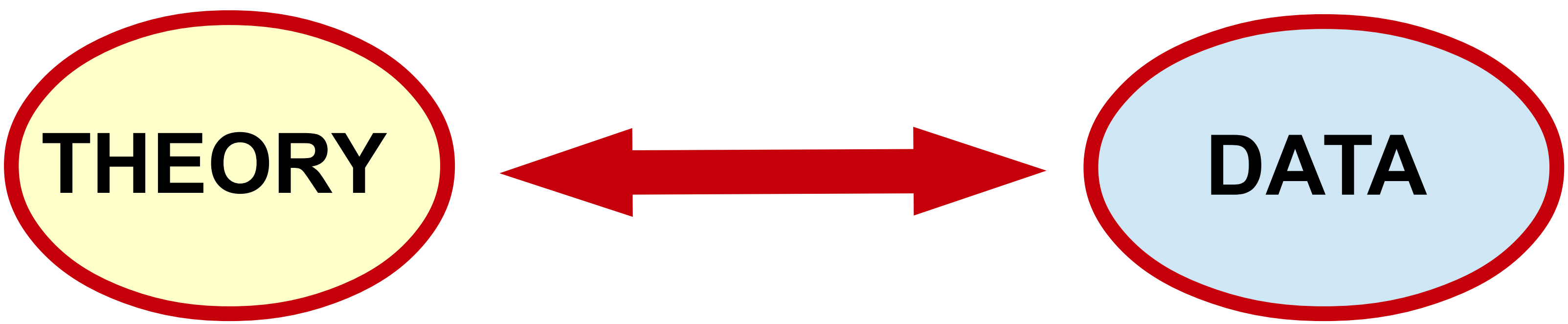
Mass ?

Stable
- Yes ?
- No ?
- symmetry behind stability ?

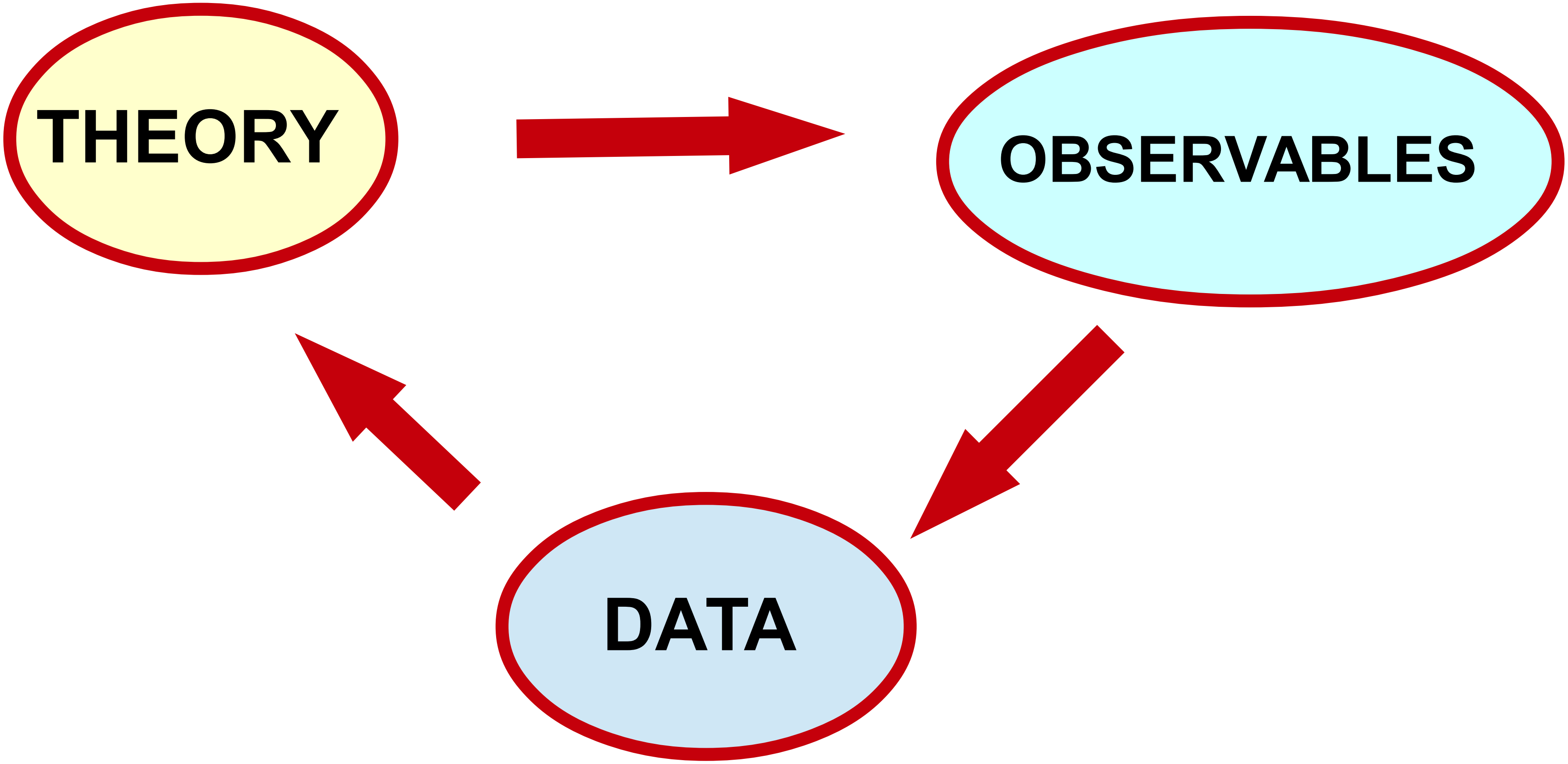
Couplings
- gravity V
- Weak ?
- Higgs ?
- Quarks/gluons ?
- Leptons ?
- New mediators ?

Thermal relic
- Yes ?
- No ?

To test DM theory we need to realise theory $\leftrightarrow$ data link which is actually a non-trivial story

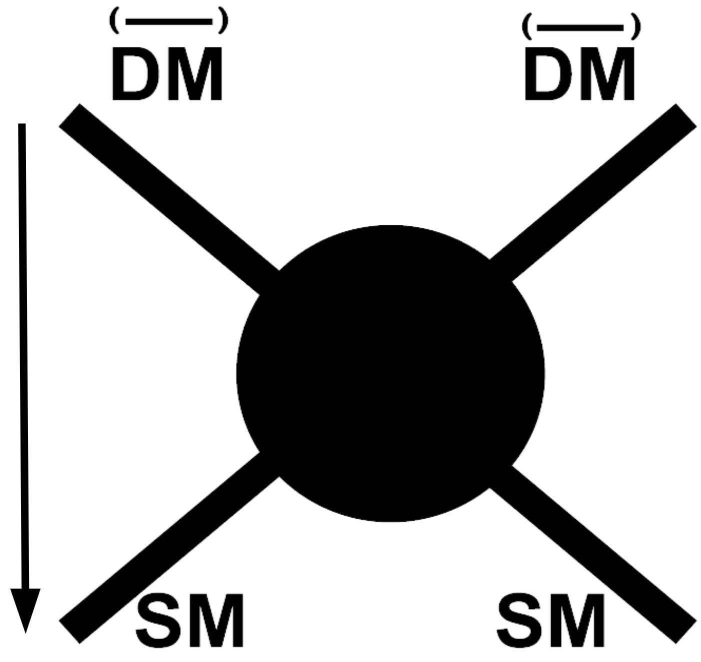


theory ↔ data requires observables to be compared with data



DM Observables: the power of WIMP

Correct Relic density: efficient (co) annihilation
WMAP, Planck ; annihilation to photons can affect CMB



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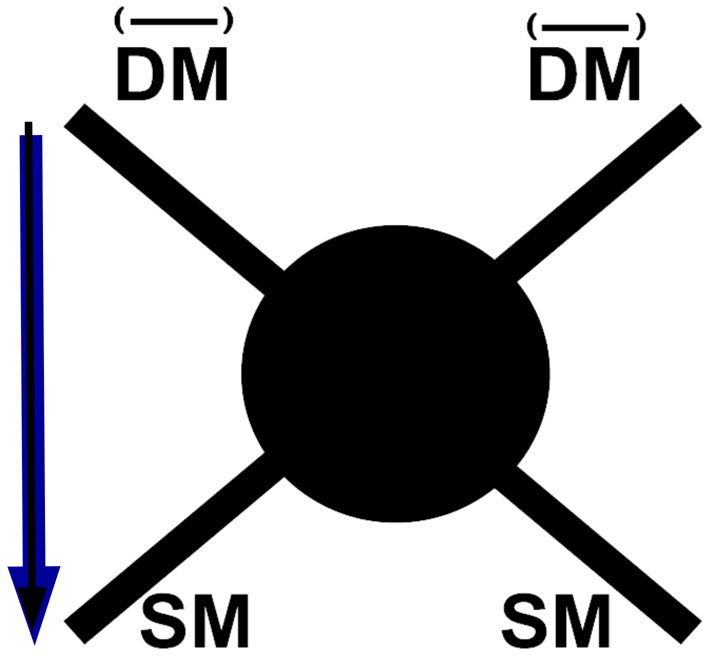
Signatures from neutralino annihilation in halo, core of the Earth and Sun

- photons,
- Anti-protons
- positrons,
- Neutrinos

Neutrino telescopes:

- Amanda
- Icecube
- Antares

Efficient annihilation now:
Indirect (ID) DM Detection



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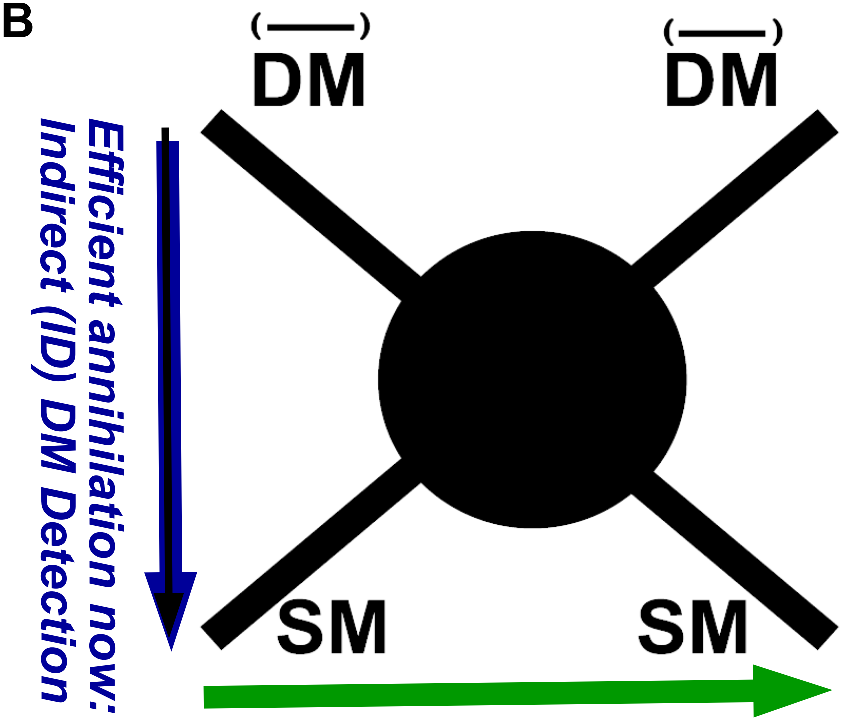

Efficient scattering off nuclei: DM Direct Detection (DD)

Signature from energy deposition from nuclei recoil: LUX, XENON, WARP,

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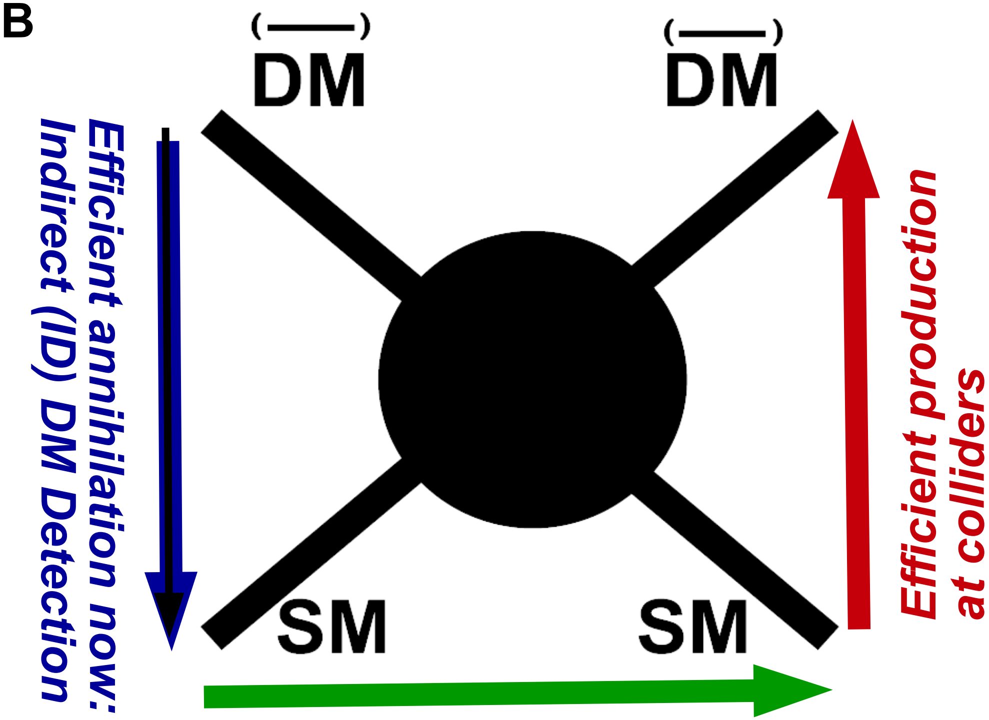

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LHC signatures

- mono-jet
- mono-photon
- mono-Z
- mono Higgs

- VBF+MET
- soft leptons+MET
- ….

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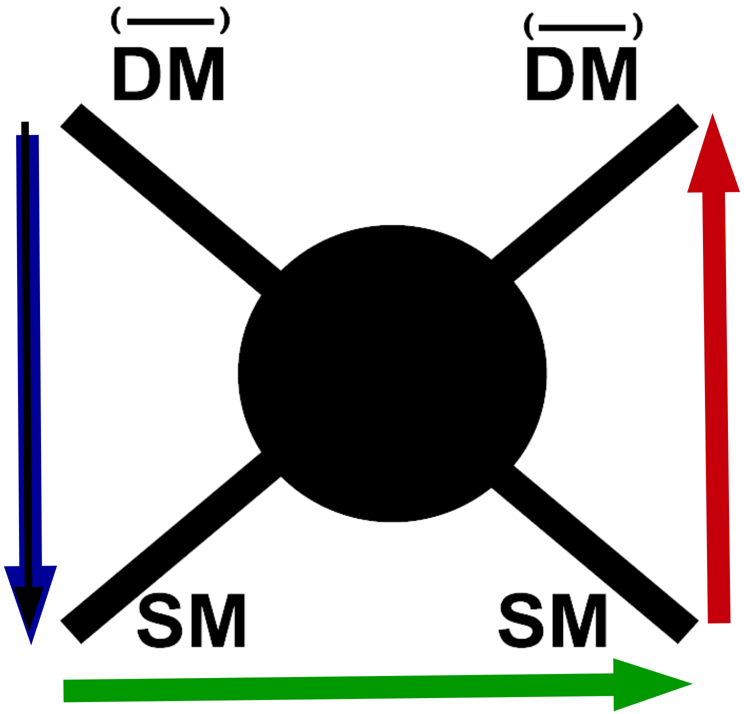


Efficient production at colliders

LHC signatures

- **mono-jet**
- **mono-photon**
- **mono-Z**
- **mono Higgs**

- **VBF+MET**
- **soft leptons+MET**
- **….**

Efficient scattering off nuclei: DM Direct Detection (DD)

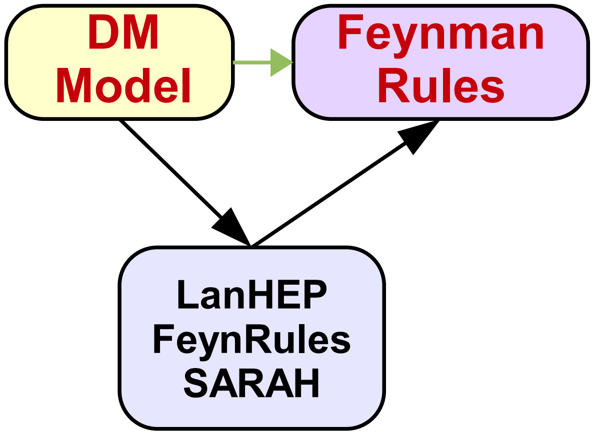
Signature from energy deposition from nuclei recoil: LUX, XENON, WARP,

Note: **there is no 100%correlation between signatures above. For example, the high rate of annihilation does not always guarantee high rate for DD!**

Actually there is a great complementarity in this:

- **In case of NO DM Signal – we can efficiently exclude DM models**
- **In case of DM signal – we can efficiently determine the nature of DM**

Tools for theory → observables link



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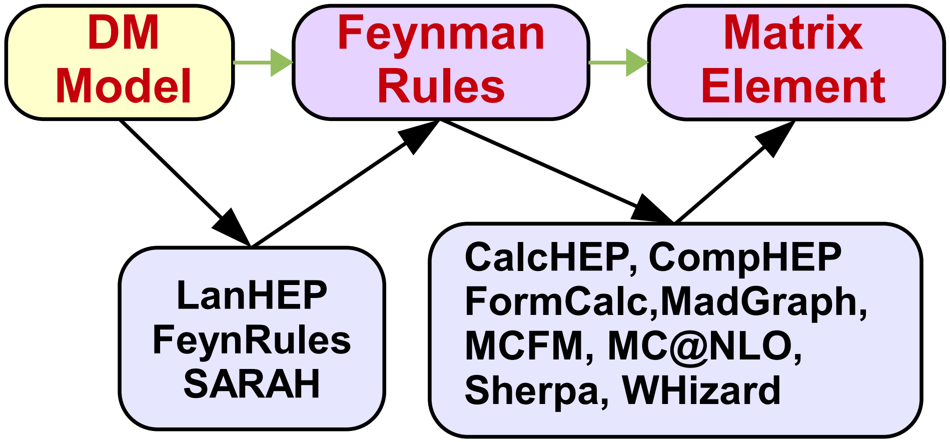

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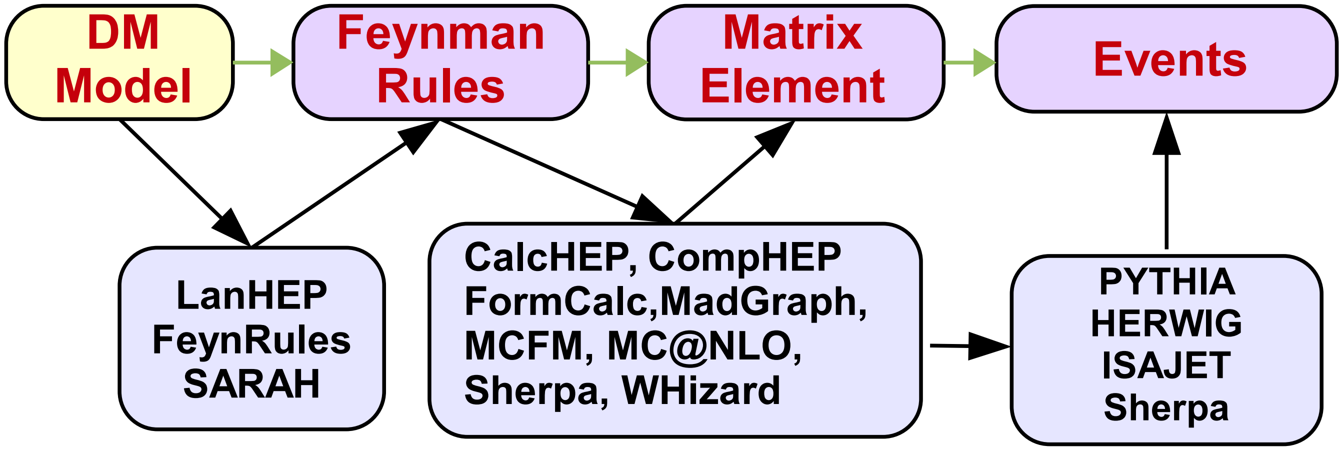

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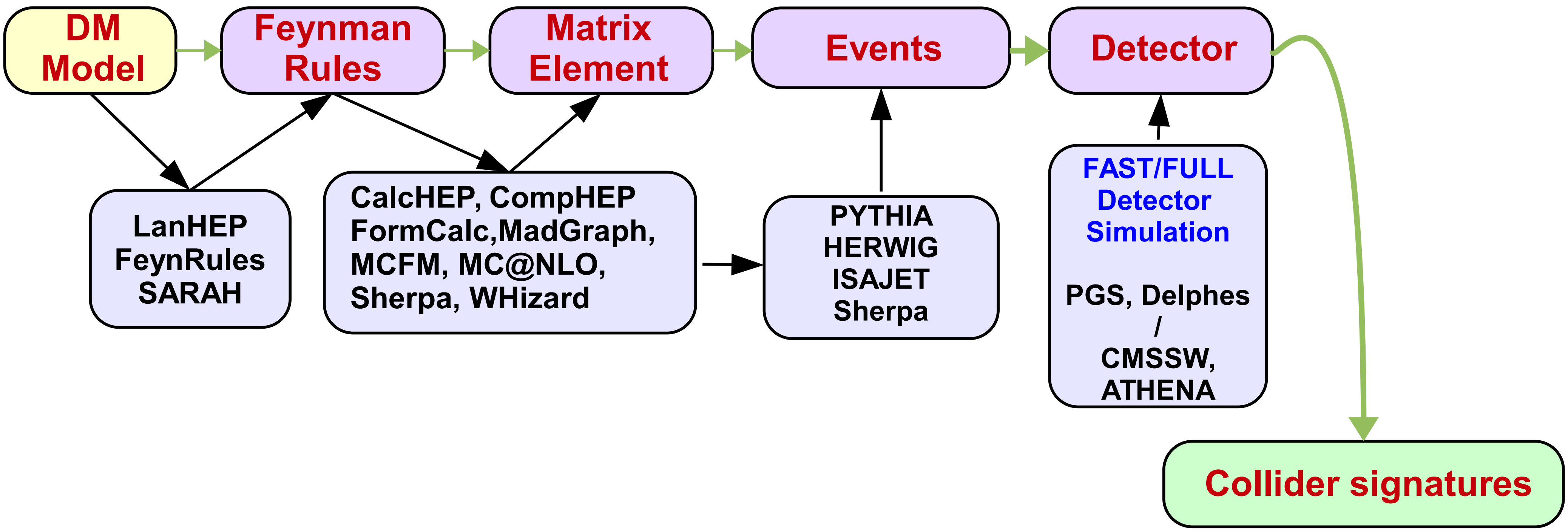

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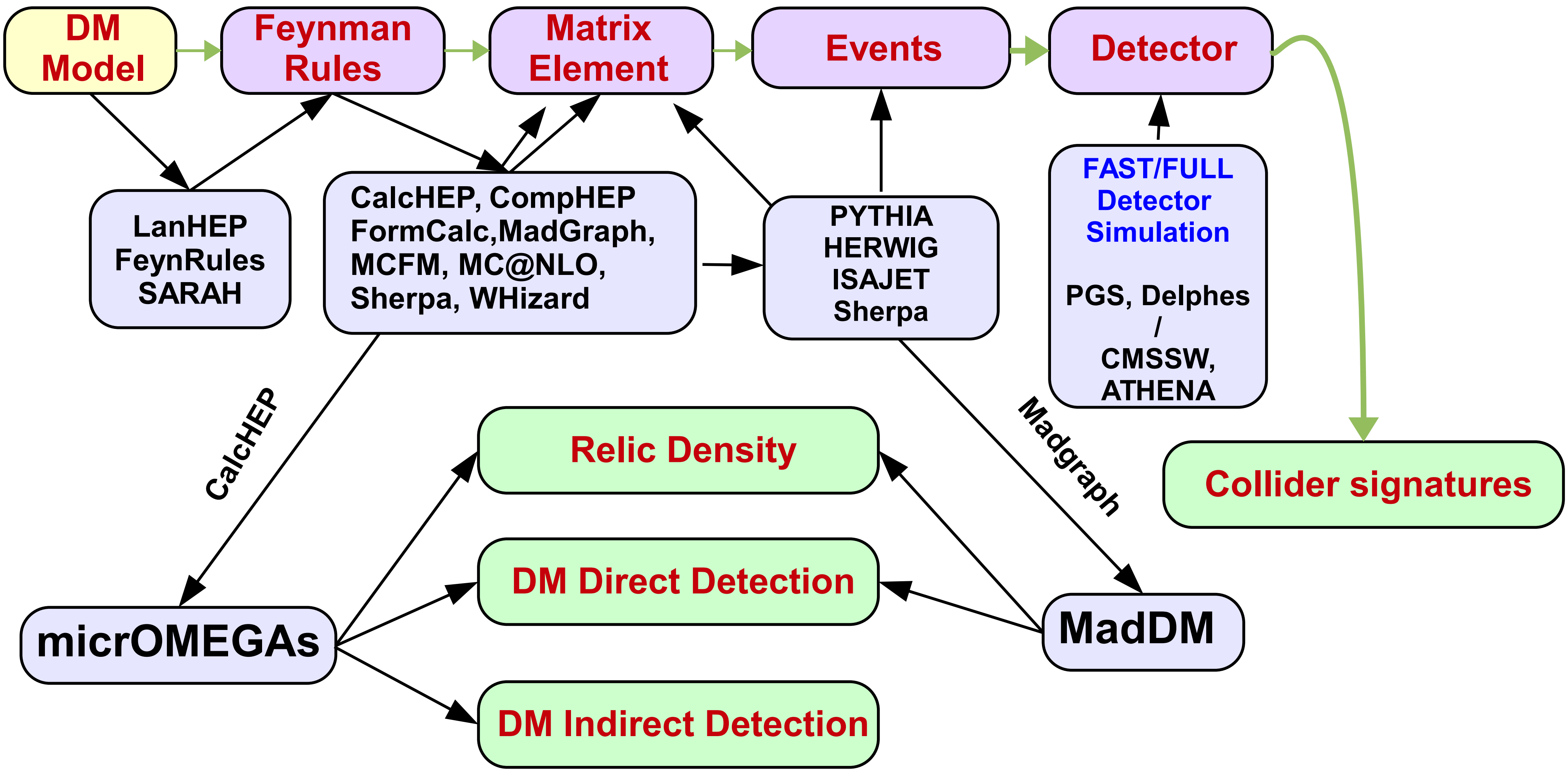

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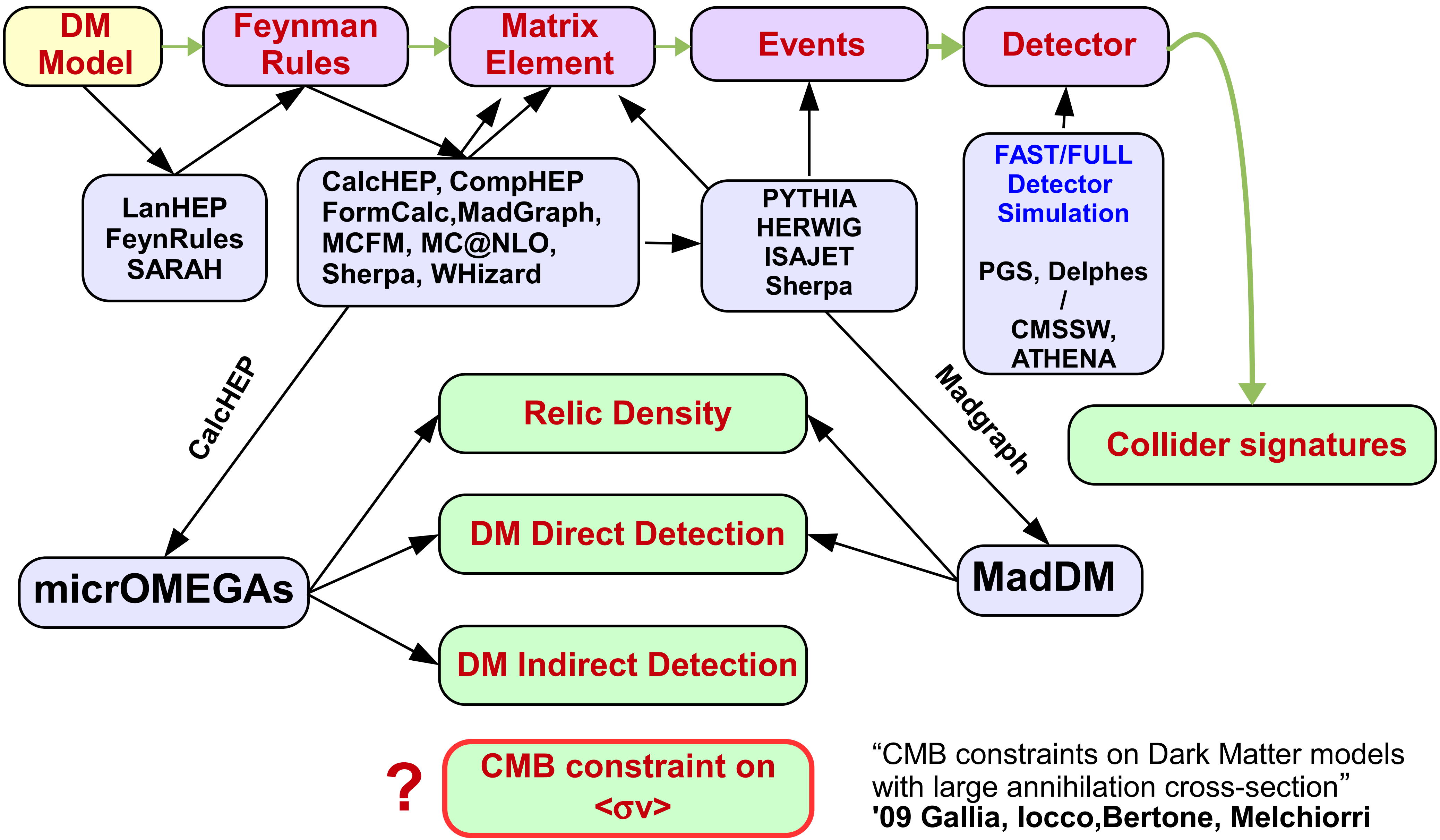

"CMB constraints on Dark Matter models with large annihilation cross-section"
'09 Gallia, Iocco,Bertone, Melchiorri

CMB constraint on <σv>

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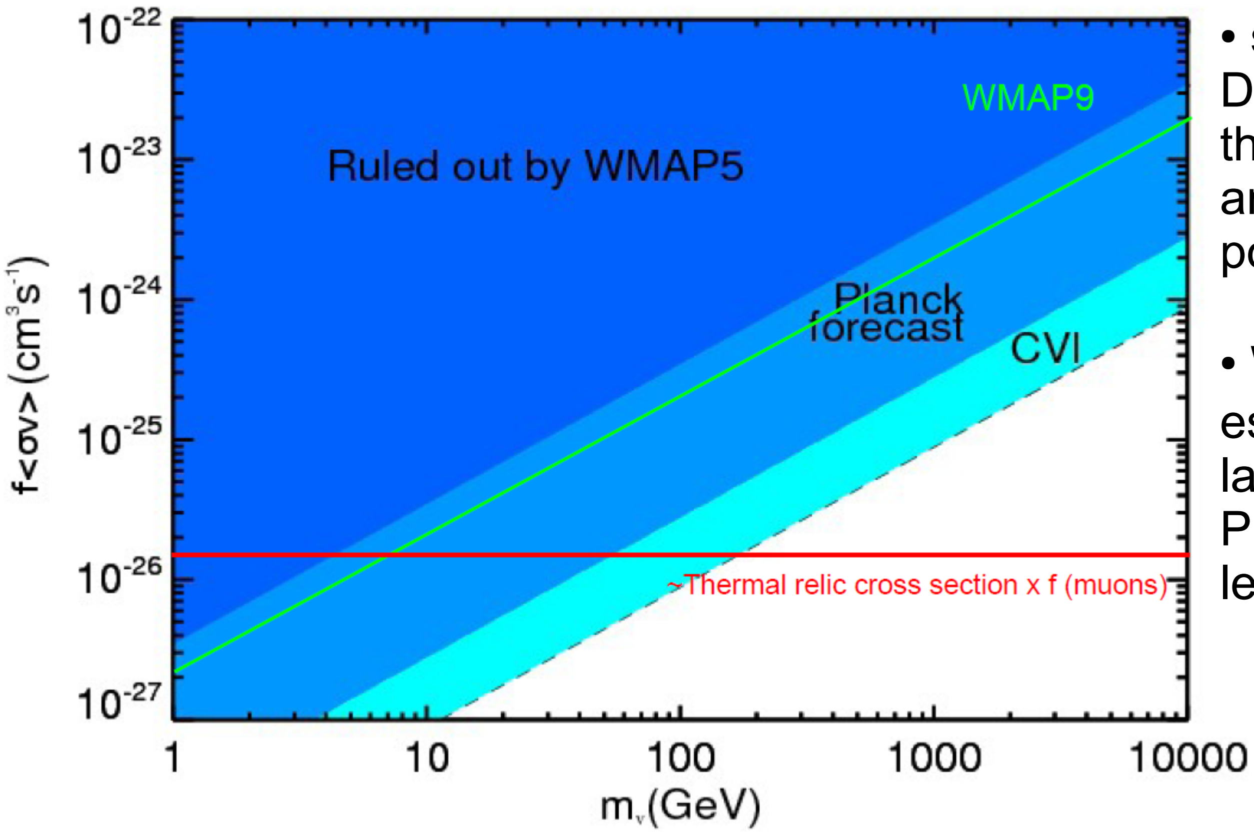

- secondary particles produced by DM annihilation with z∼1000 affect the process of recombination, leaving an imprint on CMB anisotropies and polarization

- WMAP place constraints on<σv> especially for models that exhibit a large Sommerfeld enhancement Planck improves constraints by at least one order of magnitude

- f(z) is the fraction of energy that is absorbed by the plasma at each z. Depends on DM mass and annihilation channel

It is important to incorporate this constraint to micrOMEGAs and MadDM!

MicrOMEGAs

http://lapth.in2p3.fr/micromegas
Belanger, Boudjema, Pukhov, Semenov

hep-ph/0112278, hep-ph/0405253, hep-ph/0607059, arXiv:0803.2360, arXiv:1305.0237, arXiv:1407.6129

- Was born in 2001, the latest version 4.3
- Comprehensive tool for dark matter studies : precise calculation of relic density, direct detection, indirect detection, cross section at colliders and decays
- Comes with models: MSSM, NMSSM,CPV-MSSM, RH-neutrino, Littlest Higgs, Inert doublet+singlet Z3,Z4; many more models are available at ***hepmdb.soton.ac.uk***

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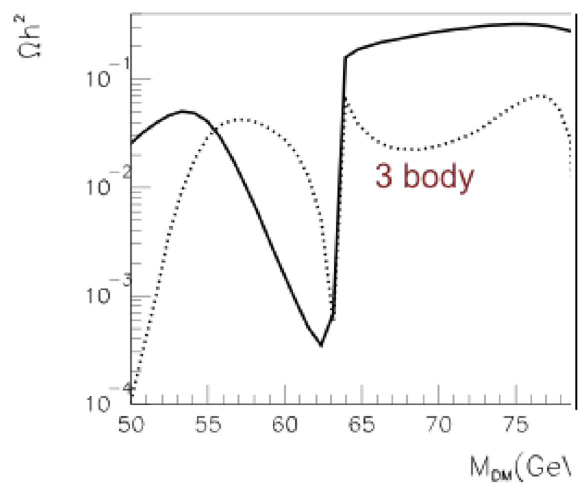
- **Recent features**
  - **Neutrino signal** from DM capture (for SuperKamiokande, IceCube), both neutrino flux and muon flux are computed
  - **Higgs 3-body decays** and loop-induced decays are included – a good agreement with HDECAY (Djouadi et al) for SM-like Higgs
  - Links to **external packages**: HiggsSignals/HiggsBounds (Bechtle et al), Smodels (Kraml et al)
  - Includes **3/4-body processes** with one/two virtual W/Z
  - Z2,Z3,Z4,Z5 symmetries and **two DM candidates**
  - **Asymmetric DM:** option to define $\Delta Y = Y^{+} - Y$
  - Collider limits for Z' on-shell mediator (Barducci et al)



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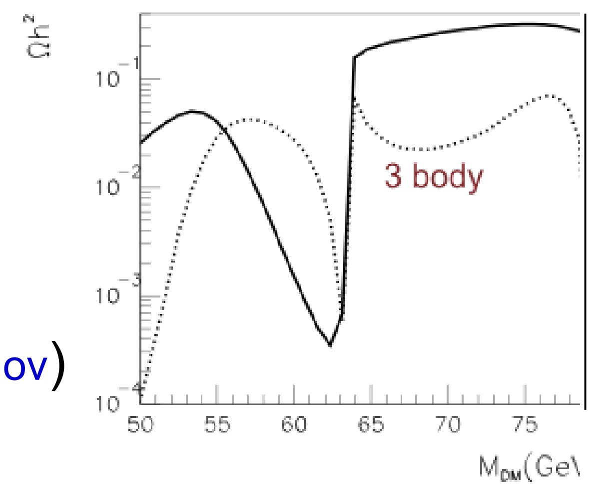


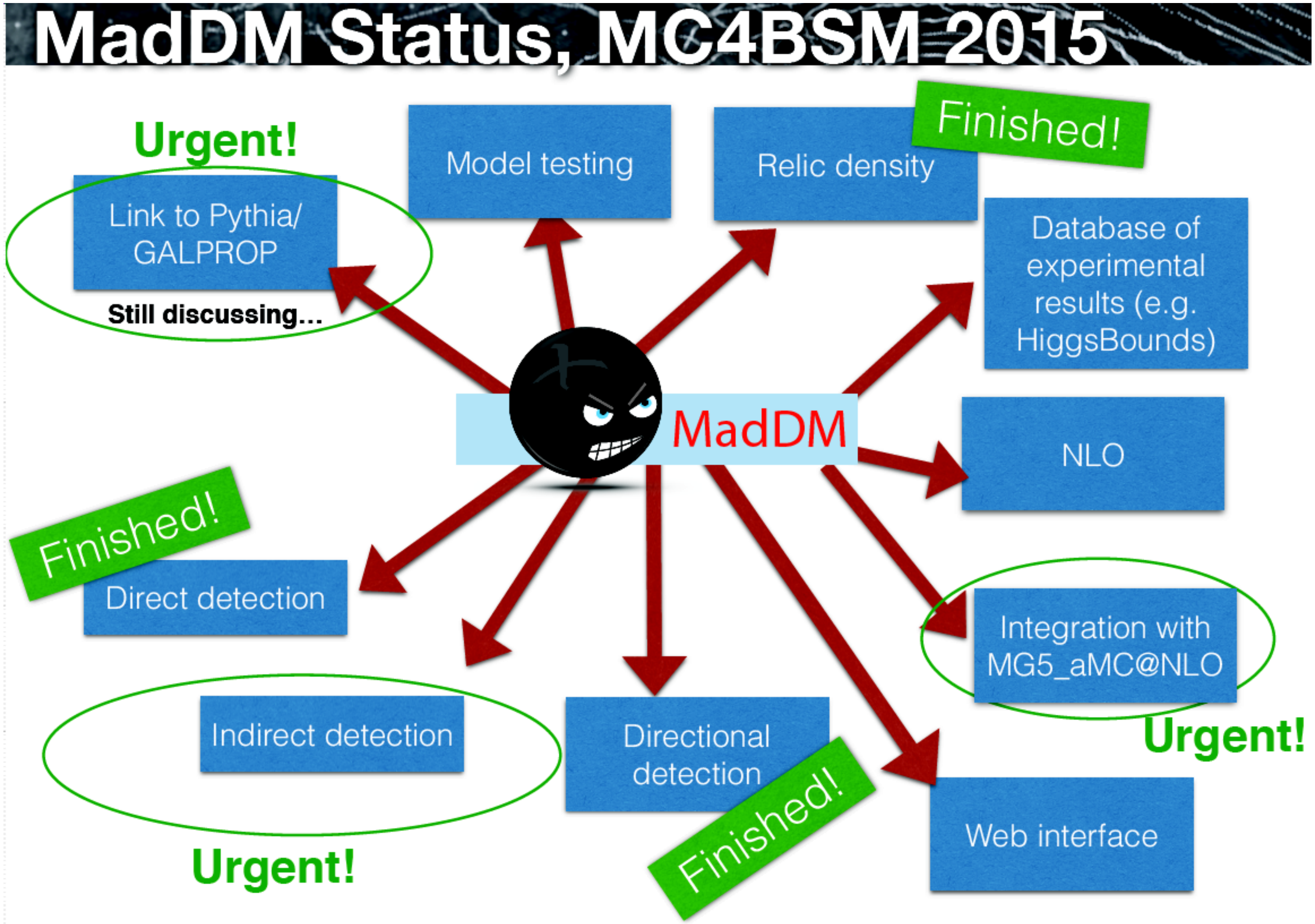
- **Prospects**
  - Collider limits for any DM model (Belanger, Barducci, AB, Pukhov)
  - Improved propagation for ID DM signals, interface to USINE, GALPROP, CLUMPY

MadDM

http://susy.phsx.ku.edu/~mihailo/index.html
https://launchpad.net/maddm
Backovic, Martini, Kong, Mattelaer, Mohlabeng

arXiv:1509.03683
arXiv:1308.4955

- Was born in 2013, version 2.1: DM relic density, DM direct and directional detection



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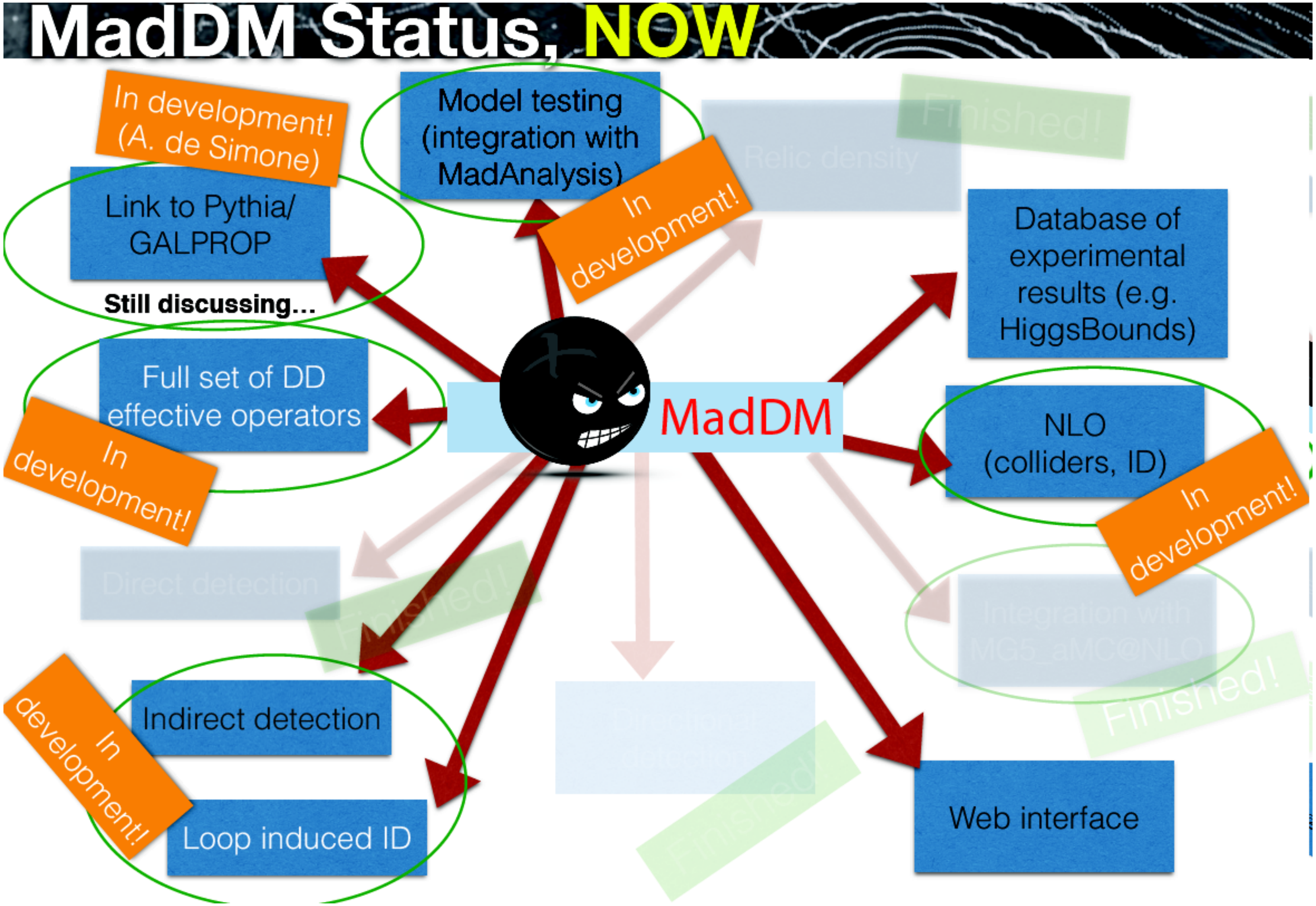
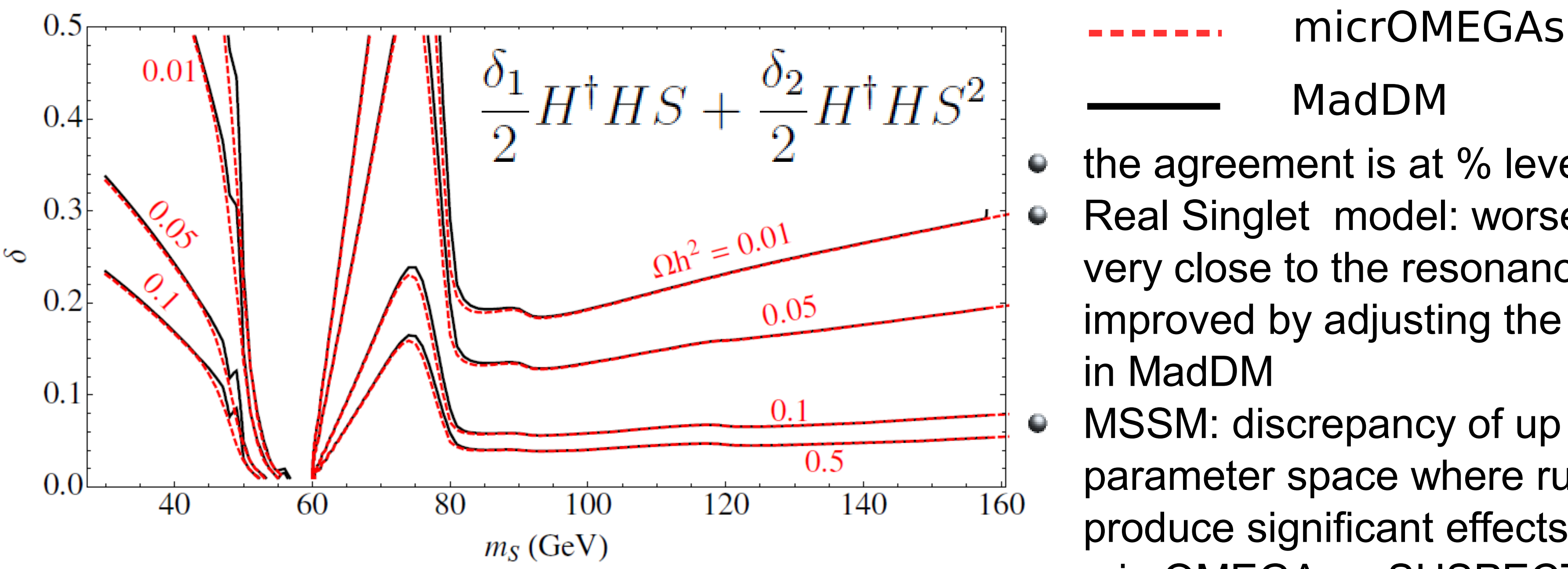


MicroMEGAs – MadDM comparison: relic density

arXiv:1308.4955



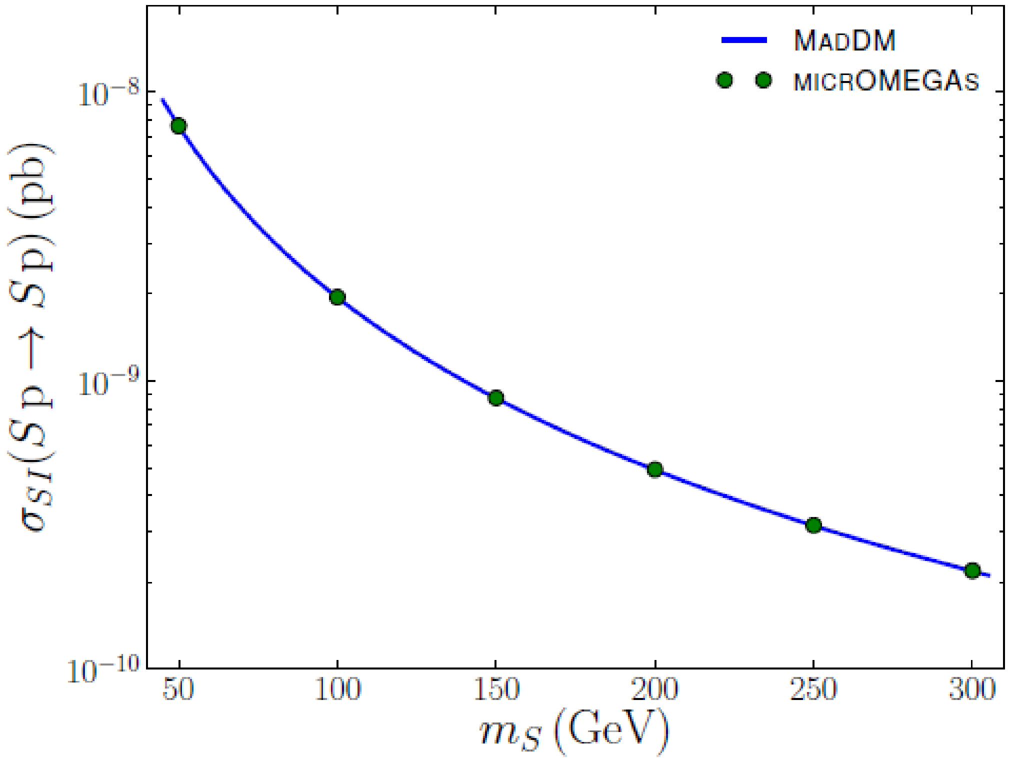
- the agreement is at % level in general
- Real Singlet model: worse in the region very close to the resonance – can be improved by adjusting the precision pars in MadDM
- MSSM: discrepancy of up to 30% in the parameter space where running b mass produce significant effects – related to micrOMEGAs – SUSPECT difference

SPS Pt.	MadDM	micrOMEGAs	Difference	Description
SPS1a	0.197	0.195	1%	neutralino DM
SPS1b	0.390	0.374	5%	coan. with stau
SPS2	7.914	7.860	1%	focus pt, higgsino DM
SPS3	0.118	0.116	2%	conn. with sleptons
SPS4	0.0596	0.0474	22%	resonance region
SPS5	0.332	0.338	−2%	neutralino DM
SPS9	0.00111	0.00117	−4%	AMSB, coan. w/ chargino

MicroMEGAs – MadDM comparison: DM DD

arXiv:1509.03683

	DM spin	Even	Odd
SI		scalar current	vector current
	0	$2M_\chi S S^* \bar\psi_q \psi_q$	$i\left(\partial_\mu S\, S^* - S\,\partial_\mu S^*\right)\bar\psi_q\gamma^\mu\psi_q$
	1/2	$\bar\psi_\chi\psi_\chi\bar\psi_q\psi_q$	$\bar\psi_\chi\gamma_\mu\psi_\chi\bar\psi_q\gamma^\mu\psi_q$
	1	$2M_\chi A^*_{\chi\mu}A^\mu_\chi\bar\psi_q\psi_q$	$i\left(A^{*\alpha}_\chi\partial_\mu A_{\chi\alpha} - A^\alpha_\chi\partial_\mu A^*_{\chi\alpha}\right)\bar\psi_q\gamma_\mu\psi_q$
SD		axial-vector current	tensor current
	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	$\sqrt{6}\left(\partial_\alpha A^*_{\chi\beta}A_{\chi\nu} - A^*_{\chi\beta}\partial_\alpha A_{\chi\nu}\right)\epsilon^{\alpha\beta\nu\mu}\bar\psi_q\gamma_5\gamma_\mu\psi_q$	$i\frac{\sqrt{3}}{2}\left(A_{\chi\mu}A^*_{\chi\nu} - A^*_{\chi\mu}A_{\chi\nu}\right)\bar\psi_q\sigma^{\mu\nu}\bar\psi_q$



- There is a good agreement between spin-Independent (SI) and spin-dependent (SD) rates

Importance of the MicroMEGAs – MadDM comparison

- Actually the main message here is the importance of the fact that two independent tools exist and are being cross checked!

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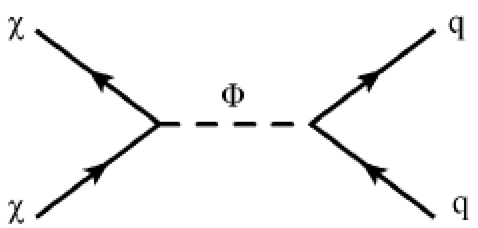

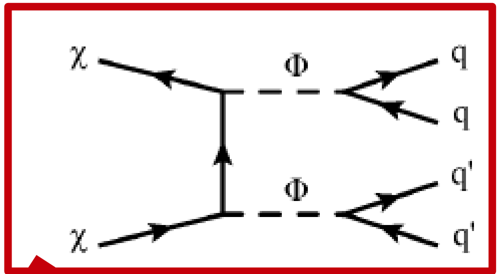

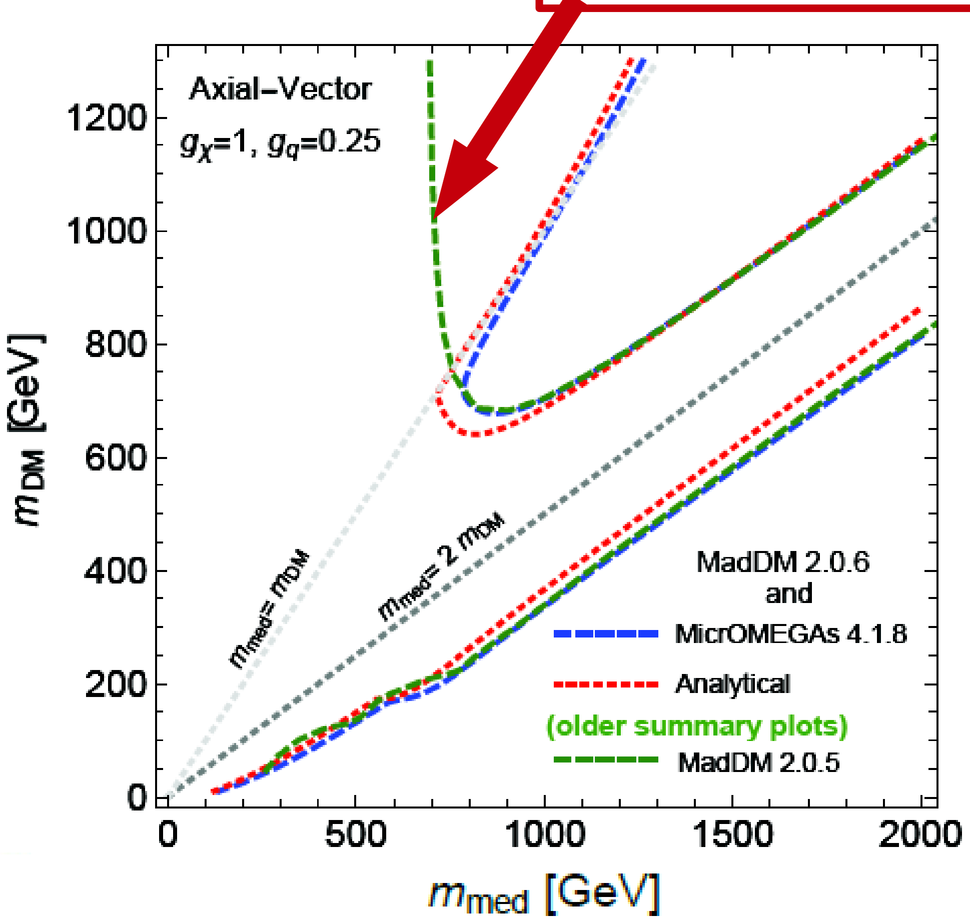

a recent example of this importance are the results for the S-mediated model used with MadDM 2.0.5 in arXiv:1603.08525 and brought at DM LHC forum (Caterina's talk):

t-channel diagram was missed in MadDM 2.0.5, leading to the erroneous results

CalcHEP for DM studies at colliders

A.Pukhov, AB, N.Christensen
http://theory.sinp.msu.ru/~pukhov/calchep.html

hep-ph/9908288
arXiv:1207.6082

- Some highlights
  - *the "engine" of micOMEGAs*
  - *has convenient graphical interface*
  - *evaluates particle widths 'on the fly'*
  - *allows to edit diagrams (inducing squared diagram level) – important for the dedicated interference studies*
  - *allows easily modify an existing model (GUI) or to implement the new one (LanHEP, FeynRules)*
  - *powerful batch interface – connects production and decay processes, allows to perform multidimensional scan and produce LHE files in one run*
  - *adopted to HPC cluster, symbolic and numerical evaluations/simulations are parallelized*
  - *exports plots to GNUPLOT, PAW and ROOT*
  - *numerous models are implemented, see CalcHEP's site and HEPMDB database*

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- DM Models:
  at CalcHEP, HEPMDB (hepmdb.soton.ac.uk) and FeynRules(feynrules.irmp.ucl.ac.be) sites

  - **Extra dimensions :** 5D UED (MUED) with 2KK and 4KK layers, 6D UED with 2KK layers
  - **SUSY :** CMSSM, MSSM, NMSSM, left-right symmetric MSSM, MSSM with CP violation, E6MSSM
  - **Technicolor & Composite Higgs models:** TC with DM, VLQ with scalar DM
  - **Little Higgs:** Littlest higss model with T-parity
  - **DM EFT operators:** The complete set of DIM5&6 operators with spin 0,1/2,1 DM

MadGraph5_aMC@NLO for DM studies at colliders

A.J. Alwall, R. Frederix, S. Frixione, M. Herquet, V. Hirschi, F.Maltoni, O. Mattelaer, H.-S. Shao, T. J. Stelzer, P. Torrielli, M. Zaro

arXiv:1106.0522
arXiv:1405.0301

http://madgraph.hep.uiuc.edu/
https://launchpad.net/mg5amcnlo

- the “engine” of MadDM
- has been most intensively used by ATLAS and CMS
- can perform NLO QCD corrections (not a generic for arbitrary model) but works for SM and NLO models located at FeynRules web site
- Includes matching to parton showers
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    - DM simplified models (s-channel spin 0,1,2)
    - SUSY-QCD

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- **NOTE**
  - **the models of LHC DM Forum svnweb.cern.ch/cern/wsvn/LHCDMF/trunk/models are not public and MG specific!**
  - **it is important to make models public and extend the models scope for both Magraph and CalcHEP for the cross-check and validation!**

Example of DM characterization using CalcHEP&Madgraph within EFT

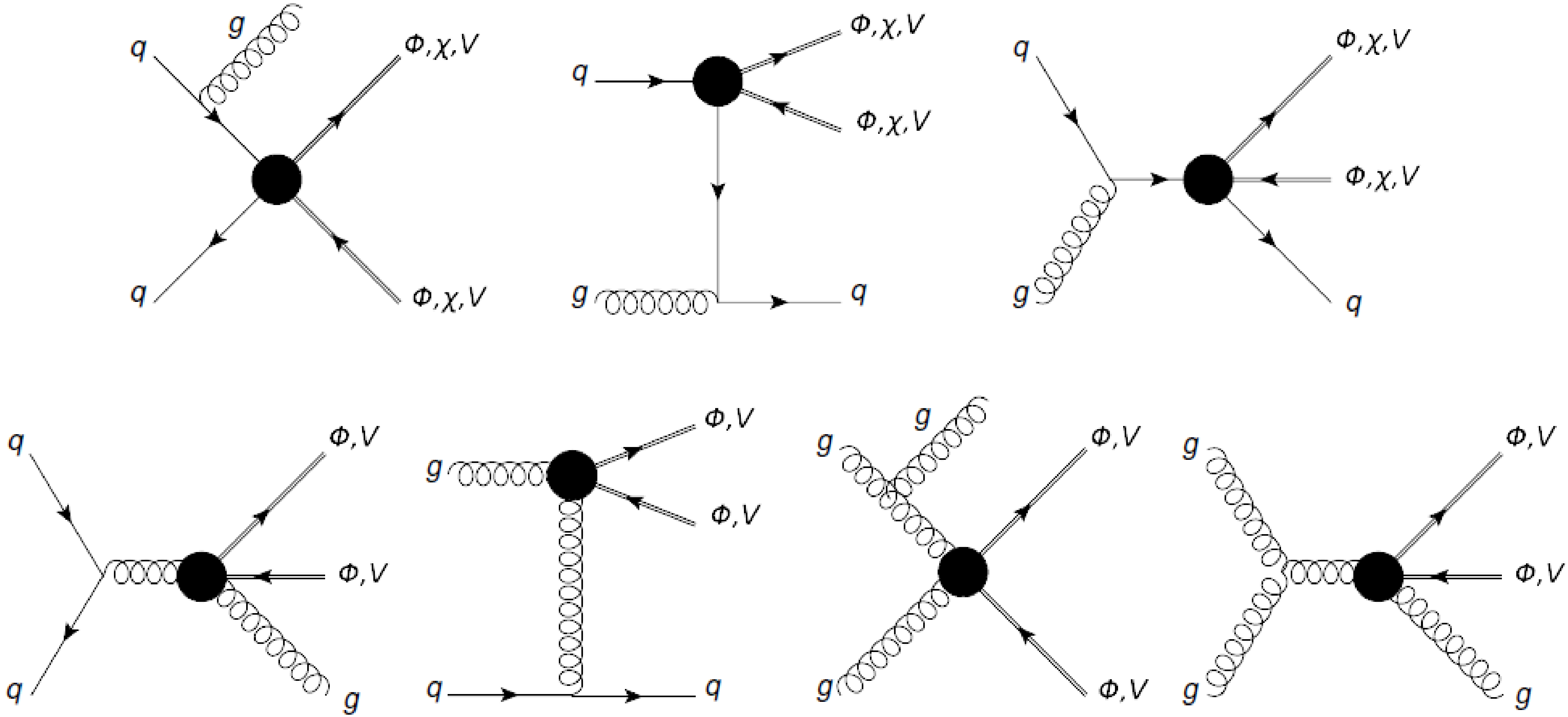
Complex Scalar DM	
$\frac{\tilde{m}}{\Lambda^2}\phi^\dagger\phi\bar{q}q$	$[C1]$
$\frac{\tilde{m}}{\Lambda^2}\phi^\dagger\phi\bar{q}i\gamma^5 q$	$[C2]$
$\frac{1}{\Lambda^2}\phi^\dagger i\overleftrightarrow{\partial_\mu}\phi\bar{q}\gamma^\mu q$	$[C3]$
$\frac{1}{\Lambda^2}\phi^\dagger i\overleftrightarrow{\partial_\mu}\phi\bar{q}\gamma^\mu\gamma^5 q$	$[C4]$
$\frac{1}{\Lambda^2}\phi^\dagger\phi G^{\mu\nu}G_{\mu\nu}$	$[C5]$
$\frac{1}{\Lambda^2}\phi^\dagger\phi\tilde{G}^{\mu\nu}G_{\mu\nu}$	$[C6]$

Dirac Fermion DM	
$\frac{\tilde{m}}{\Lambda^3}\bar{\chi}\chi\bar{q}q$	[D1]
$\frac{\tilde{m}}{\Lambda^3}\bar{\chi}i\gamma^5\chi\bar{q}q$	[D2]
$\frac{\tilde{m}}{\Lambda^3}\bar{\chi}\chi\bar{q}i\gamma^5 q$	[D3]
$\frac{\tilde{m}}{\Lambda^3}\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	[D4]
$\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	[D5]
$\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	[D6]
$\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	[D7]
$\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	[D8]
$\frac{1}{\Lambda^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	[D9]
$\frac{1}{\Lambda^2}\bar{\chi}\sigma^{\mu\nu}i\gamma^5\chi\bar{q}\sigma_{\mu\nu}q$	[D10]

Complex Vector DM	
$\frac{\tilde{m}}{\Lambda^2}V_\mu^\dagger V^\mu\bar{q}q$	[V1]
$\frac{\tilde{m}}{\Lambda^2}V_\mu^\dagger V^\mu\bar{q}i\gamma^5 q$	[V2]
$\frac{1}{2\Lambda^2}(V_\nu^\dagger\partial_\mu V^\nu - V^\nu\partial_\mu V_\nu^\dagger)\bar{q}\gamma^\mu q$	[V3]
$\frac{1}{2\Lambda^2}(V_\nu^\dagger\partial_\mu V^\nu - V^\nu\partial_\mu V_\nu^\dagger)\bar{q}i\gamma^\mu\gamma^5 q$	[V4]
$\frac{\tilde{m}}{\Lambda^2}V_\mu^\dagger V_\nu\bar{q}i\sigma^{\mu\nu}q$	[V5]
$\frac{\tilde{m}}{\Lambda^2}V_\mu^\dagger V_\nu\bar{q}\sigma^{\mu\nu}\gamma^5 q$	[V6]
$\frac{1}{2\Lambda^2}(V_\nu^\dagger\partial^\nu V_\mu + V^\nu\partial^\nu V_\mu^\dagger)\bar{q}\gamma^\mu q$	[V7P]
$\frac{1}{2\Lambda^2}(V_\nu^\dagger\partial^\nu V_\mu - V^\nu\partial^\nu V_\mu^\dagger)\bar{q}i\gamma^\mu q$	[V7M]
$\frac{1}{2\Lambda^2}(V_\nu^\dagger\partial^\nu V_\mu + V^\nu\partial^\nu V_\mu^\dagger)\bar{q}\gamma^\mu\gamma^5 q$	[V8P]
$\frac{1}{2\Lambda^2}(V_\nu^\dagger\partial^\nu V_\mu - V^\nu\partial^\nu V_\mu^\dagger)\bar{q}i\gamma^\mu\gamma^5 q$	[V8M]
$\frac{1}{2\Lambda^2}\epsilon^{\mu\nu\rho\sigma}(V_\nu^\dagger\partial_\rho V_\sigma + V_\nu\partial_\rho V_\sigma^\dagger)\bar{q}\gamma_\mu q$	[V9P]
$\frac{1}{2\Lambda^2}\epsilon^{\mu\nu\rho\sigma}(V_\nu^\dagger\partial^\nu V_\mu - V^\nu\partial^\nu V_\mu^\dagger)\bar{q}i\gamma_\mu q$	[V9M]
$\frac{1}{2\Lambda^2}\epsilon^{\mu\nu\rho\sigma}(V_\nu^\dagger\partial_\rho V_\sigma + V_\nu\partial_\rho V_\sigma^\dagger)\bar{q}\gamma_\mu\gamma^5 q$	[V10P]
$\frac{1}{2\Lambda^2}\epsilon^{\mu\nu\rho\sigma}(V_\nu^\dagger\partial^\nu V_\mu - V^\nu\partial^\nu V_\mu^\dagger)\bar{q}i\gamma_\mu\gamma^5 q$	[V10M]
$\frac{1}{\Lambda^2}V_\mu^\dagger V^\mu G^{\rho\sigma}G_{\rho\sigma}$	$[V11]$
$\frac{1}{\Lambda^2}V_\mu^\dagger V^\mu\tilde{G}^{\rho\sigma}G_{\rho\sigma}$	$[V12]$

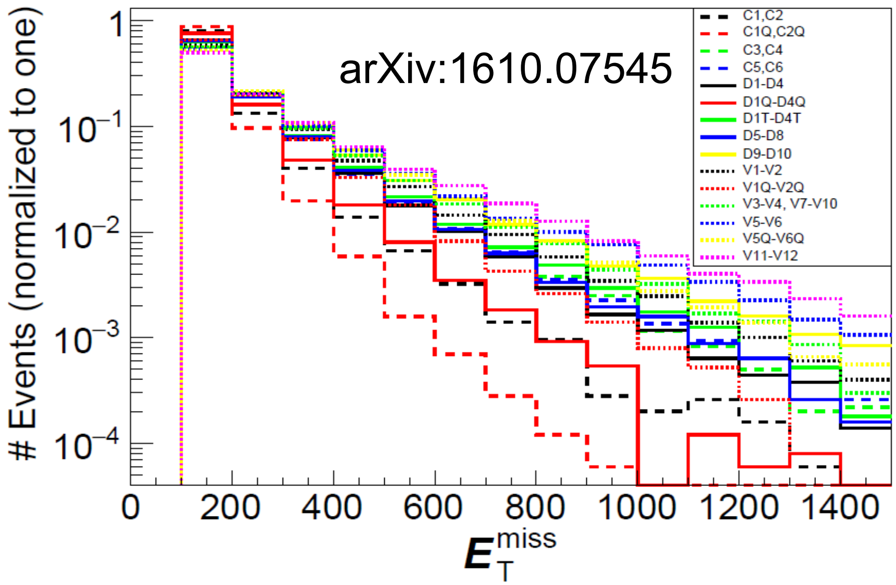
Example of DM characterization using CalcHEP&Madgraph within EFT

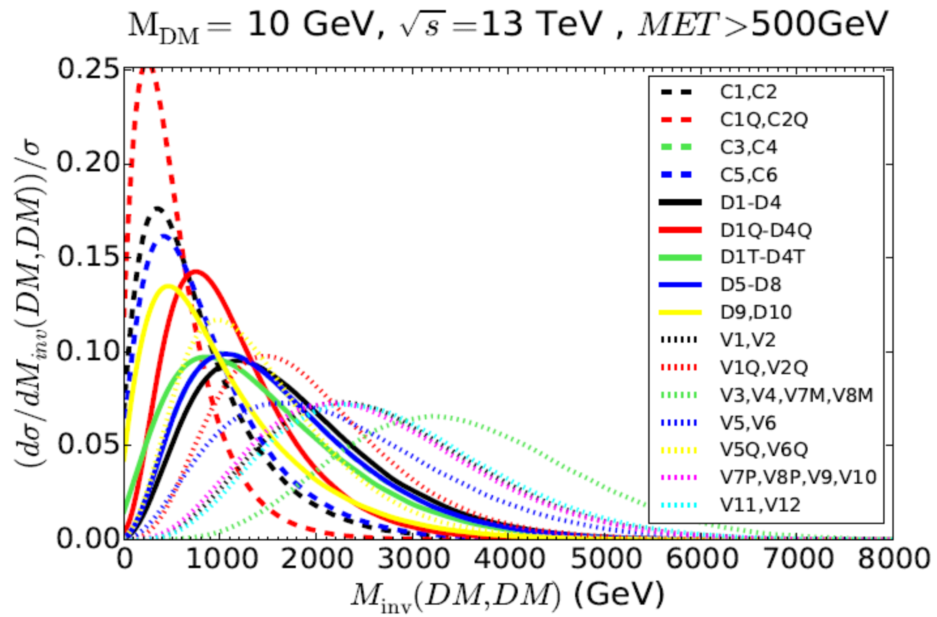
AB,L. Panizzi, A. Pukhov, M.Thomas: arXiv:1610.07545



One can distinguish some EFT operators with different DM spins

Different MET shapes   are correlated with M(DM,DM) distributions





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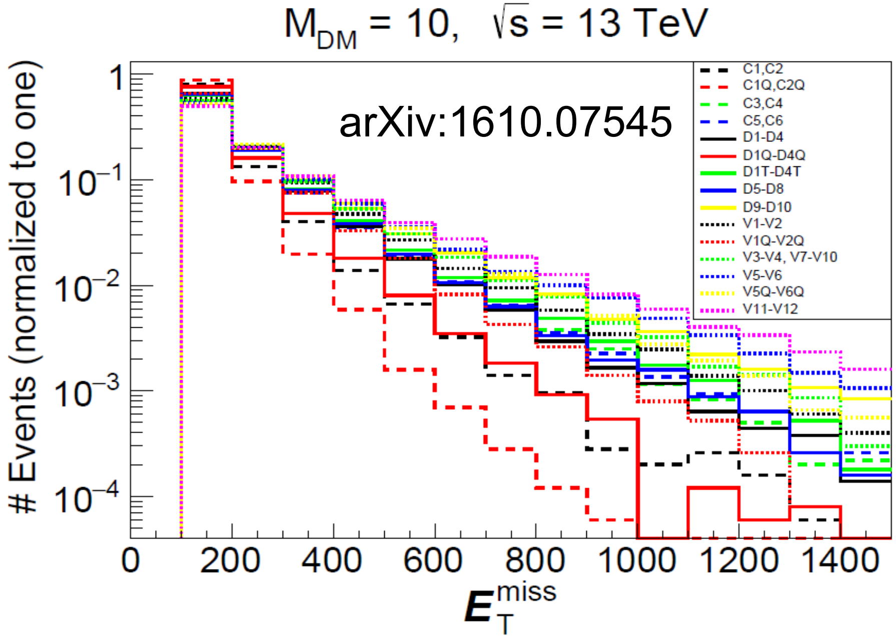
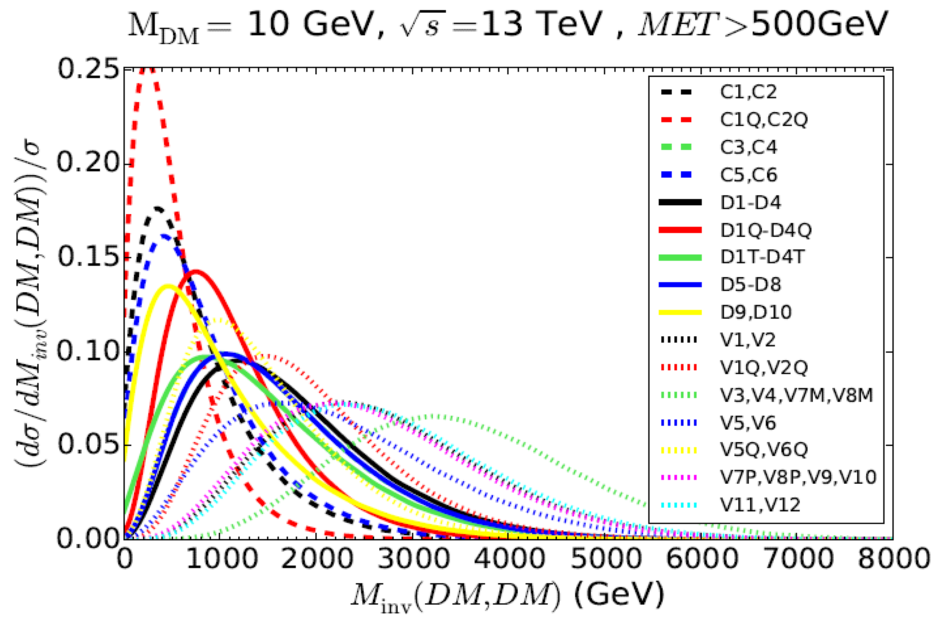
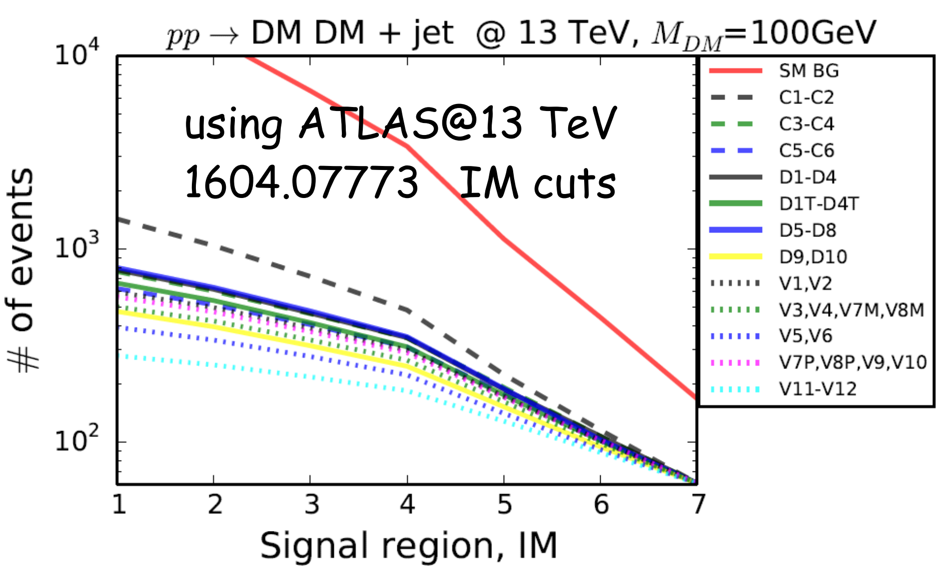




different efficiencies for EFT operators



- energy dependence of the DM operator → M_{DMDM} distributions → slopes of MET
- projection for 300 fb^{-1}: some operators C1-C2,C5-C6,D9-D10,V1-V2,V3-V4,V5-V6 and V11-12 can be distinguished from each other
- Application beyond EFT: when the DM mediator is not produced on-the-mass-shell and M_{DMDM} is not fixed: t-channel mediator or mediators with mass below $2M_{DM}$

Importance of the operator running in the DM DD ↔ Collider interplay

- the connection between physics at high and low energy is crucial to properly explore complementarity collider and non-collider DM experiments
- RGEs for the EFT introduce the mixing between different operators

Kopp,Niro,Schwetz,Zupan(2009); Hill, Solon(2012); Frandsen, Haisch, Kahlhoefer, Mertsch, Schmidt-Hoberg (2012); Kopp,Michaels, Smirnov(2014); Crivellin,D'Eramo,Procura(2014);Crivellin, Haisch(2014); Berlin, Robertson,Solon,Zurek(2016); D'Eramo, de Vries, Panci(2016); D'Eramo,Kavanagh, Panci(2016)

$$\mathcal{L} \supset -\frac{J^\mu_{DM} J_{SM,\mu}}{\Lambda^2}, \qquad J^{SM}_\mu = \sum_{i=1}^{3}\left[c^{(i)}_{Vq}(\Lambda)\,\overline{q^{(i)}}\gamma_\mu q^{(i)} + c^{(i)}_{Aq}(\Lambda)\,\overline{u^{(i)}}\gamma_\mu\gamma_5 u^{(i)} + \dots\right]$$

let us take, for example, $J^\mu_{DM} = c_{V\chi}\,\overline{\chi}\gamma^\mu\chi + c_{A\chi}\,\overline{\chi}\gamma^\mu\gamma_5\chi$

Once the wilson coefficient are evolved at the low scale, we need to match the low energy parton-level lagrangian with the low energy nucleon one

$$\mathcal{L} \supset -\frac{J^\mu_{DM}}{\Lambda^2}\left(c^{(N)}_V\overline{N}\gamma_\mu N + c^{(N)}_A\overline{N}\gamma_\mu\gamma_5 N\right)$$

and

$$\sigma^N_{SI} = \frac{\mu^2_N}{\pi}\frac{(c_{V\chi}c^{(N)}_V)^2}{\Lambda^4}$$

where $\mu_N = m_\chi m_N/(m_\chi + m_N)$

Importance of the operator running in the DM DD ↔ Collider interplay

- In case of axial operators, e.g

$$c_A^{(q)} c_\chi \overline{\chi}\gamma^\mu \chi \overline{q}\gamma_\mu\gamma_5 q \qquad (D7) \qquad \text{or} \qquad c_A^{(q)} c_\phi \phi^\dagger \overleftrightarrow{\partial}_\mu \phi \overline{q}\gamma^\mu\gamma_5 q \qquad (C4)$$

  couplings $\mathbf{c_V^{(q)}}$ arise due to the running of the wilson coeffcient $\mathbf{c_A^{(q)}}$ leading to sizable constraints on the DM DD constraints
- One can use **runDM** program (**github.com/bradkav/runDM**) by **F. D'Eramo, B. J. Kavanagh & P. Panci**

$\mathbf{c_A^{(u)}, c_A^{(d)}, c_V^{(u)}, c_V^{(d)}=(1,1,0,0)}$[5TeV] → (**1.1, 1.1, 0.04, -0.07**)[1GeV]

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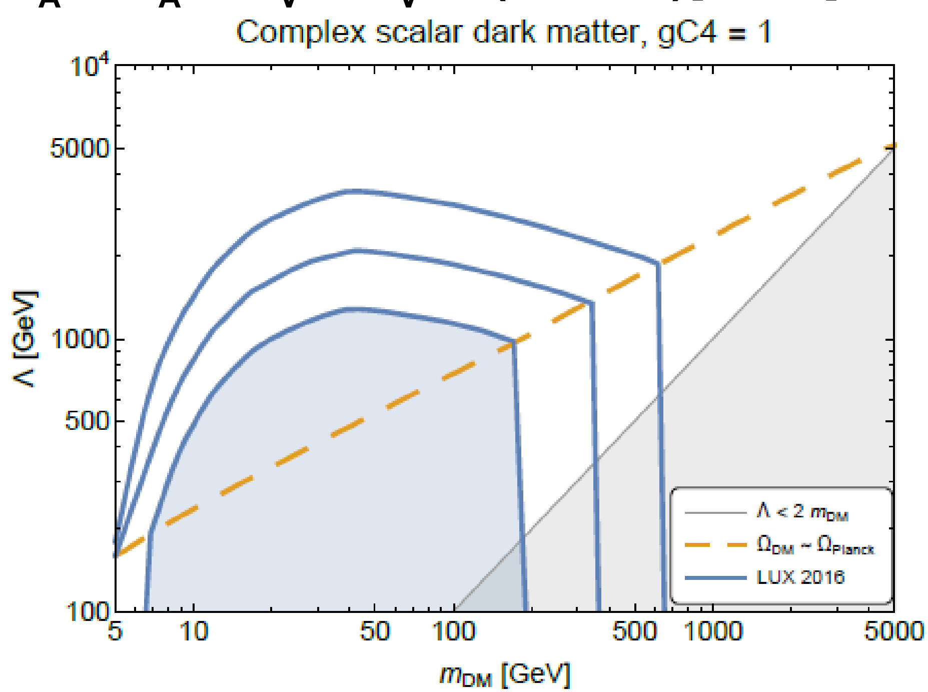
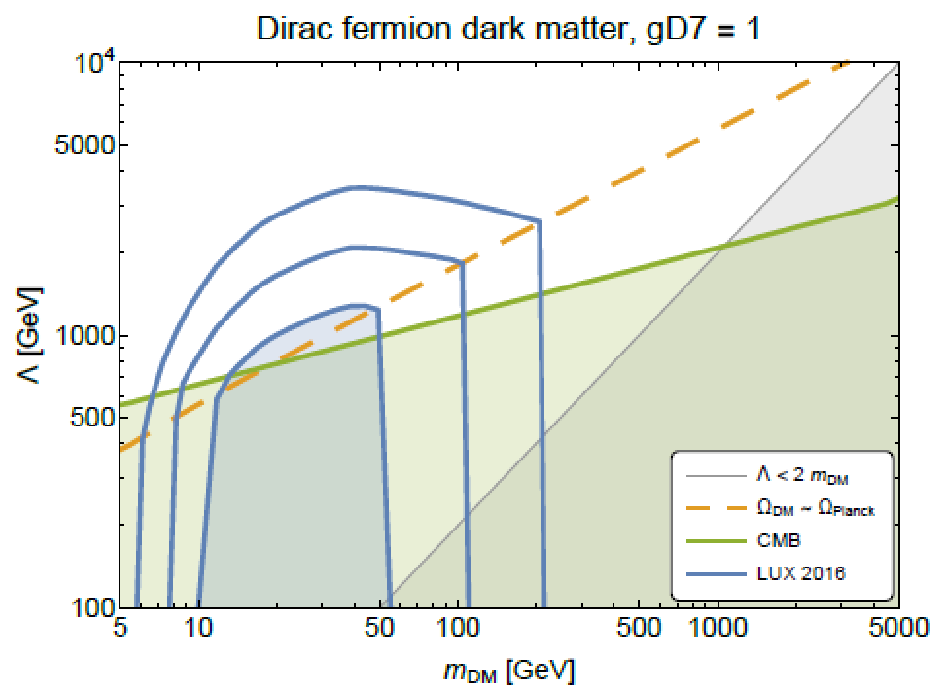
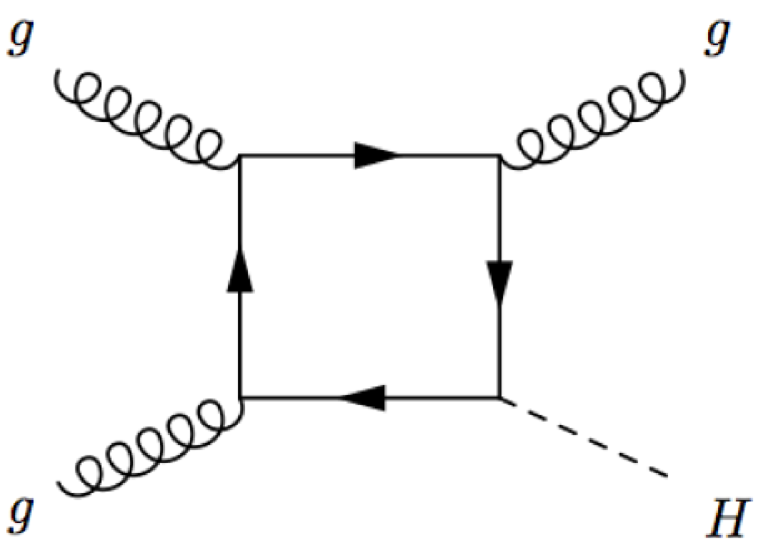




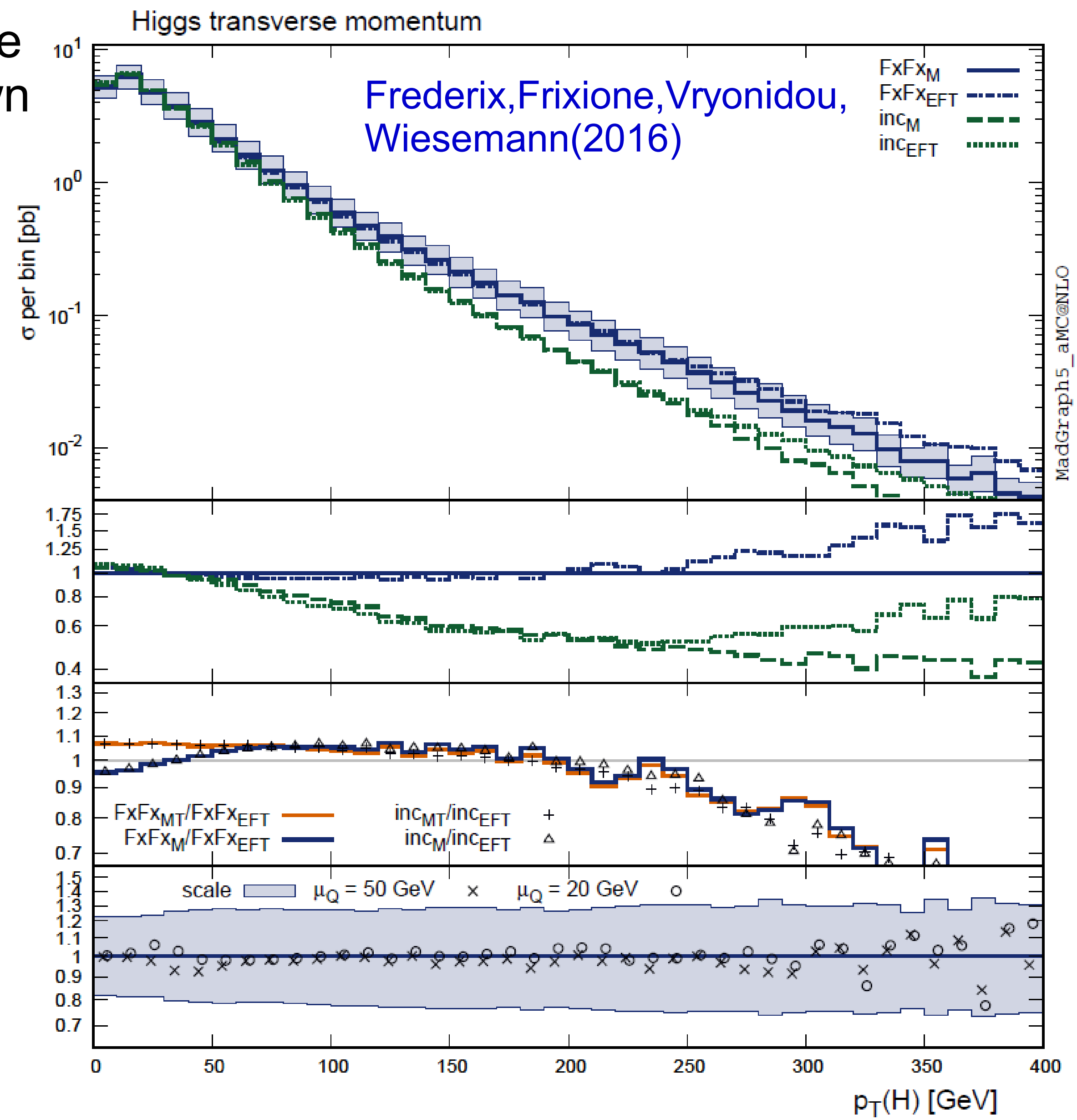
AB, Bertuzzo, Caniu, Eboli, di Cortona (preliminary)

The effect of ggH loop resolution with high PT jet: the effective ggH versus exact evaluation

- At high Higgs PT one expects the EFT ggH approach to break down



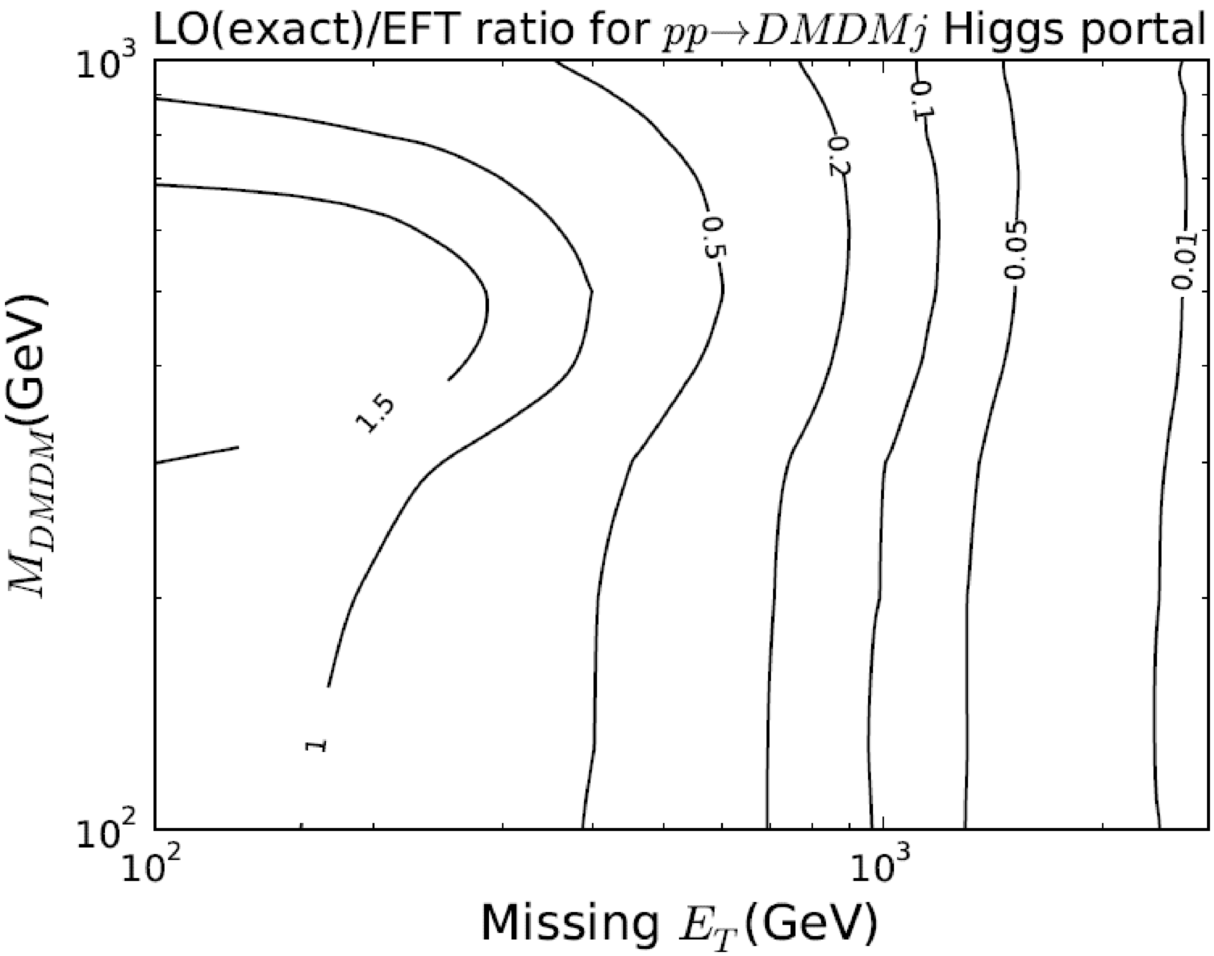
Alwall, Maltoni, Matched(2011)
Buschmann, Goncalves, Kuttimalai, Schonherr, Krauss Plehn(2014)
Frederix,Frixione,Vryonidou, Wiesemann(2016)
Greiner,Höche,Luisoni,Schönherr, Winter(2016)



- for Higgs PT ~ 400 GeV, EFT/EXACT = 1.4-1.5. What is about higher PT and different MH?

The effect of ggH loop resolution with high PT jet: the effective ggH versus exact evaluation

- There factor 10 difference for MET~ 1TeV and 100 for MET~2.5 TeV so EFT ggH approximation badly breaks down!



AB, Tomei, Gregores, Mercadante, Moon, Moretti, Novaes, Panizzi, Qazi, Rojas, Santos,Thomas: **preliminary results**

Tools for observables ↔ data link

- CheckMATE V2 (**checkmate.hepforge.org**)
  arXiv:1312.2591, arXiv:1503.01123, arXiv:1611.09856
  Drees, Schmeier,Dercks,Desai,Kim ,Rolbiecki,Tattersall, Weber

- MadAnalysis (**madanalysis.irmp.ucl.ac.be**)
  arXiv:1206.1599, arXiv:1405.3982, arXiv:1509.03639
  Conte,Dumont,Fuks,Schmitt,Kraml,Bein,Chalons

- both tools became leaders in verification of the BSM theories against the LHC data
  - monojet/mono-photon analysis from ATLAS (yet) are validated at the moment
  - quickly developing support from users (analysis validation)
  - Relies on Delphes fast simulation
  - Incorporates projection analysis (**CheckMATE only**)
  - Great potential in creating **public library of the analysis**
  - **Needs validation of more DM searches and boosted objects analysis**

Data → Theory link

- probably the most challenging problem to solve – **the inverse problem of decoding of the underlying theory from signal**
  - requires database of models, database of signatures
  - requires smart procedure based on machine learning of matching signal from data with the pattern of the signal from data

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- **HEPMDB (High Energy Physics Model Database)** was created in 2011 to make the first step towards this: **hepmdb.soton.ac.uk/phenodata**
  - recently has got a status of the permanent server at Southampton
  - convenient centralized storage environment for HEP models
  - it allows to evaluate the LHC predictions and perform event generation using CalcHEP, Madgraph for any model stored in the database
  - users can upload their own model and perform simulation – became a very attractive feature for all range of researchers
  - **no database of signatures yet** (is under development) – you input could play and important role

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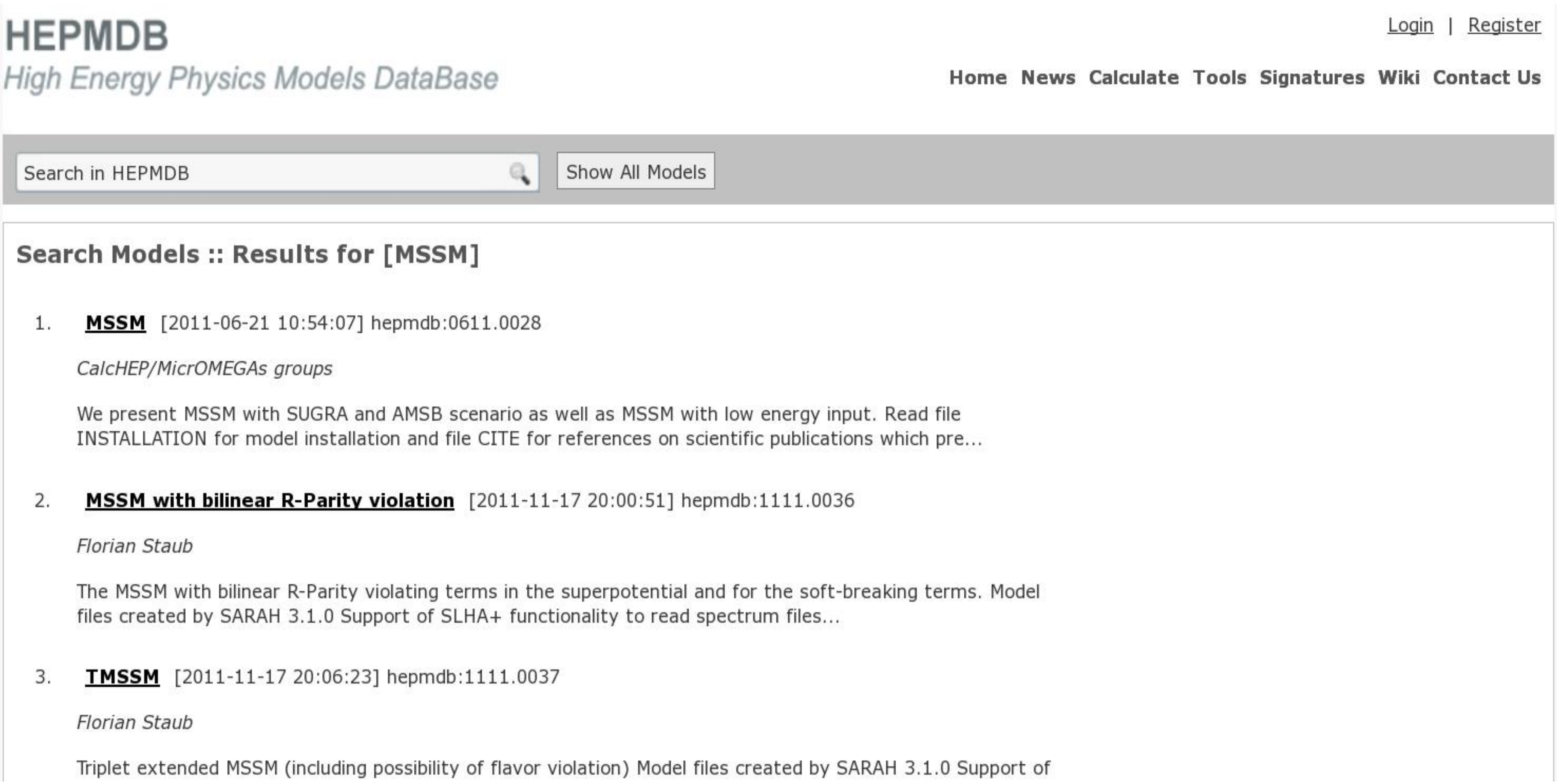

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- As a HEPMDB spin-off the **PhenoData** project was created **hepmdb.soton.ac.uk/phenodata**
  - stores data (digitized curves from figures, tables etc) from those HEP papers which did not provide data in arXiv or HEPData, and to avoid duplication of work of HEP researchers on digitizing plots.
  - has an easy search interface and paper identification via arXiv, DOI or preprint numbers. PhenoData is not intended to be a replication of any existing archive

What is NOT discussed in this talk

- **Model-specific tools**
  - **Isajet: http://www.nhn.ou.edu/~isajet/**
  - specialized for valious SUSY models, has DM relic density (**IsaRED**)and DM DD modules (**IsaRES**) as parts of **IsaTOOLS**
  - **DarkSUSY: http://www.darksusy.org/**
    besides relic density and DM DD, predicts also DM ID, uses GLAPROP
    ....
- **LanHEP and FeynRules:**
  tools for Feynman rules (model) generation starting from the Lagrangian

- **Some Recasting tools, especially those which are not puboic yet**
  https://twiki.cern.ch/twiki/bin/view/LHCPhysics/RecastingTools
  - **GAMBIT :** the Global and Modular Beyond-Standard Model Inference Tool (GAMBIT) is a global fitting code for generic Beyond the Standard Model theories, designed to allow fast and easy definition of new models, observables, likelihoods, scanners and backend physics codes
  - **ATOM** :Atom is a general purpose framework for reinterpreting existing experimental analyses and designing new ones. Originally started as a fork of Rivet

Conclusions and Outlook

- DM Tools are powerful but should not blindly trusted or blamed!
- We should use independent public programs for the cross-check and the great point is that these are exist
- Not only tools but also models should be public – this will help us to validate and improve them – HEPMDB and FeynRules are good examples
- **Model** → **Signatures** → **Data** tools are in the good shape, it is time to start working on **Data** → **Model** link