New constraints on the Inert Doublet Model from Run 1 of the LHC

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arXiv:1503.07367, in collaboration with
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March 31, 2015

2HDMs and the IDM

addition of a second Higgs doublet to the SM:

$$
\begin{aligned}
V = {} & m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - \left[m_{12}^2 \Phi_1^\dagger \Phi_2 + \text{h.c.} \right] \\
& + \frac{1}{2}\lambda_1 (\Phi_1^\dagger \Phi_1)^2 + \frac{1}{2}\lambda_2 (\Phi_2^\dagger \Phi_2)^2 + \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) \\
& + \left\{ \frac{1}{2}\lambda_5 (\Phi_1^\dagger \Phi_2)^2 + \left[\lambda_6 (\Phi_1^\dagger \Phi_1) + \lambda_7 (\Phi_2^\dagger \Phi_2) \right] \Phi_1^\dagger \Phi_2 + \text{h.c.} \right\}
\end{aligned}
$$

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addition of a second Higgs doublet to the SM:

$$V = m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - \left[m_{12}^2 \Phi_1^\dagger \Phi_2 + \mathrm{h.c.} \right]$$
$$+ \frac{1}{2}\lambda_1 (\Phi_1^\dagger \Phi_1)^2 + \frac{1}{2}\lambda_2 (\Phi_2^\dagger \Phi_2)^2 + \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1)$$
$$+ \left\{ \frac{1}{2}\lambda_5 (\Phi_1^\dagger \Phi_2)^2 + \left[\lambda_6 (\Phi_1^\dagger \Phi_1) + \lambda_7 (\Phi_2^\dagger \Phi_2) \right] \Phi_1^\dagger \Phi_2 + \mathrm{h.c.} \right\}$$

Inert Doublet Model defined with the following assumptions:

i. exact Z_2 symmetry $\Phi_1 \to -\Phi_1$; implies $\lambda_6 = \lambda_7 = m_{12} = 0$

ii. Type I Yukawa couplings (all fermions couple to Φ_2)

iii. $\langle \Phi_1 \rangle = 0$

only Φ_2 breaks the EW symmetry and couples to fermions; Φ_1 is "inert"

five physical states instead of just one:

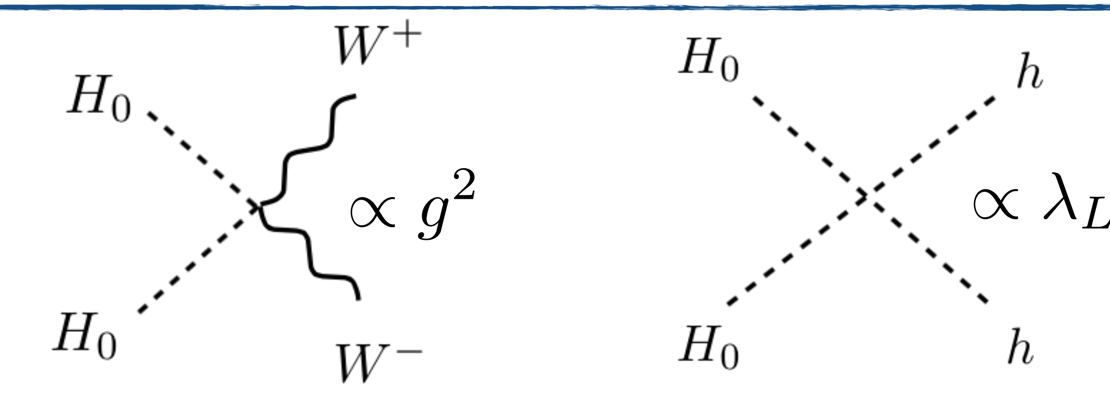
- from Φ_2 : h^0 (SM-like Higgs boson)
- from Φ_1 : H^0, A^0, H^+, and H^-

Z_2 symmetry: pair production only, lightest particle is stable and a dark matter candidate

Dark matter relic density

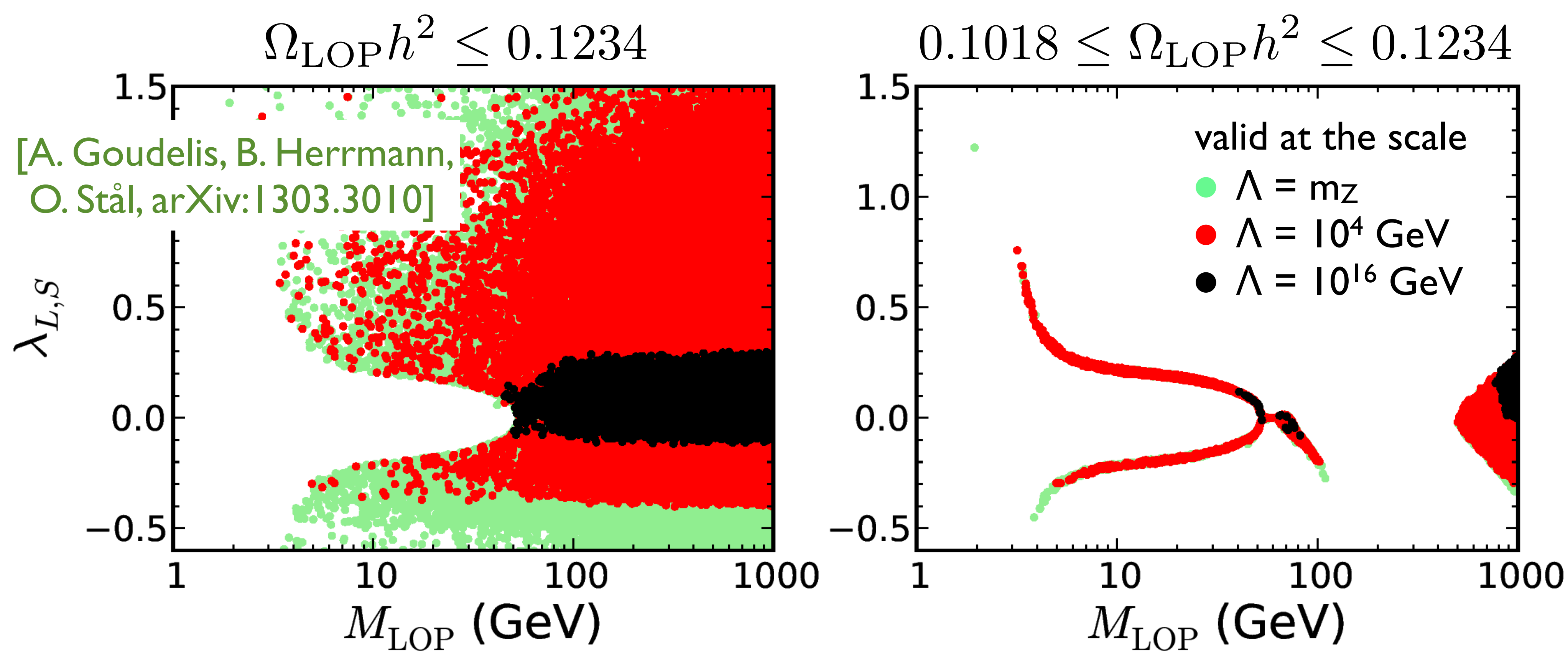
H^0 or A^0 can be the lightest Z_2-odd particle (LOP)

important diagrams include:



$$\lambda_L = \frac{1}{2}(\lambda_3 + \lambda_4 + \lambda_5)$$

H^0-H^0-h^0-h^0 coupling



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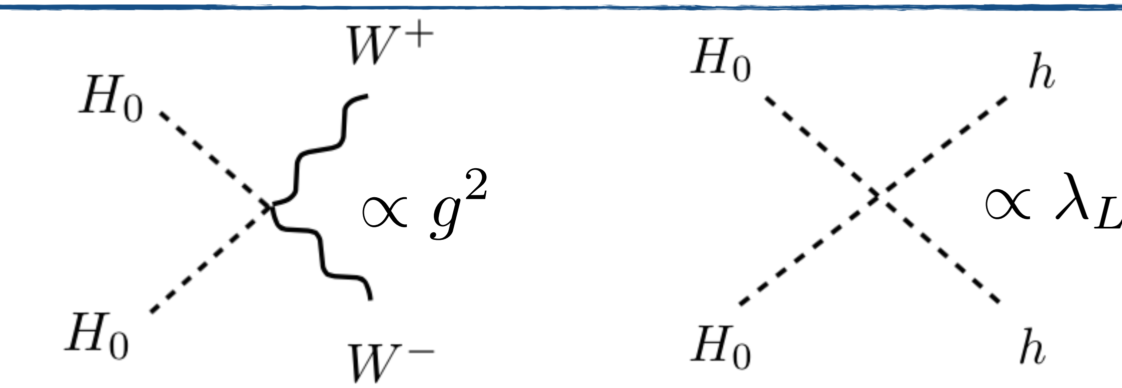

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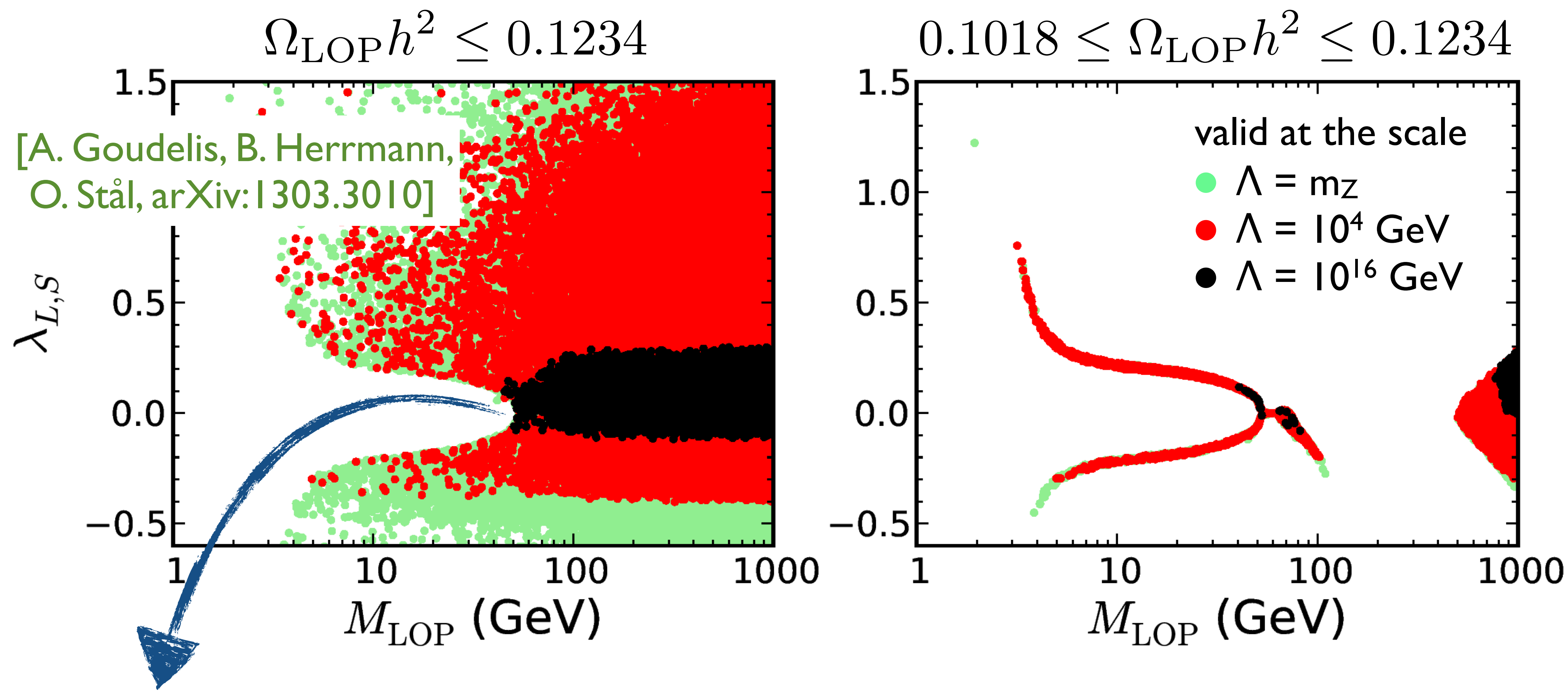

two effects are at play for $M_{LOP} \approx 50$ GeV:

i. proximity with the resonance at $m_h/2 \approx 62.5$ GeV

ii. annihilation into WW^* (gauge interaction)

Dark matter relic density

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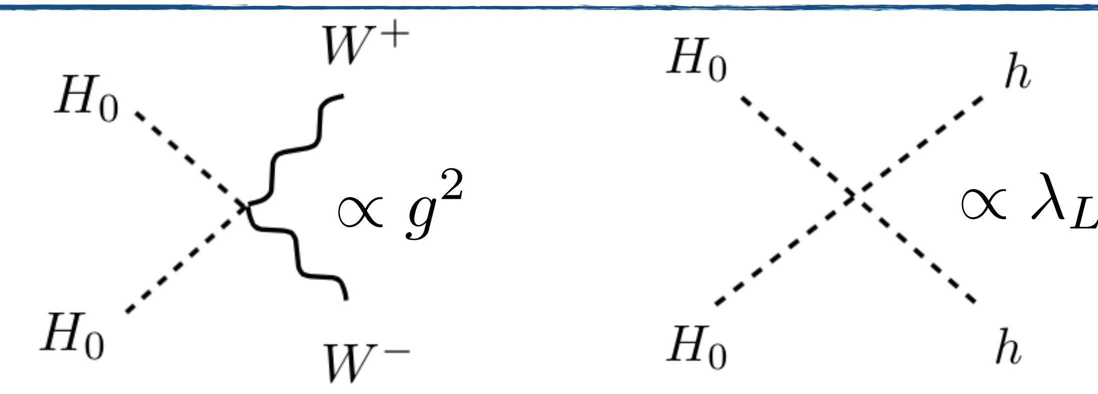

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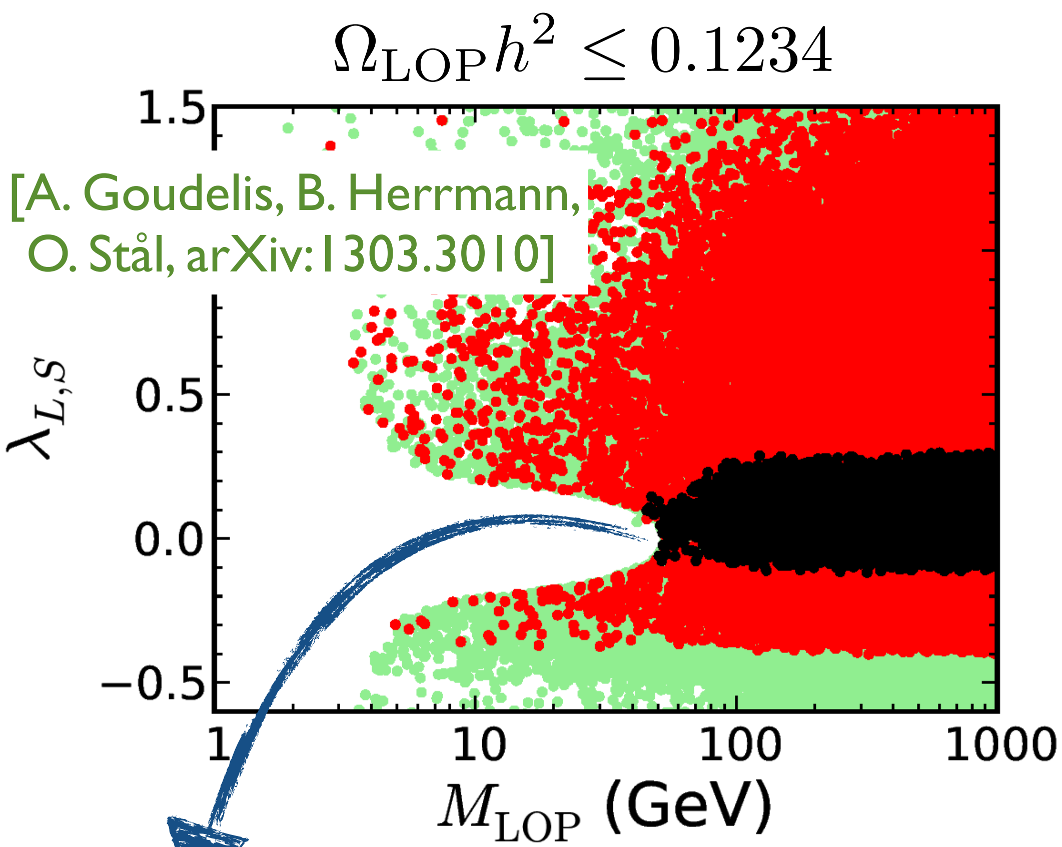
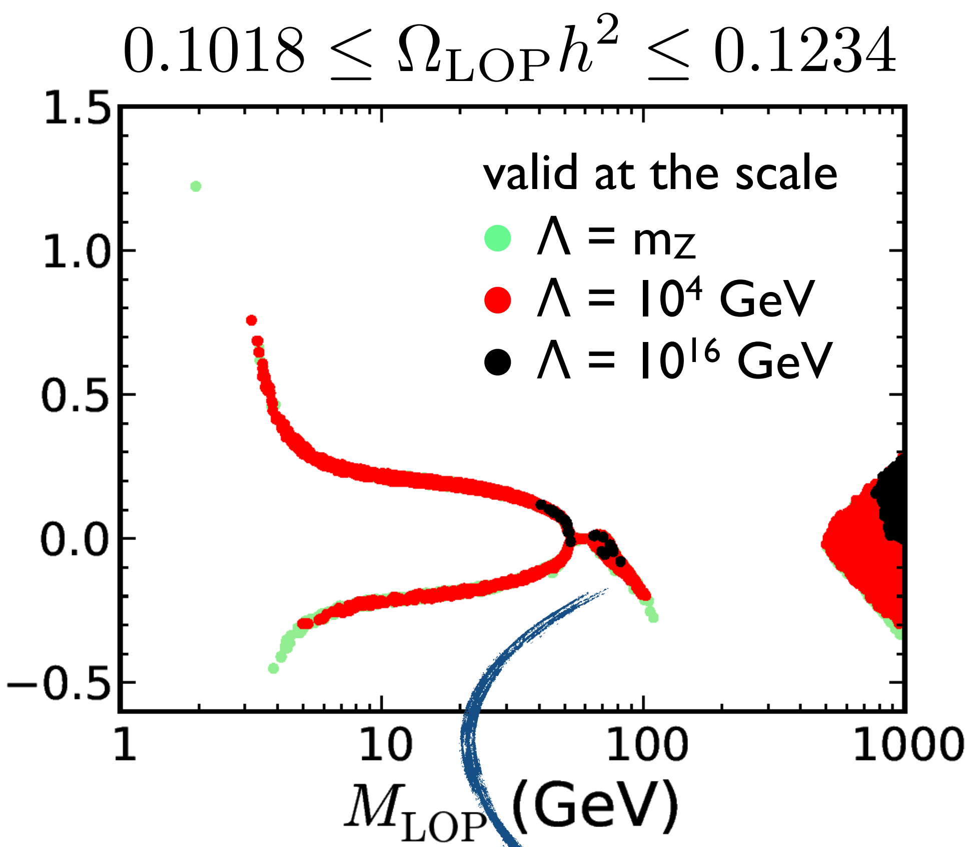
H^0-H^0-h^0-h^0 coupling



[A. Goudelis, B. Herrmann, O. Stål, arXiv:1303.3010]



[L. Lopez-Honorez, C. E. Yaguna, arXiv:1011.1411]

two effects are at play for $M_{LOP} \approx 50$ GeV:

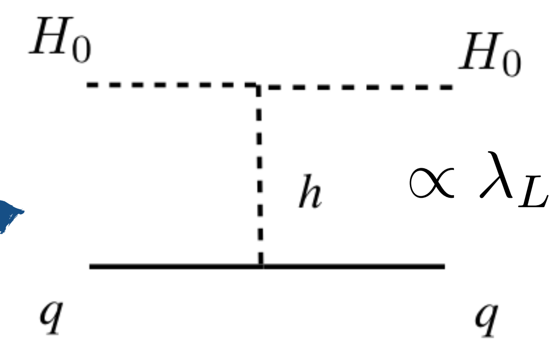
i. proximity with the resonance at $m_h/2 \approx 62.5$ GeV

ii. annihilation into WW^* (gauge interaction)

destructive interference for the annihilation into WW (direct or h^0 mediated)

Direct direction of dark matter

main contribution to the SI scattering cross section through the exchange of h^0



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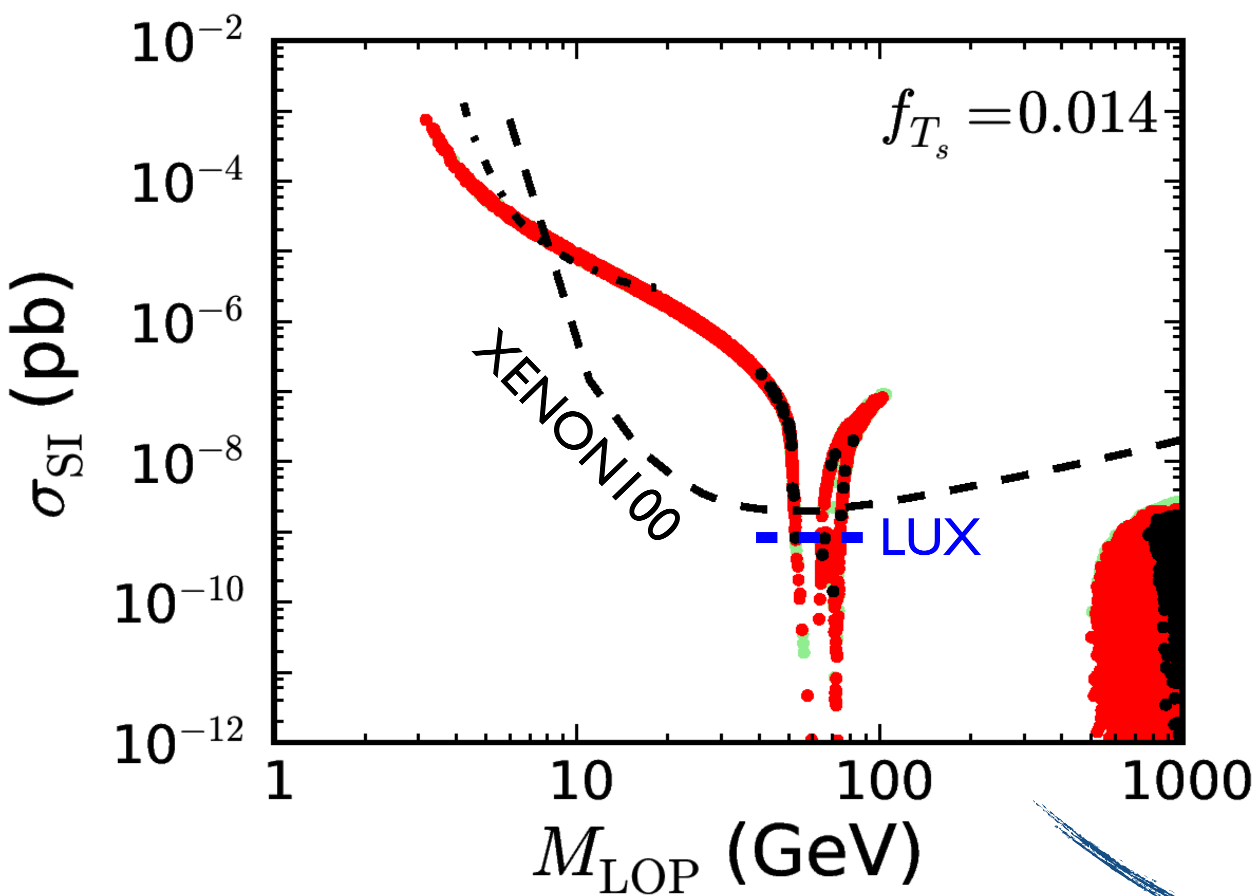
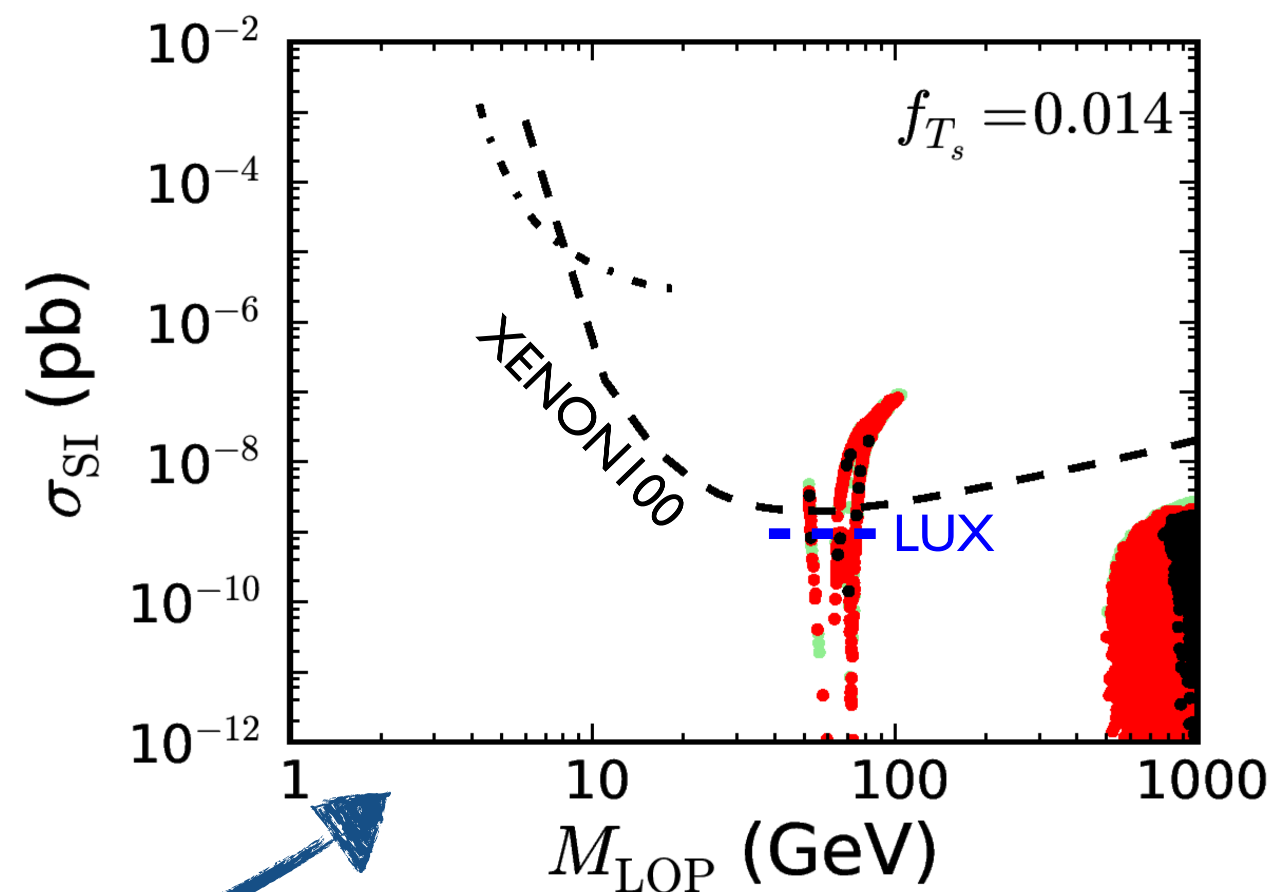




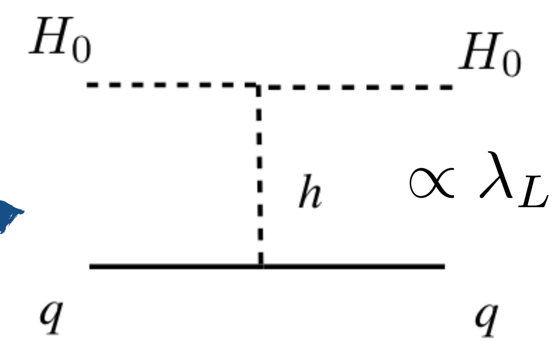
$\mathrm{BR}(h^0 \to \mathrm{inv.}) < 0.65$

(restricts $\lambda_{L,S} \lesssim O(0.01)$)

→ IDM dark matter excluded for $M_{LOP} \lesssim 55$ GeV

Direct direction of dark matter

main contribution to the SI scattering cross section through the exchange of h^0



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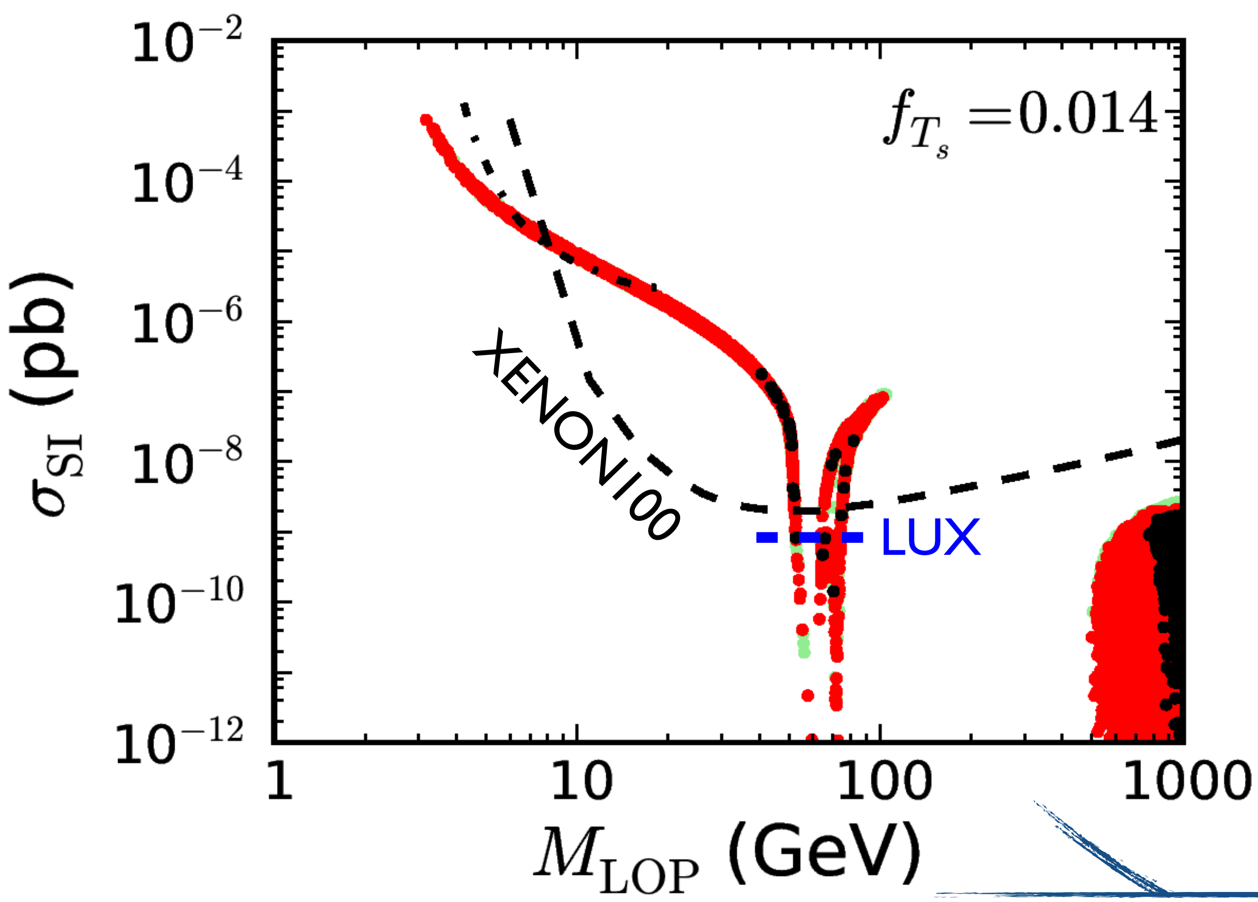
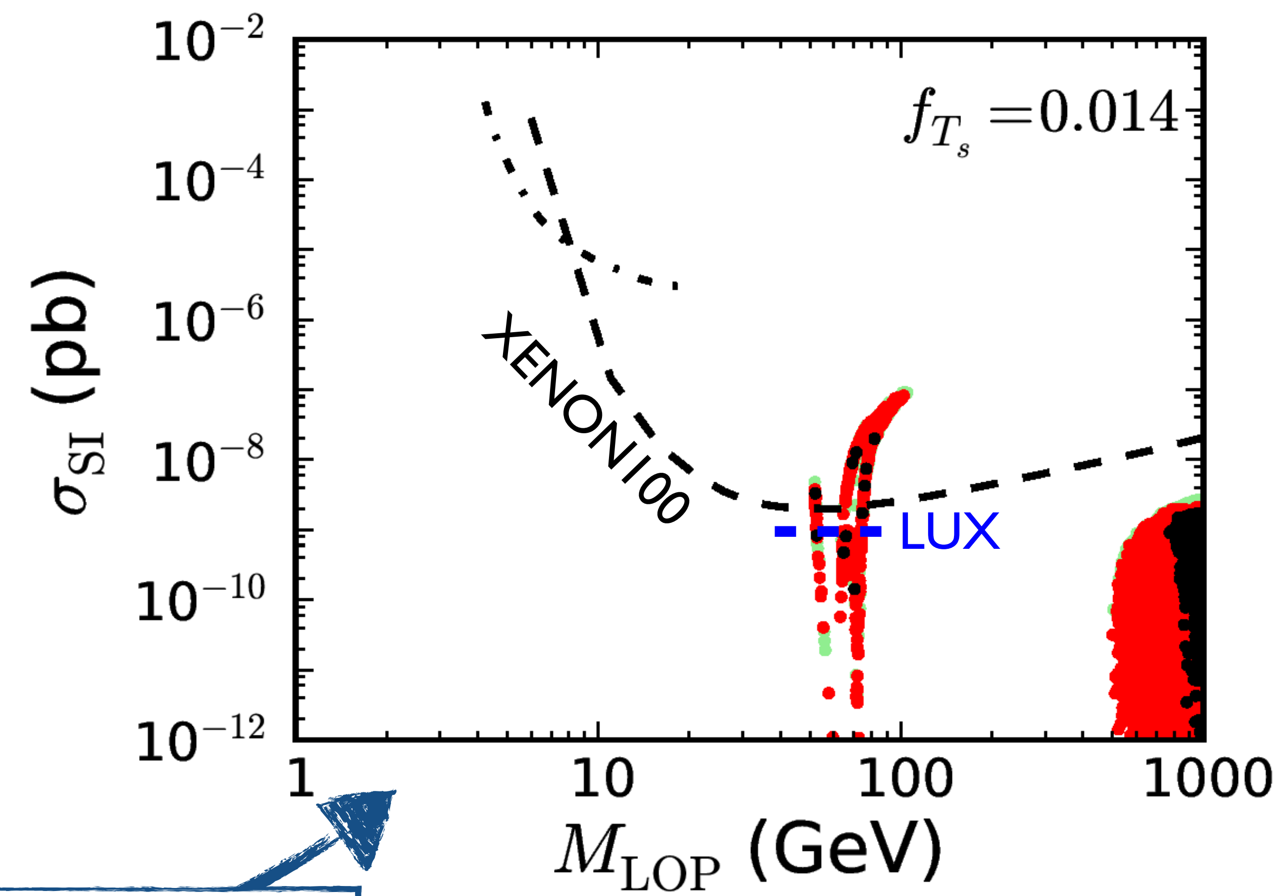




current limit on invisible Higgs decays:

$$\mathrm{BR}(h^0 \to \mathrm{inv.}) \lesssim 0.12$$

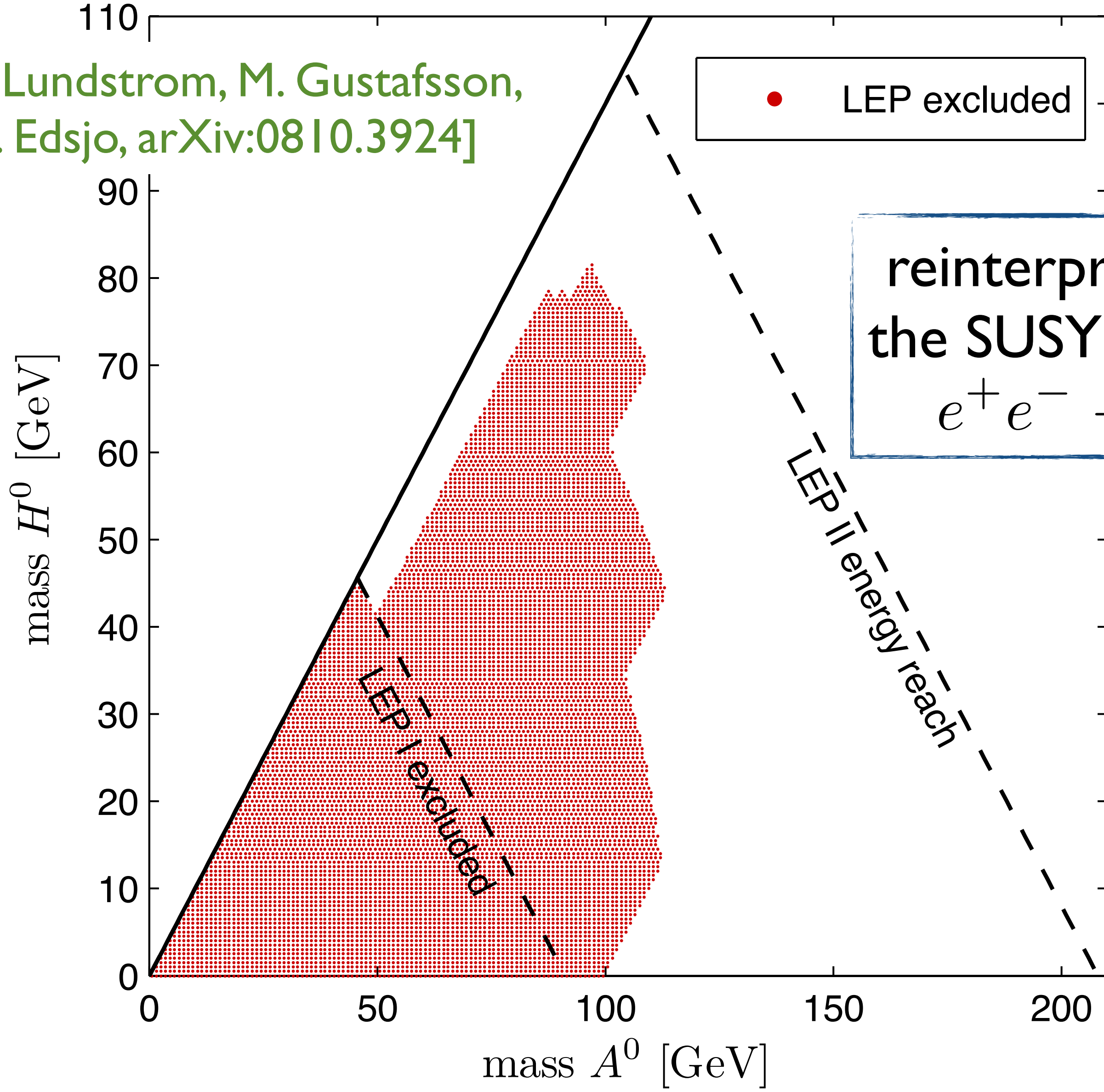
[Bernon, BD, Kraml, arXiv:1409.1588]

→ IDM dark matter excluded for $M_{LOP} \lesssim 55$ GeV

Constraints from LEP

$$e^+e^- \to A^0 H^0$$
$$A^0 \to Z^{0(*)}(\to \ell^+\ell^-)H^0$$

[E. Lundstrom, M. Gustafsson, J. Edsjo, arXiv:0810.3924]



reinterpretation of the SUSY search for $e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_1^0$

$$e^+e^- \to H^+H^-$$
$$H^\pm \to W^{\pm(*)}(\to \ell\nu)H^0$$

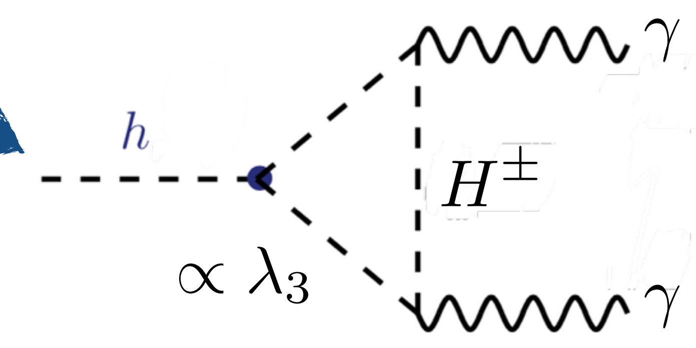
[A. Pierce, J. Thaler, hep-ph/0703056]

reinterpretation of the SUSY search for $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$

$$m_{H^\pm} \gtrsim 70 - 90 \text{ GeV}$$

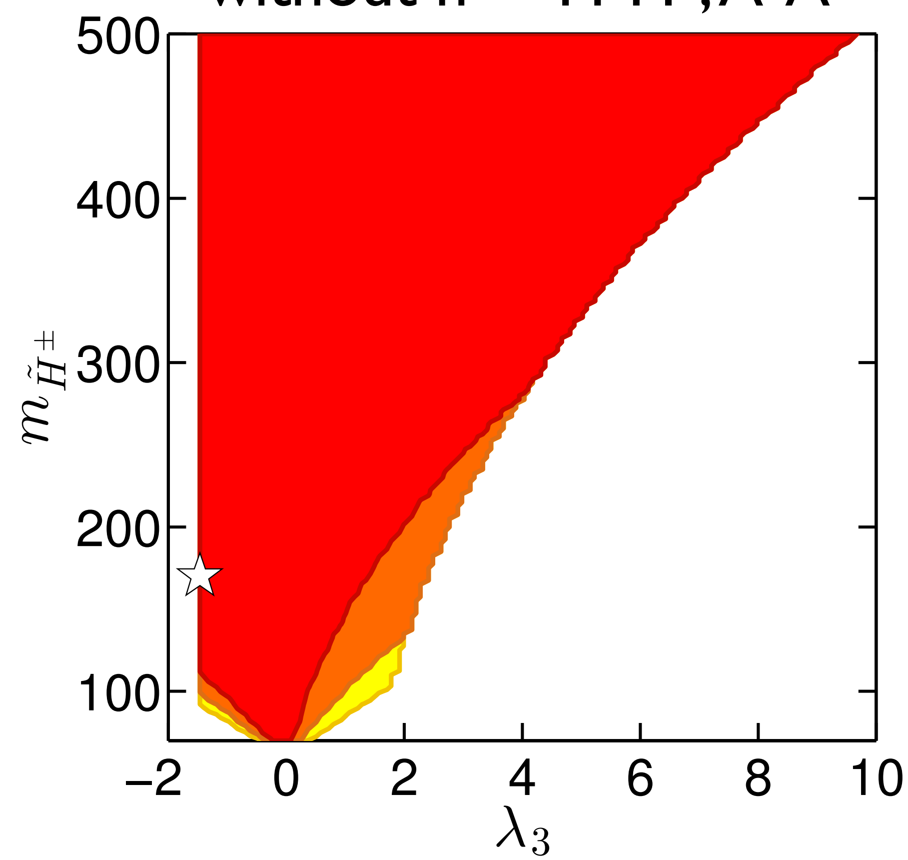
Constraints from the LHC (I)

- couplings of the h^0: SM-like at tree-level
  at loop-level: charged Higgs contribution to $h^0 \to \gamma\gamma$

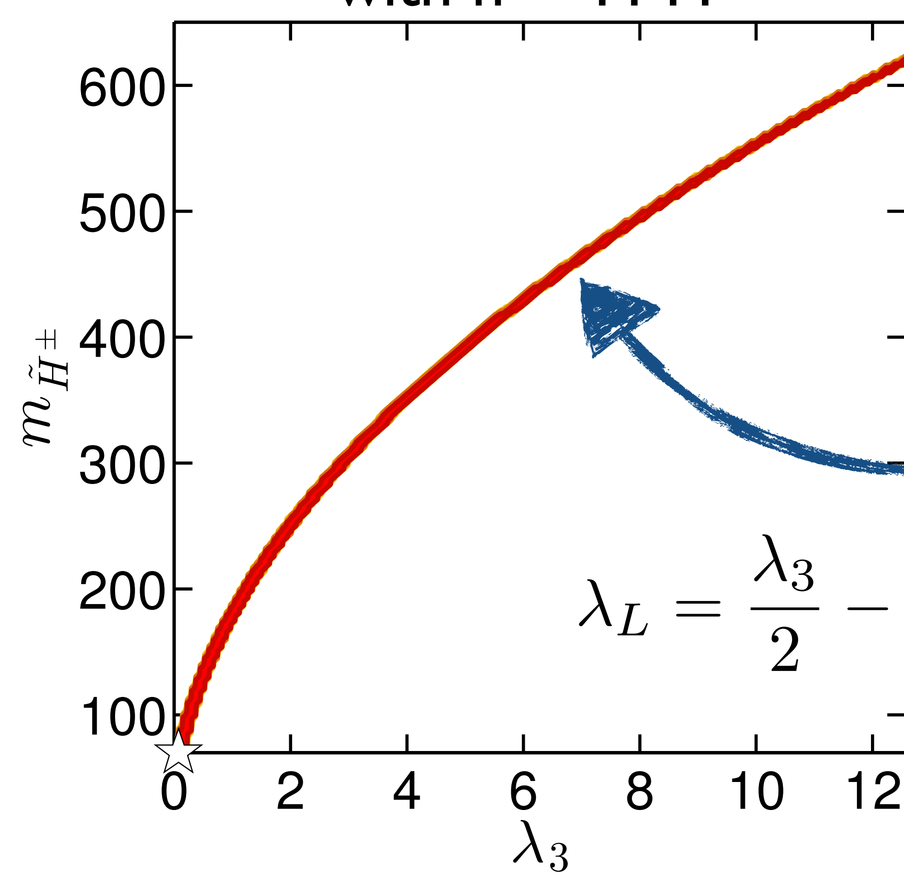


- from a global fit to the properties of the Higgs boson:
  [G. Bélanger, BD, U. Ellwanger, J. F. Gunion, S. Kraml, arXiv:1306.2941]

without $h^0 \to H^0H^0, A^0A^0$



with $h^0 \to H^0H^0$



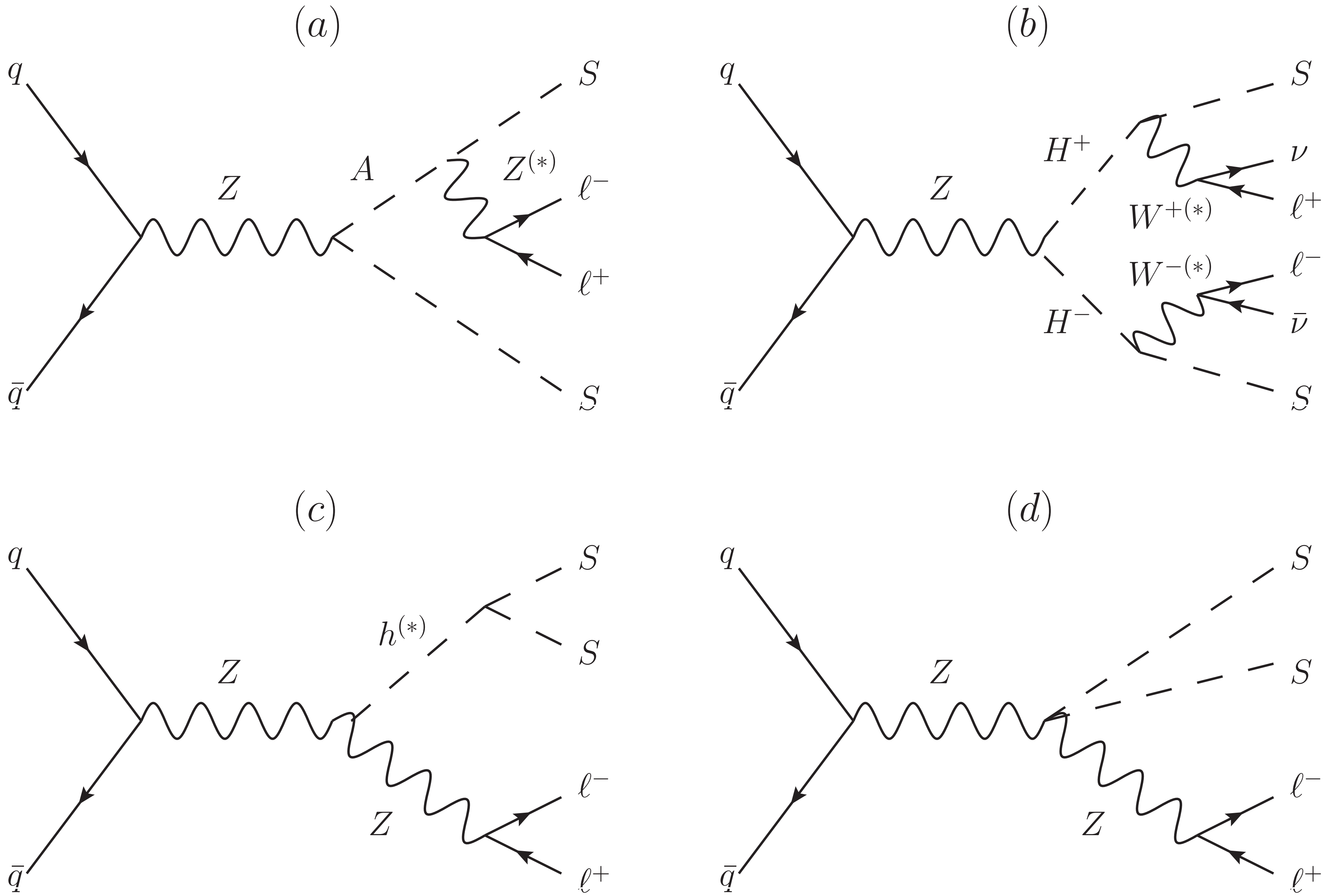
vanishing λ_L

$$\lambda_L = \frac{\lambda_3}{2} - \frac{1}{v^2}(m^2_{H^\pm} - m^2_{H^0})$$

- Higgs constraints only relevant for light $H^\pm$ and large λ_L

Constraints from the LHC (2)

inert doublet coupled to the SM through EW interactions
cascade decay to the LOP through W and Z bosons
→ *n* leptons + MET final states; we focus on *n*=2



(a) IDM equivalent of the SUSY process $pp \to \tilde{\chi}_2^0 \tilde{\chi}_1^0$ (no dedicated search at the LHC yet)

(b) IDM equivalent of the SUSY process $pp \to \tilde{\chi}_1^+ \tilde{\chi}_1^-$

(c),(d) can be constrained by searches for $Zh^0 \to \ell\ell$+inv.

→ existing LHC SUSY and Higgs searches can constrain the IDM

[E. Dolle, X. Miao, S. Su, B. Thomas, arXiv:0909.3094]

The need for new interpretations

- we need to go beyond the interpretations given in the experimental papers
  → separate implementations of the analyses using public fast simulation tools (e.g. Delphes [de Favereau et al., arXiv:1307.6346]) are necessary
- selection criteria of LHC analyses are re-implemented in the framework of MadAnalysis 5, validated and integrated to the public database of LHC analyses
  → see Dipan's talk tomorrow

[Conte, BD, Fuks, Wymant, arXiv:1405.3982; BD, Fuks, Kraml, et al., arXiv:1407.3278]

- we consider two ATLAS analyses from the database (accessible at http://madanalysis.irmp.ucl.ac.be/wiki/PhysicsAnalysisDatabase)

Analysis	Short Description	Implemented by	Code	Validation note	Status
ATLAS-SUSY-2013-05 (published)	stop/sbottom search: 0 leptons + 2 b-jets	G. Chalons	Inspire	PDF (figures)	done
ATLAS-SUSY-2013-11 (published)	EWK-inos, 2 leptons + MET	B. Dumont	Inspire	PDF (source)	done
ATLAS-HIGG-2013-03 (published)	ZH->ll+invisible	B. Dumont	Inspire	PDF (source)	done
ATLAS-EXOT-2014-06 (published)	mono-photons + MET	D. Barducci	Inspire	PDF	done

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ATLAS-SUSY-2013-11

[arXiv:1407.3278]

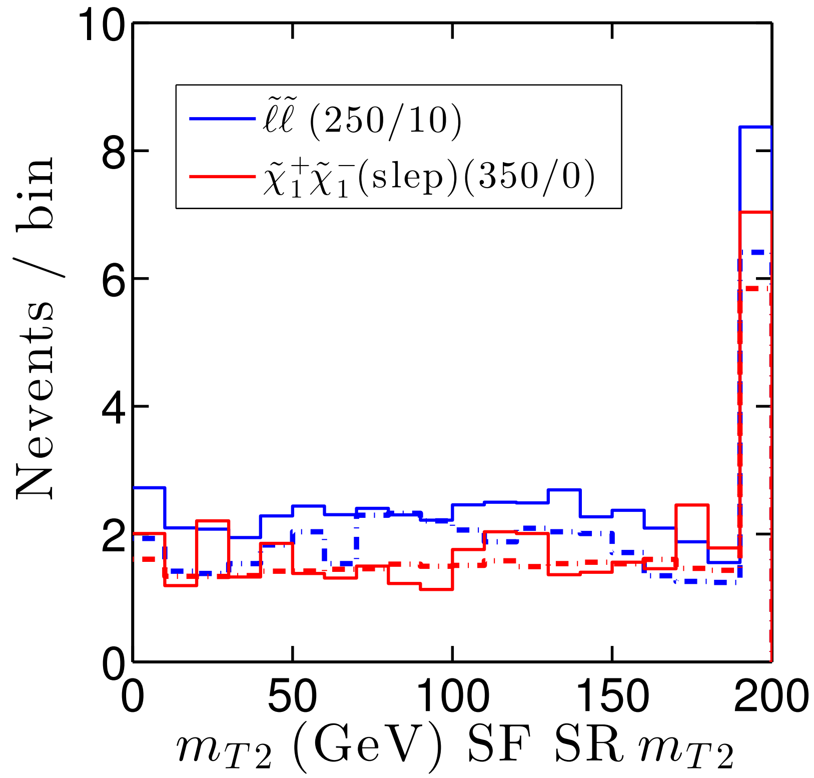
- ATLAS search for electroweak-inos and sleptons in 2 lepton + MET final states

SR	m_{T2}^{90}	m_{T2}^{120}	m_{T2}^{150}	WWa	WWb	WWc	$Zjets$
lepton flavour	DF,SF	DF,SF	DF,SF	DF,SF	DF,SF	DF,SF	SF
central light jets	0	0	0	0	0	0	≥ 2
central b-jets	0	0	0	0	0	0	0
forward jets	0	0	0	0	0	0	0
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	> 10	> 10	> 10	> 10	> 10	> 10	< 10
$m_{\ell\ell}$ [GeV]	—	—	—	< 120	< 170	—	—
$E_T^{\text{miss,rel}}$ [GeV]	—	—	—	> 80	—	—	> 80
$p_{T,\ell\ell}$ [GeV]	—	—	—	> 80	—	—	> 80
m_{T2} [GeV]	> 90	> 120	> 150	—	> 90	> 100	—
$\Delta R_{\ell\ell}$	—	—	—	—	—	—	[0.3,1.5]
m_{jj} [GeV]	—	—	—	—	—	—	[50,100]

- SR-m_{T2} target:
  $pp \to \tilde{\ell}^+\tilde{\ell}^- \to \ell^+\tilde{\chi}_1^0\ell^-\tilde{\chi}_1^0$
  $pp \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to \ell^+\nu\tilde{\chi}_1^0\ell^-\nu\tilde{\chi}_1^0$
- SR-WW target:
  $pp \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to W^+\tilde{\chi}_1^0W^-\tilde{\chi}_1^0$
- SR-Zjets targets:
  $pp \to \tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to W^\pm\tilde{\chi}_1^0Z\tilde{\chi}_1^0$

- validation results include:

cut	ATLAS result	MA5 result
Initial number of events		152.2
2 OS leptons		46.9
$m_{\ell\ell} > 20$ GeV		46.9
τ veto		46.9
$\mu\mu$ leptons	16.4	24.2
≥ 2 central light jets	13.2	15.4
b and forward jet veto	9.5	12.4
Z window	9.1	11.6
$p_{T,\ell\ell} > 80$ GeV	8.0	10.1
$E_T^{\text{miss,rel}} > 80$ GeV	5.1	7.0
$0.3 < \Delta R_{\ell\ell} < 1.5$	4.2	5.9
$50 < m_{jj} < 100$ GeV	2.7	3.6
$p_T(j_1, j_2) > 45$ GeV	1.8	1.6



ATLAS-HIGG-2013-03

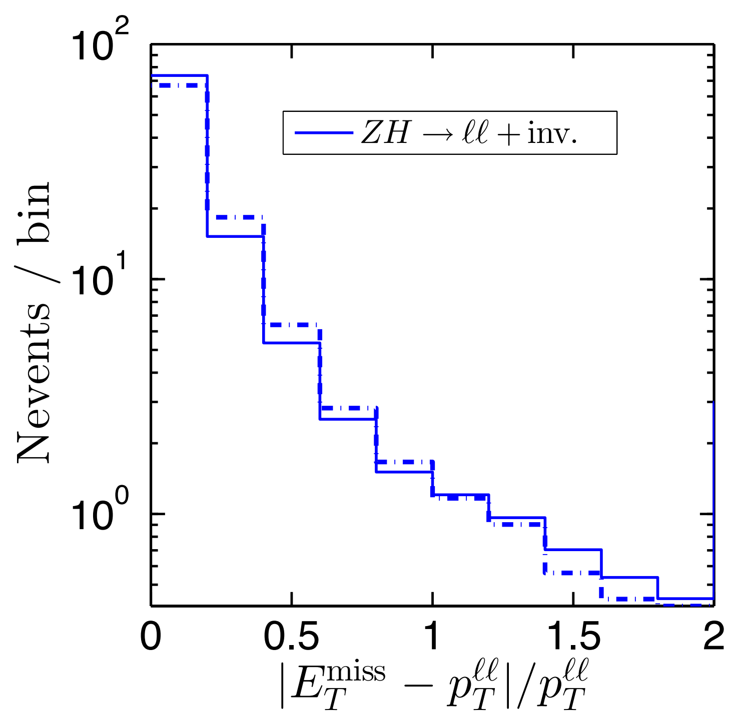
[arXiv:1402.3244]

- ATLAS search for invisible decays of the Higgs boson in the 2 lepton + MET final state

- only one SR, where it is required:
  - $|m_{\ell\ell} - m_{Z^0}| < 15$ GeV
  - $E_T^{\rm miss} > 90$ GeV
  - $\Delta\phi(p_T^{\ell\ell}, E_T^{\rm miss}) > 2.6$
  - $\Delta\phi(\ell, \ell) < 1.7$
  - $|E_T^{\rm miss} - p_T^{\ell\ell}|/p_T^{\ell\ell} < 0.2$
  - no jet
  - $\Delta\phi(E_T^{\rm miss}, p_T^{\rm miss}) < 0.2$ (avoid fake MET from misreconstructed energy in the calorimeter)

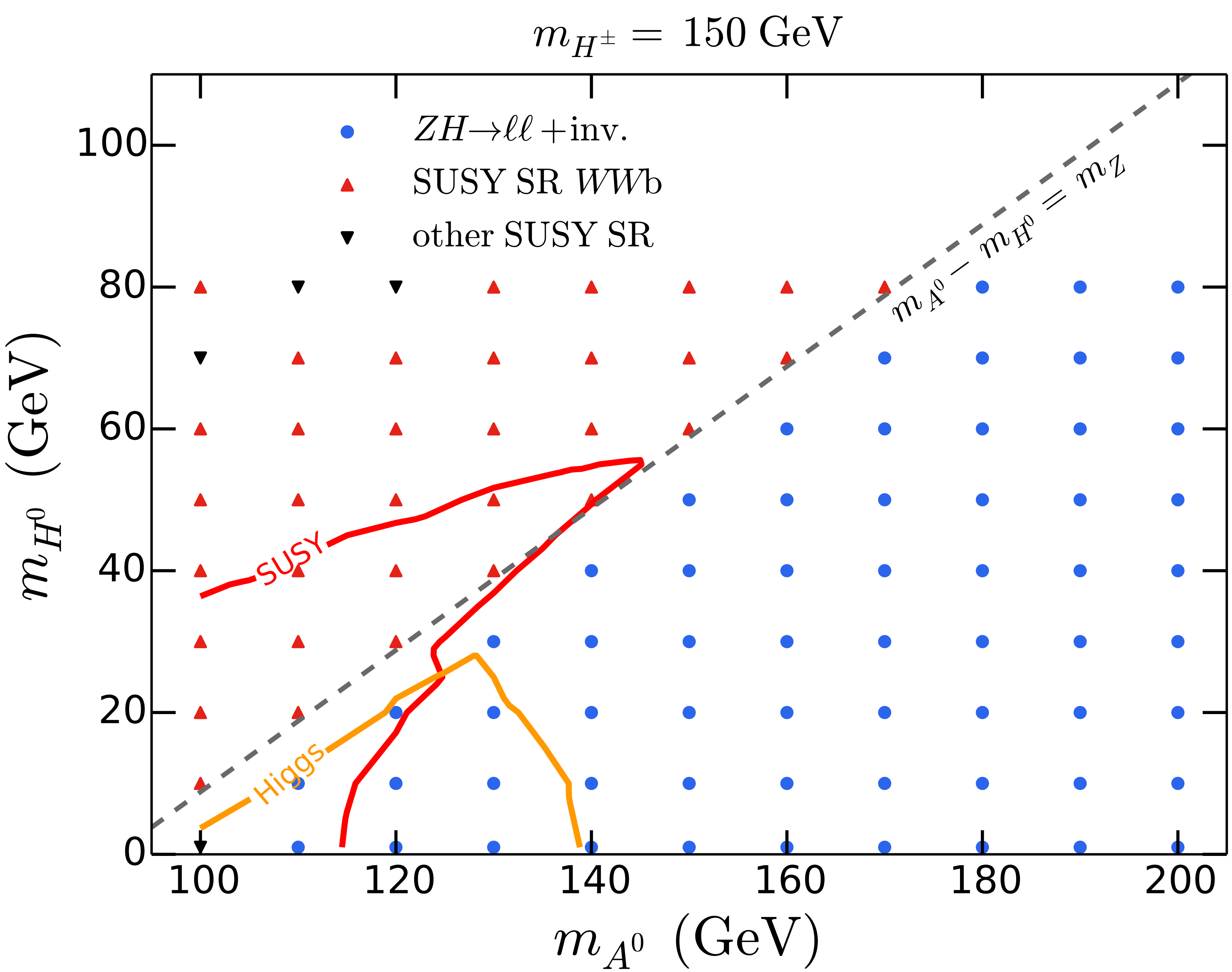
- validation results include:

cut	ATLAS result	MA5 result
Initial number of events		838.9
2 OS leptons		256.2
$\|m_{\ell\ell} - m_{Z^0}\| < 15$ GeV	243	244.1
$E_T^{\rm miss} > 90$ GeV	103	105.1
$\Delta\phi(p_T^{\ell\ell}, E_T^{\rm miss}) > 2.6$		91.7
$\Delta\phi(\ell, \ell) < 1.7$		82.9
$\Delta\phi(E_T^{\rm miss}, p_T^{\rm miss}) < 0.2$		76.5
$\|E_T^{\rm miss} - p_T^{\ell\ell}\|/p_T^{\ell\ell} < 0.2$		63.2
jet veto	$44 \pm 1 \pm 3$	54.8



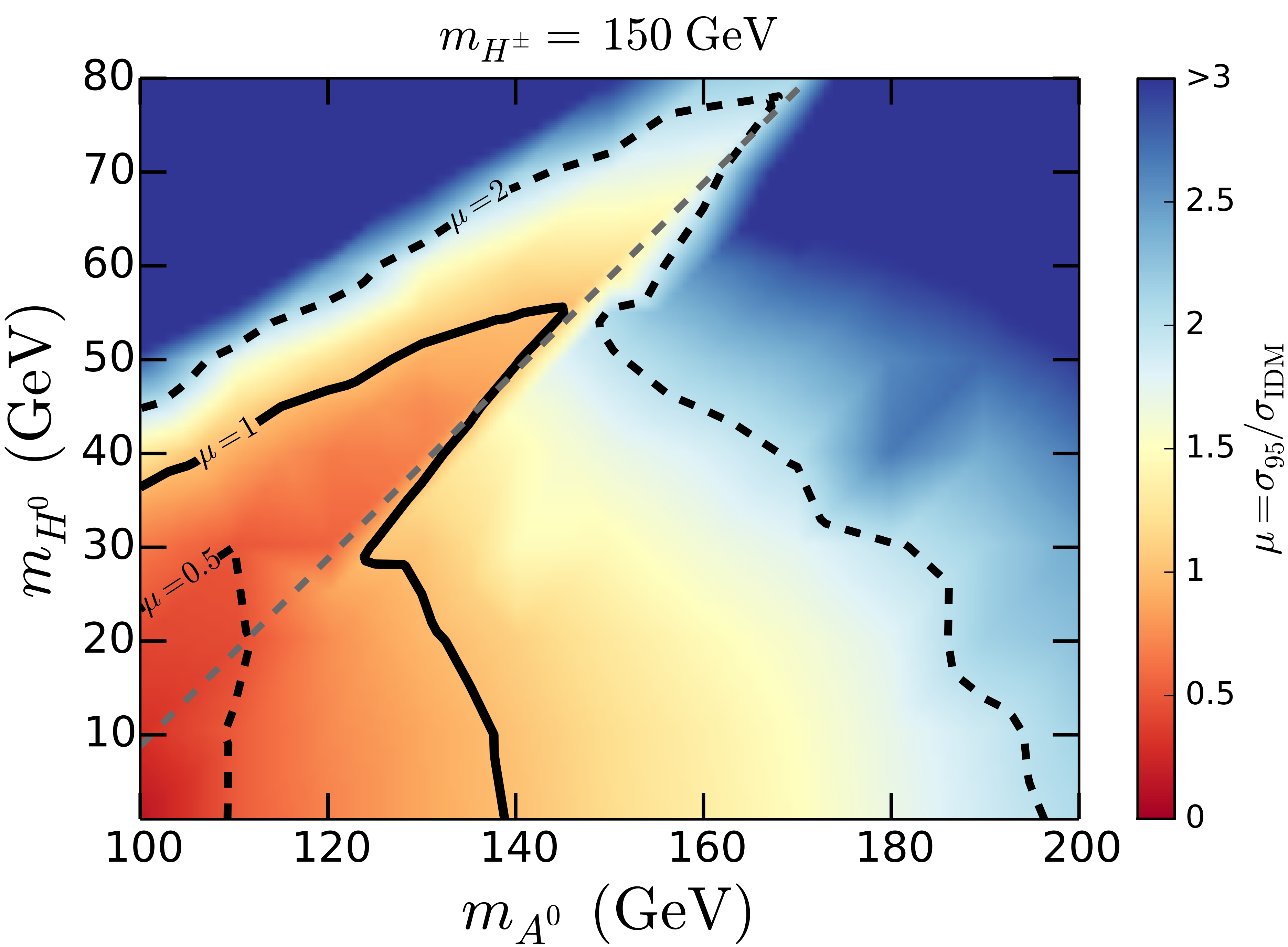
Results (1)

we performed a scan of the IDM, generating events using MadGraph 5 and PYTHIA 6
Delphes 3 is used for the detector simulation
we assume $\lambda_L = 0$ (vanishing H^0-H^0-h^0(-h^0) coupling)



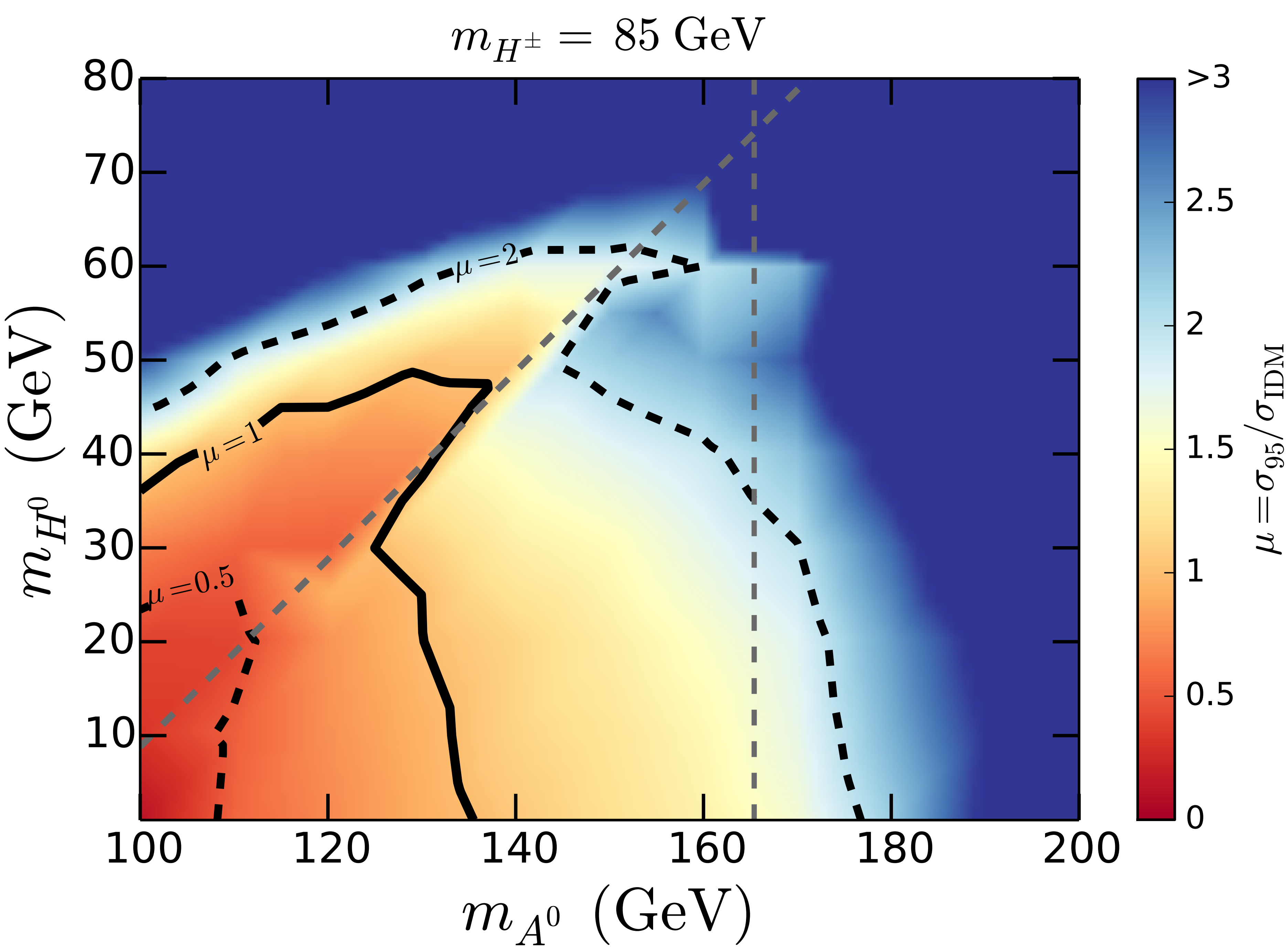
- dominant process is always found to be $pp \to A^0 H^0$ with $A^0 \to Z^{0(*)}(\to \ell^+\ell^-)H^0$ (the H± plays a little role)
- the Higgs search requires $|m_{\ell\ell} - m_{Z^0}| < 15$ GeV
  the SUSY search requires $|m_{\ell\ell} - m_{Z^0}| > 10$ GeV
- SR WWb optimized for $pp \to \tilde{\chi}_1^+ \tilde{\chi}_1^-$ with $\tilde{\chi}_1^\pm \to W^\pm(\to \ell\nu)\tilde{\chi}_1^0$
- we exclude up to $m_H = 55$ GeV for $m_A = 145$ GeV

Results (2)



- color indicates μ value for the combined results
  μ < 1
  ⇔ excluded at > 95% CL
- two regions can "easily" be probed:
  - $m_A \gg m_H$
    (Higgs search)
  - $m_A - m_H = m_Z$ - few GeV
    (SUSY search)

Results (3)



- $H^\pm$ just above the LEP bound: modest change except at high m_A
- at high m_A one has $A^0 \to H^\pm W^\mp$ with $H^\pm \to W^\pm H^0$ can also give two leptons but they are much softer (→ very small acceptance)
- we have also checked for $m_{H\pm}$ = 300 GeV: same results as for the $m_{H\pm}$ = 150 GeV case

Conclusions

- LHC results significantly extend previous limits from LEP on the Inert Doublet Model
  the process driving the exclusion is always $pp \to A^0 H^0$ with $A^0 \to Z^{0(*)}(\to \ell^+\ell^-)H^0$

- we exclude up to m_H = 55 GeV for m_A = 145 GeV and $m_{H\pm}$ = 150 GeV
  the charged Higgs plays a little role (but should be $\lesssim$ 250-300 GeV for a viable T parameter)

- we are at the edge of starting to probe the viable region for dark matter
  plus, these results may already be relevant for dark matter in a non-minimal setup
  e.g. U(1)IDM, Z_3 symmetry, … [P. Ko, Y. Omura, C. Yu, arXiv:1405.2138; G. Belanger, K. Kannike, A. Pukhov, M. Raidal, arXiv:1403.4960; …]

- results will quickly improve at Run II
  dedicated searches targeting $pp \to A^0 H^0$ (or $pp \to \tilde{\chi}_2^0 \tilde{\chi}_1^0$)
  would have more sensitivity to the IDM using angular separation variables

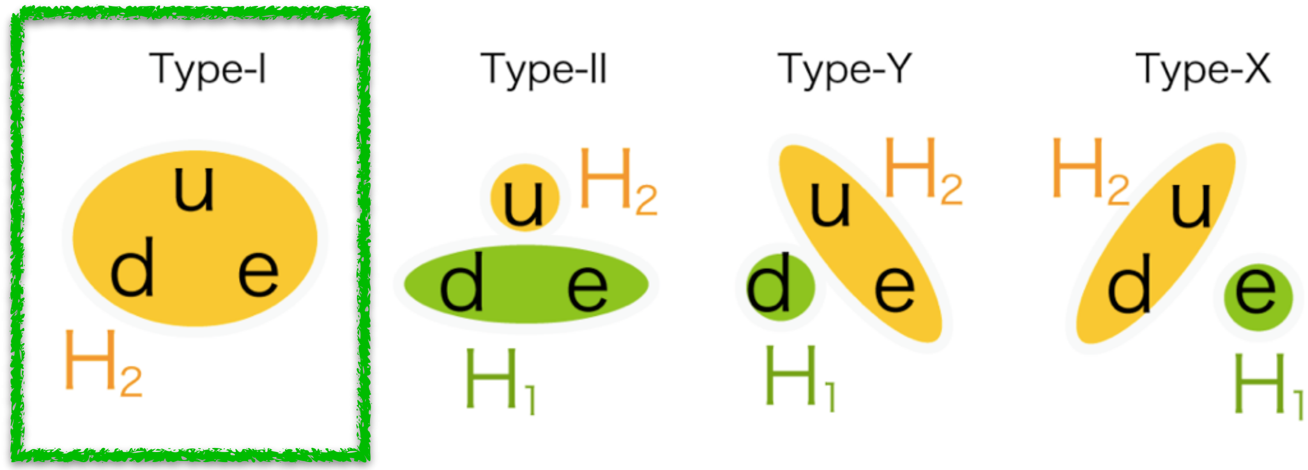
backup slides

IDM

2HDM types and couplings

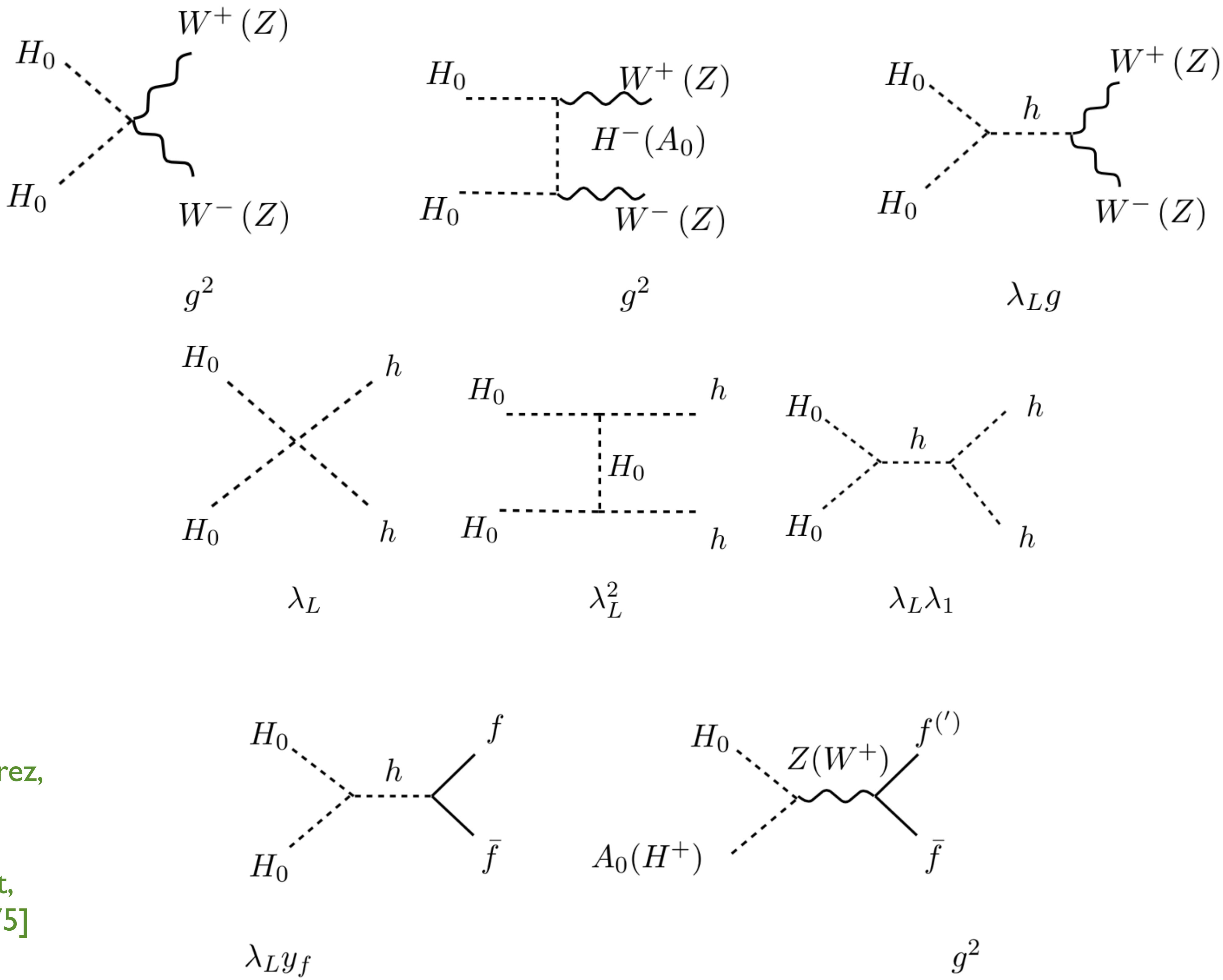
with a Z_2 symmetry there are several patterns for the Yukawa sector of the theory:

	u_R	d_R	e_R
Type I	$+$	$+$	$+$
Type II	$+$	$-$	$-$
Type Y	$+$	$-$	$+$
Type X	$+$	$+$	$-$



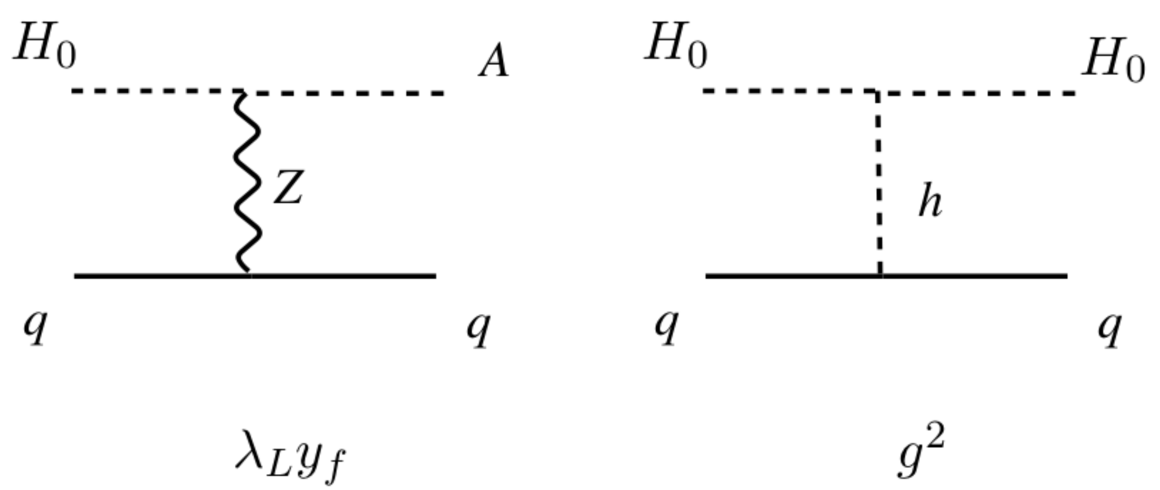
AKA: fermiophobic | MSSM-like | flipped I', 4, IV | lepton specific II', 3, III

Dark matter annihilation



[L. Lopez-Honorez,
E. Nezri,
J. F. Oliver,
M. H. G. Tytgat,
hep-ph/0612275]

Dark matter direct detection



[L. Lopez-Honorez,
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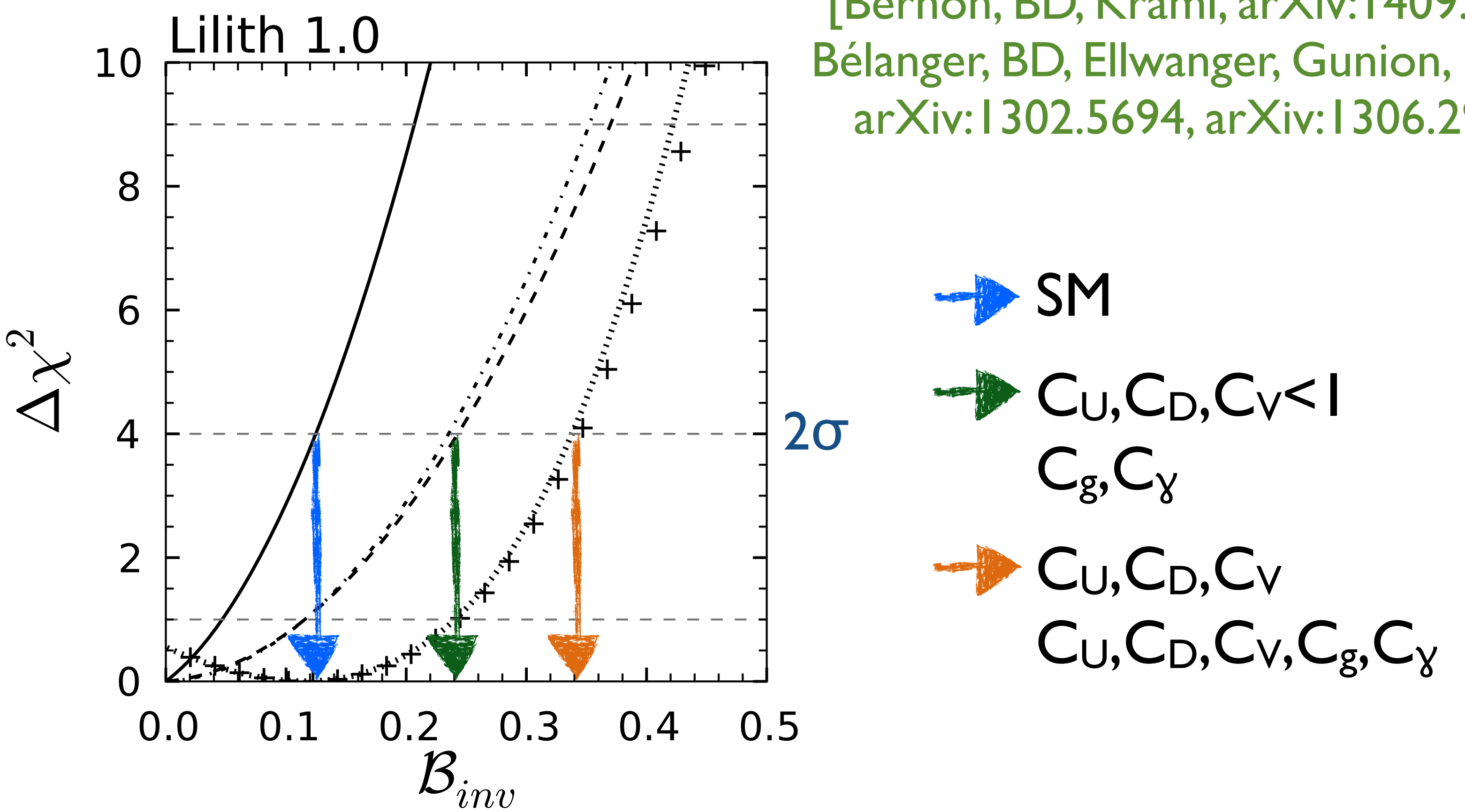
Status as of today: invisible decays

[Bernon, BD, Kraml, arXiv:1409.1588; Bélanger, BD, Ellwanger, Gunion, Kraml, arXiv:1302.5694, arXiv:1306.2941]

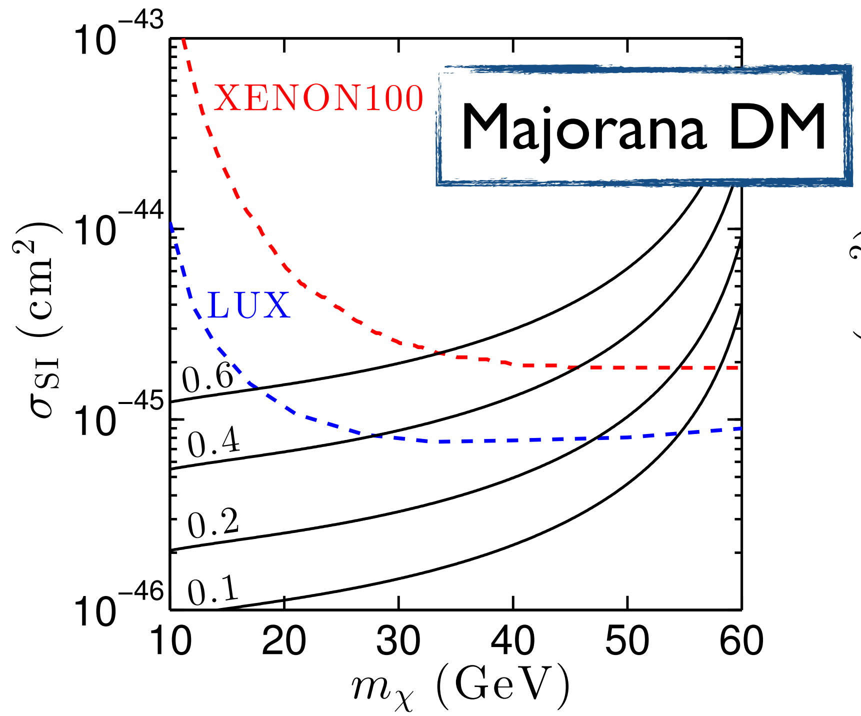
- global fit with invisible decays, under different assumptions on the couplings
- width effects in global fit more constraining than direct searches for invisible decays (if $C_V<1$, i.e. no flat direction)

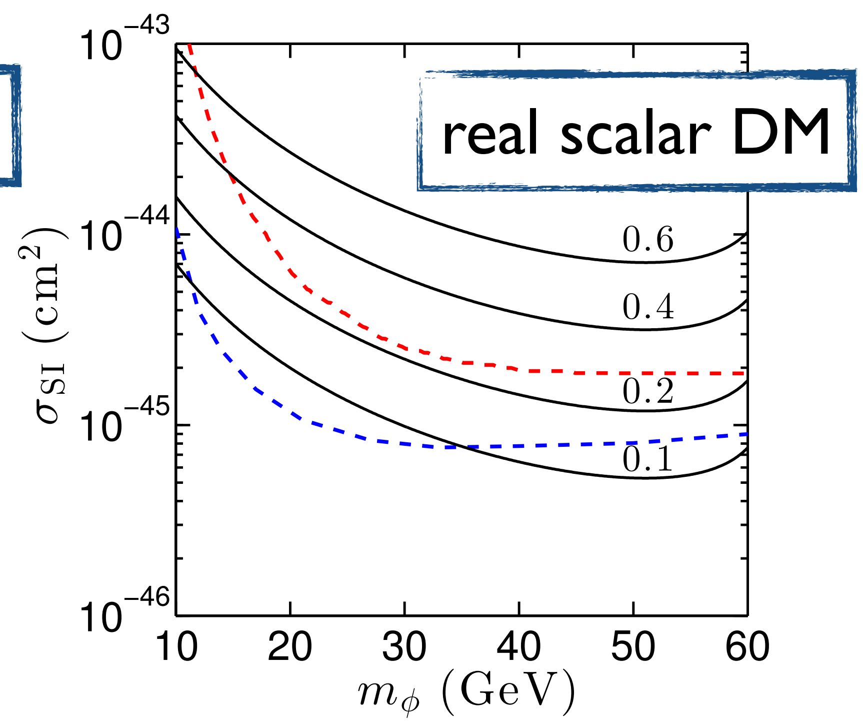


- **if**
  1. invisible = dark matter
  2. dark matter interacts only via the Higgs (Higgs portal)

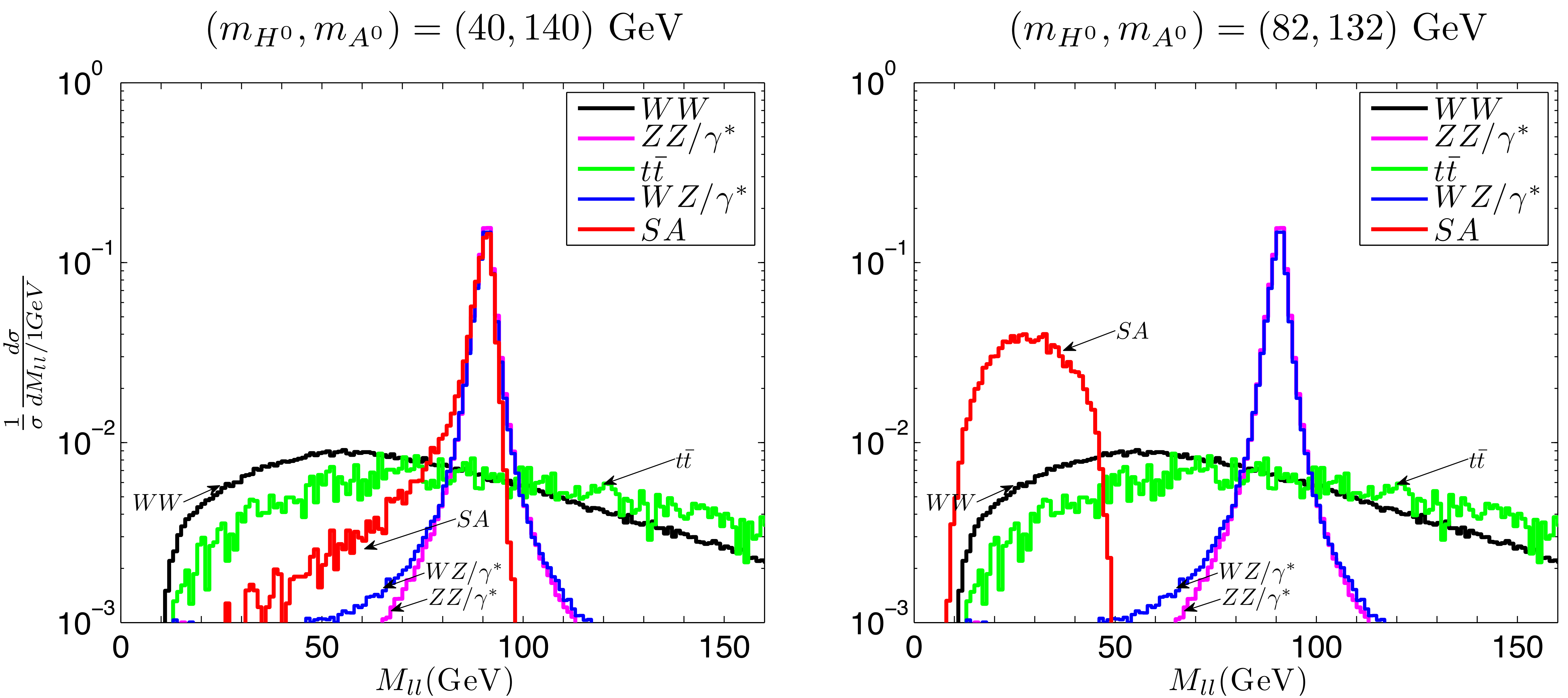
  then:

upper bound on invisible decays
⇔ upper bound on σ_{SI}





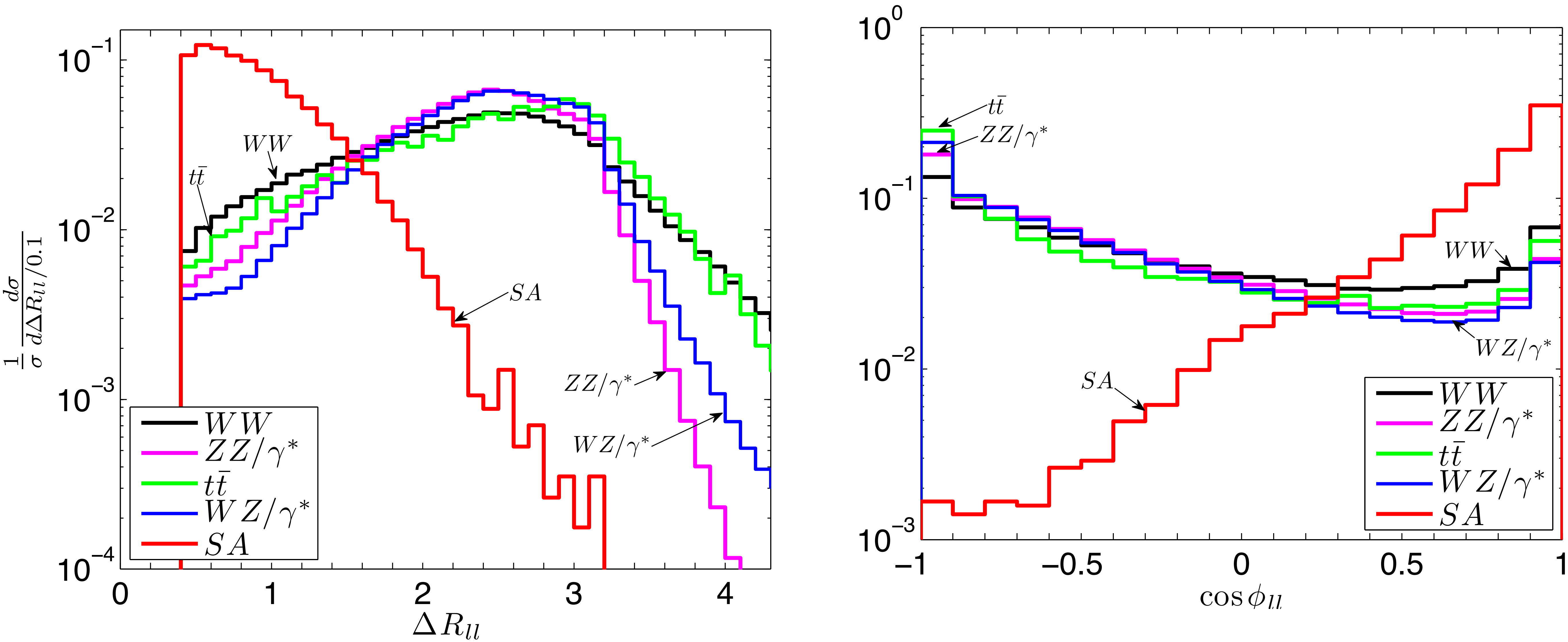
Dilepton invariant mass



[E. Dolle, X. Miao, S. Su, B. Thomas, arXiv:0810.3924]

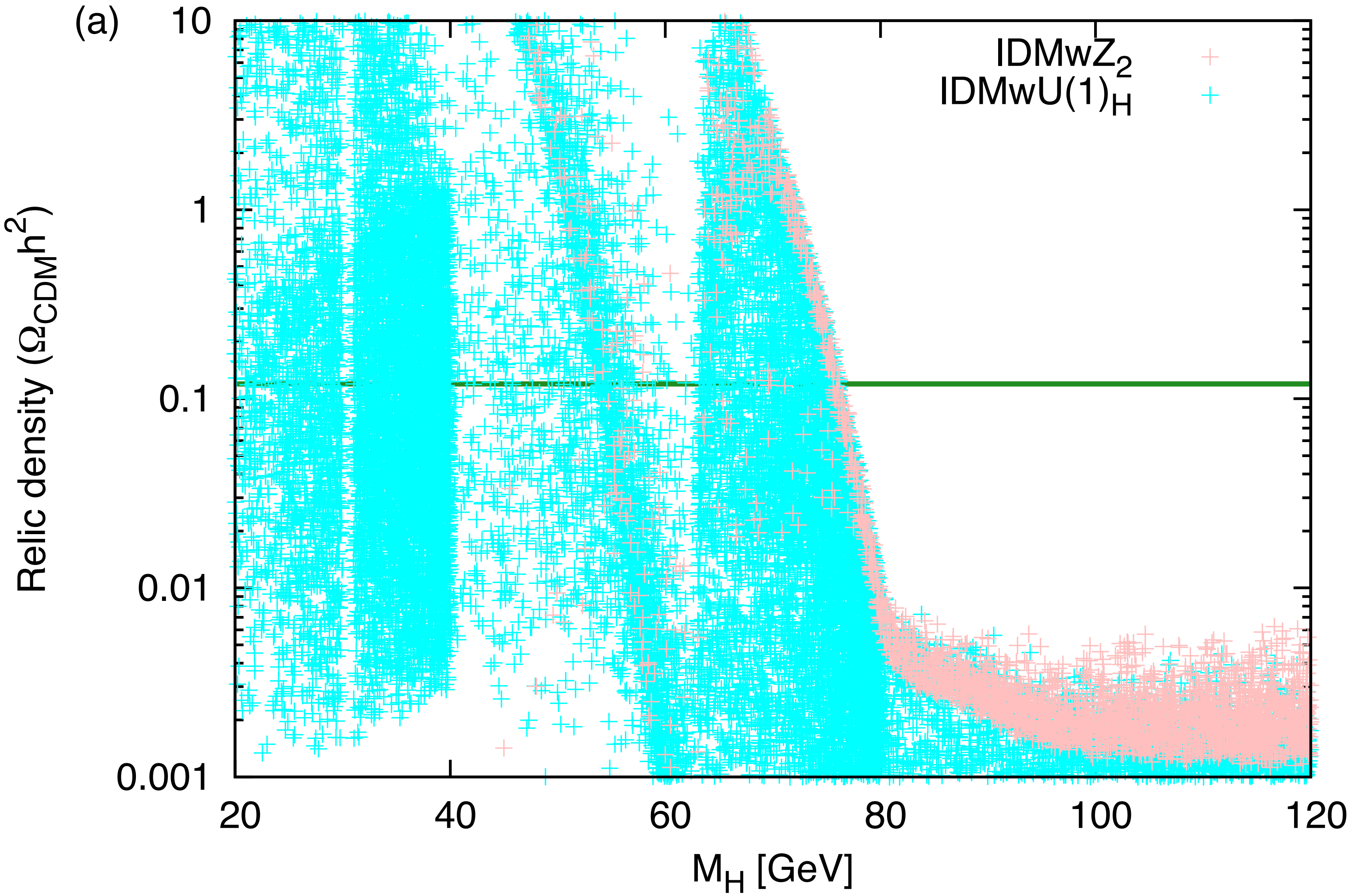
Angular separation variables

$$(m_{H^0}, m_{A^0}) = (82, 132)\ \mathrm{GeV}$$



[E. Dolle, X. Miao, S. Su, B. Thomas, arXiv:0810.3924]

U(1)IDM

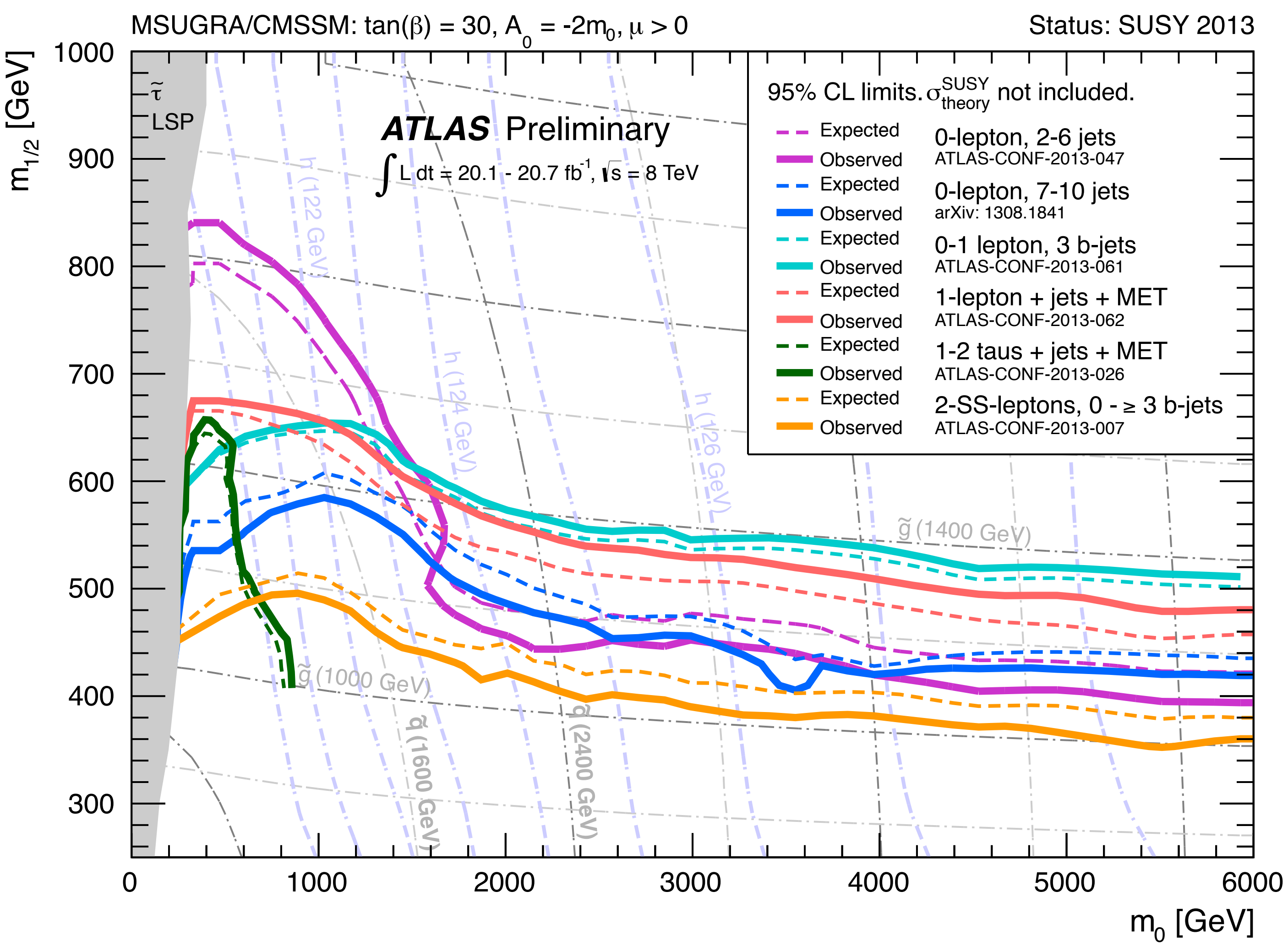


[P. Ko, Y. Omura, C. Yu, arXiv:1405.2138]

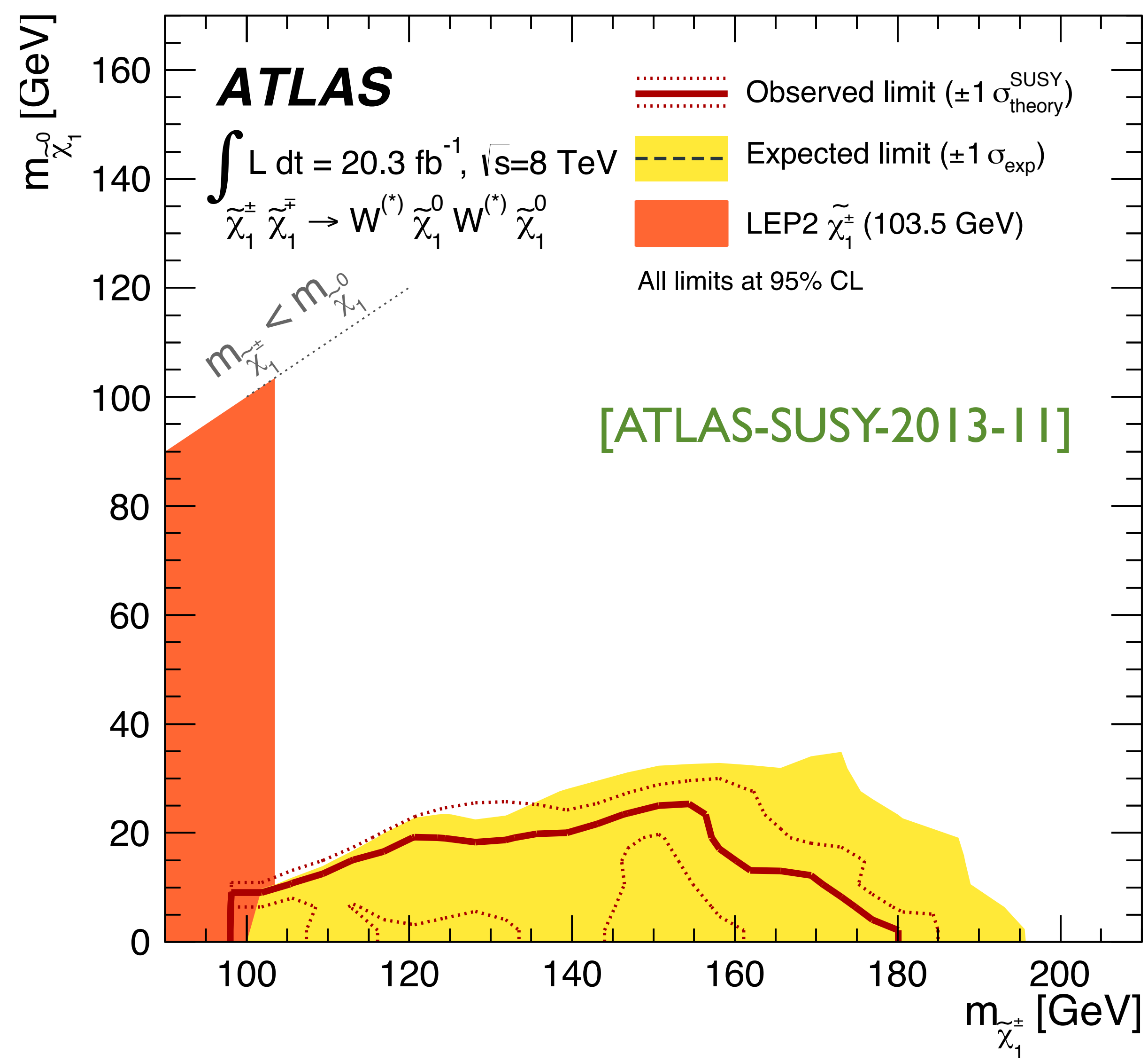
MA5 & PAD

Interpretations of BSM searches

"full" model
e.g. the CMSSM



simplified model
e.g. $\tilde{\chi}_1^+ \tilde{\chi}_1^- \to W^{(*)} \tilde{\chi}_1^0 W^{(*)} \tilde{\chi}_1^0$



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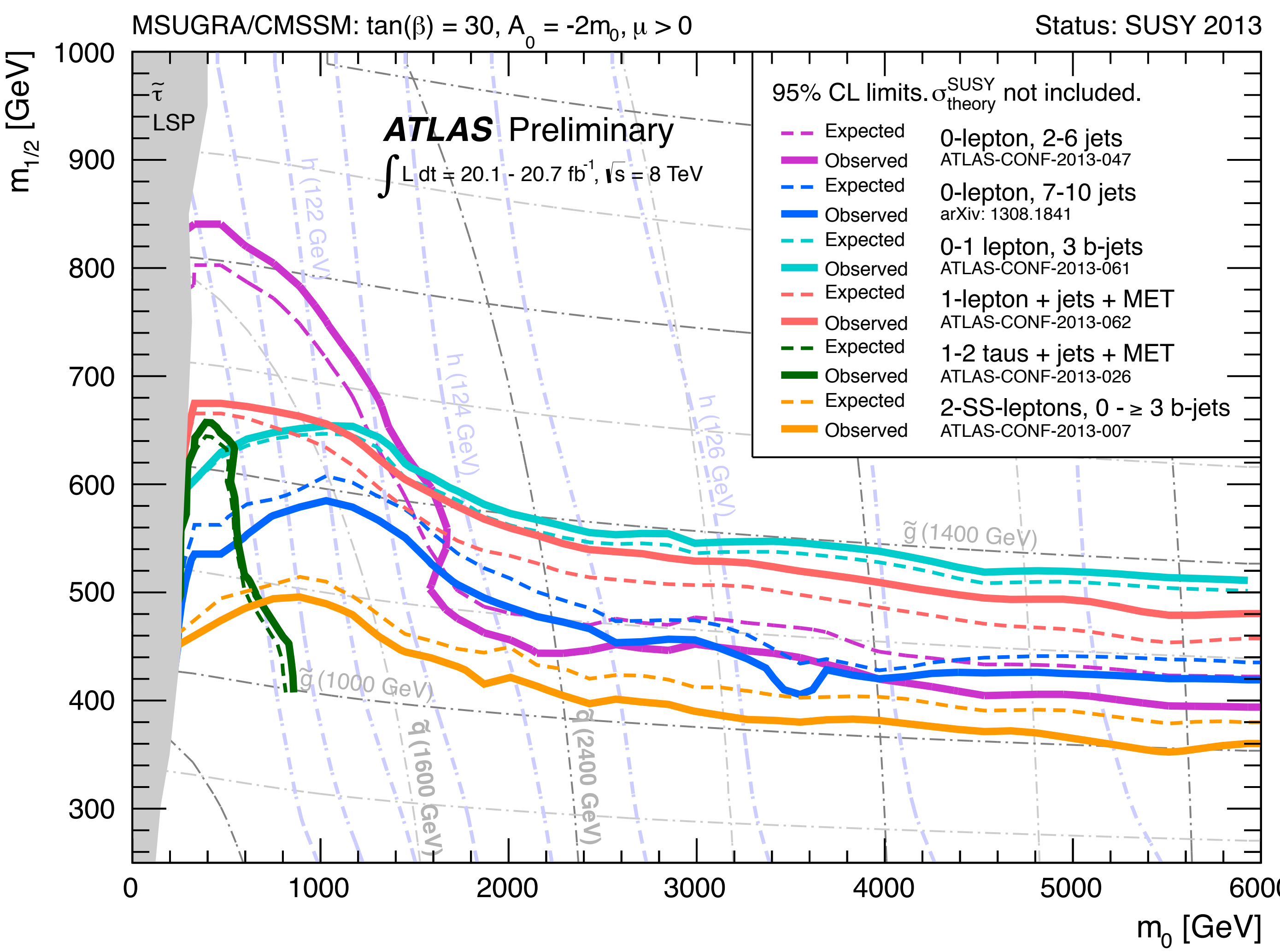

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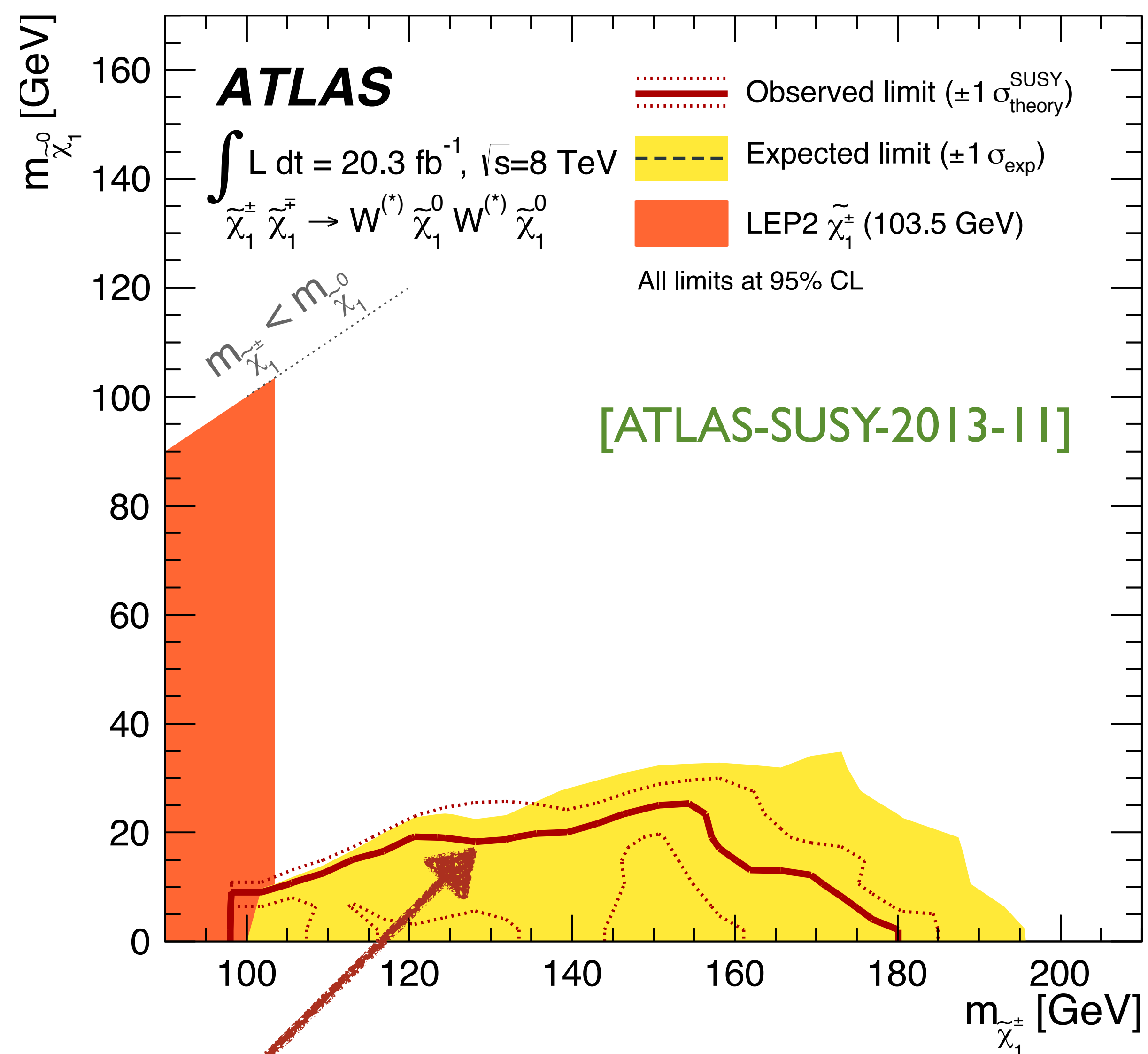
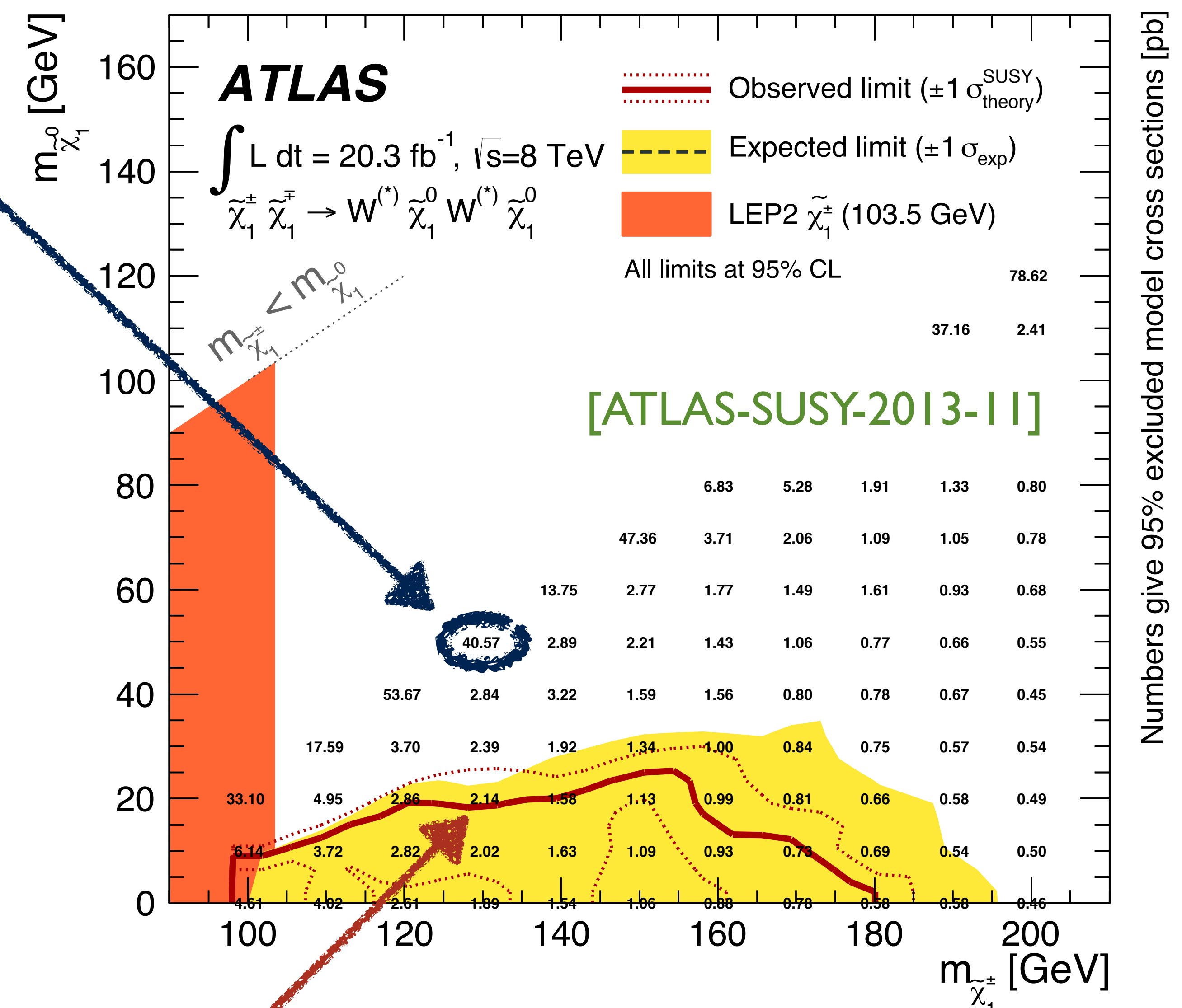


strong assumptions:
i. $\mathrm{BR}(\tilde{\chi}_1^\pm \to W^{(*)} \tilde{\chi}_1^0) = 100\%$
ii. pure wino chargino

Interpretations of BSM searches

model cross section
excluded at 95% CL
for a given $(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0})$

simplified model
e.g. $\tilde{\chi}_1^+\tilde{\chi}_1^- \to W^{(*)}\tilde{\chi}_1^0 W^{(*)}\tilde{\chi}_1^0$



- makes it possible to test different production cross sections (e.g. higgsino-like $\tilde{\chi}_1^\pm$) and BR < 100% (e.g. intermediate sleptons)
- this information is now systematically provided for the SUSY searches by ATLAS and CMS
- one can decompose a model into all possible σ×BR and match it to the simplified model results provided by ATLAS and CMS
- this method is implemented in SModelS [Kraml et al., arXiv:1312.4175] for more than 50 ATLAS and CMS SUSY searches at 8 TeV → http://smodels.hephy.at

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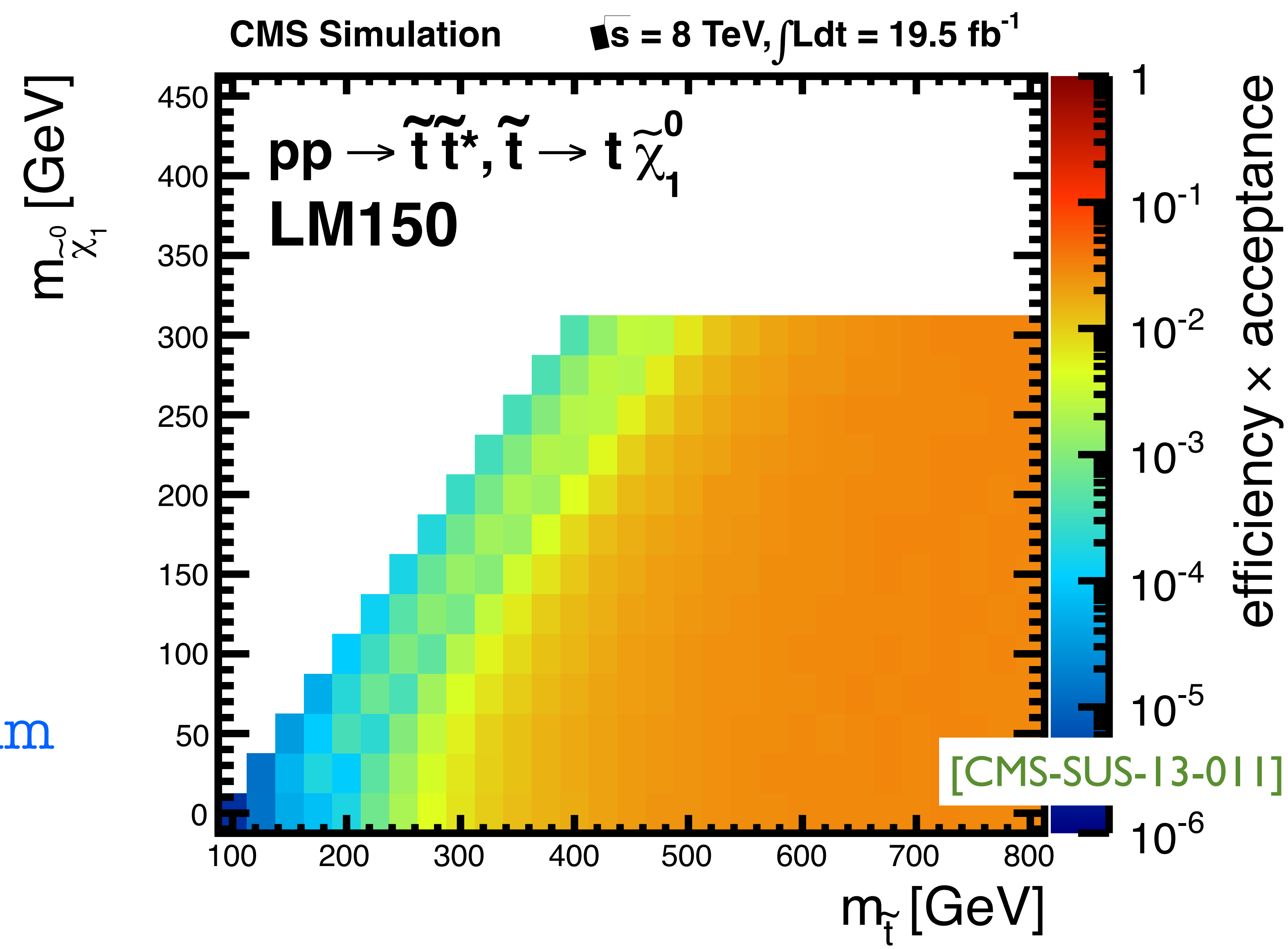
Acceptance×efficiency maps

- an alternative way of using simplified models to constrain new physics: using acceptance×efficiency maps instead of 95% CL upper bounds on the model cross section

- for every signal region in any LHC analysis, one can decompose the number of signal events as

$$n_s = \sum_{i=1}^{n} \sigma_i \times (A \times \varepsilon)_i \times \mathscr{L}$$

for every "simplified model" i
(e.g. $\tilde{t}\tilde{t}^* \to t\tilde{\chi}_1^0 t\tilde{\chi}_1^0$)

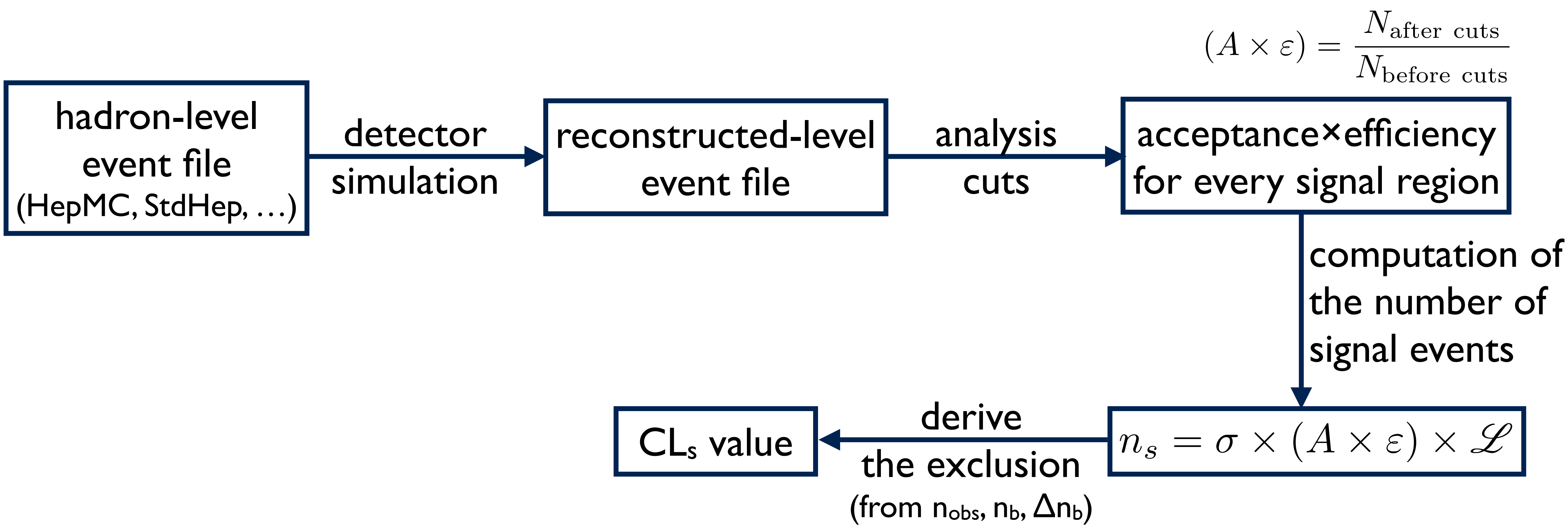


- problem: one needs to have acceptance×efficiency maps for every relevant simplified model in every signal region
(usually not provided by ATLAS or CMS!)

- this method is implemented in FastLim
[Papucci et al., arXiv:1402.0492]
for 10 ATLAS SUSY searches at 8 TeV
→ http://fastlim.web.cern.ch/fastlim/

The need for new interpretations

- we need to go beyond the interpretations given in the experimental papers
  → separate implementations of the analyses using public fast simulation tools (e.g. Delphes [de Favereau et al., arXiv:1307.6346]) are necessary
- for a given analysis, the working principle is the following:



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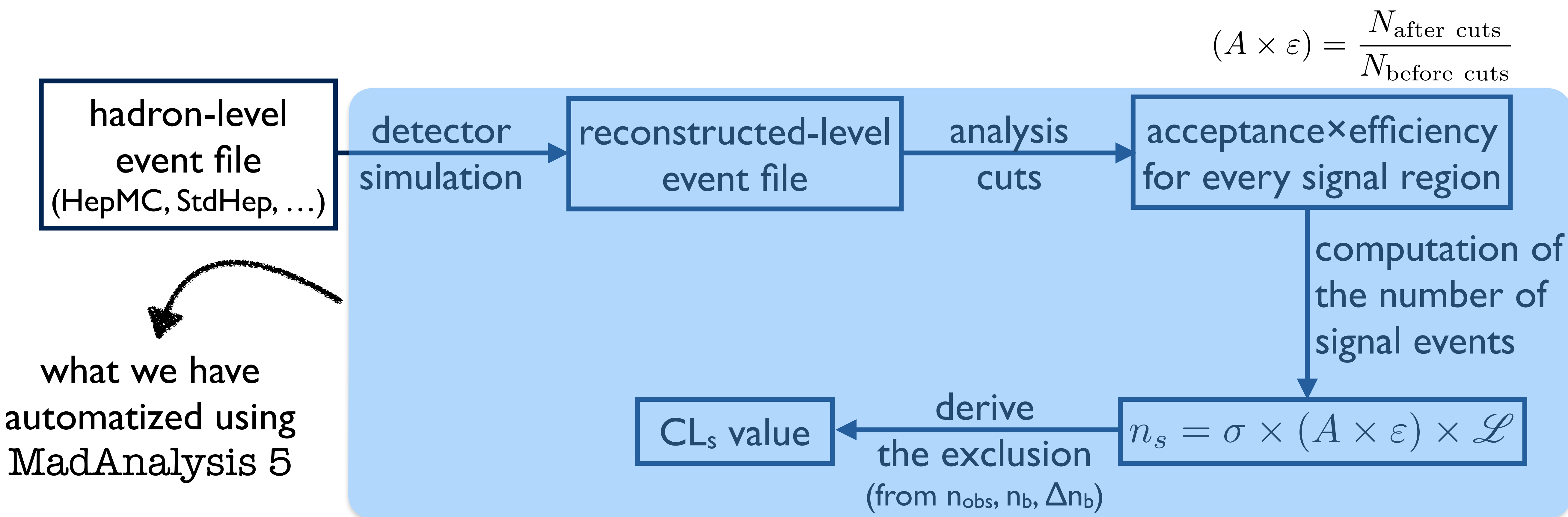


- see also CheckMATE [Drees et al., arXiv:1312.2591] and ATOM [Ian-Woo Kim et al., in preparation]

Our framework: MadAnalysis 5

[Conte, Fuks, Serret, arXiv:1206.1599,
Conte, Fuks, arXiv:1309.7831,
Conte, BD, Fuks, Wymant, arXiv:1405.3982]

- what is MadAnalysis 5?
  - a public framework for phenomenological analyses
  - any level of sophistication: partonic, hadronic, detector reconstructed
  - several input format: StdHep, HepMC, LHE, LHCO, ROOT (from Delphes)
  - user-friendly, flexible and fast
- normal mode:
  - intuitive commands typed in the Python interface
  - human-readable output: HTML and LaTeX
- expert mode:
  - C++/ROOT programming within the SampleAnalyzer framework
  - powerful and well-suited for the implementation of LHC SUSY analyses

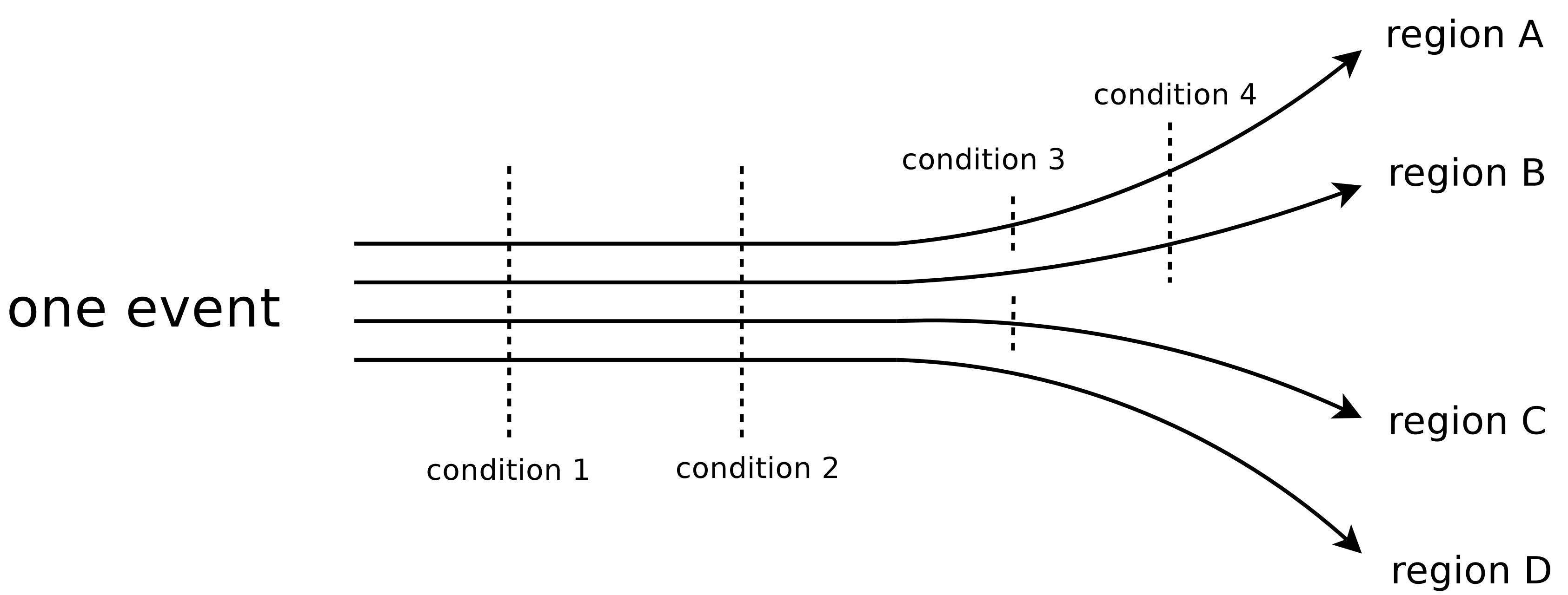
https://launchpad.net/madanalysis5

Our framework: MadAnalysis 5

[Conte, BD, Fuks, Wymant, arXiv:1405.3982]

recent extensions of the expert mode:

- support for several sub-analyses
- new ready-to-use observables (M_{T2}, M^{W}_{T2})
- new optimized handling of cuts and histograms



the naive approach
is not efficient

```
if (condition 3)
{
  count the event in region C
  if (condition 4)
  {
    count the event in region A
  }
}
if (condition 4)
{
  count the event in region B
}
```

- a more efficient algorithm has been implemented
  - each cut condition is only evaluated once
  - it is applied to all "surviving" regions simultaneously
- similar treatment for histograms

The need for validation materials

- we cannot reproduce exactly what is done by ATLAS and CMS:
  - they use full GEANT4 simulation of the detector (non public), we use fast simulation
  - the definition of the preselected objects cannot be reproduced exactly (we need to rely on approximate reconstruction/identification/isolation efficiency factors)
- besides, we want to make sure that the re-implementation of the cuts is correct
  → validation against official results is needed
- we aim at reproducing the number of signal events after cuts at the level of ~20%

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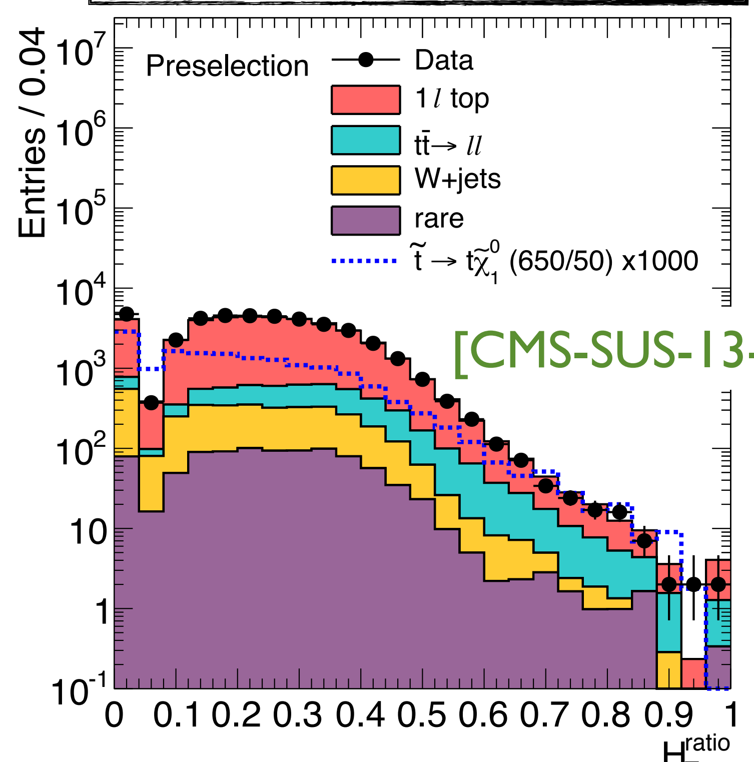
cutflows

$(m_{\tilde{\ell}}, m_{\tilde{\chi}_1^0})$	(191, 90) GeV	
Lepton flavour	e^+e^-	$\mu^+\mu^-$
Two signal leptons	135.4	147.8
Jet veto	60.5	64.7
Z Veto	55.7	60.0
SR-m_{T2}^{90}	21.8	21.7
SR-m_{T2}^{120}	8.0	8.5
SR-m_{T2}^{150}	0.6	1.1

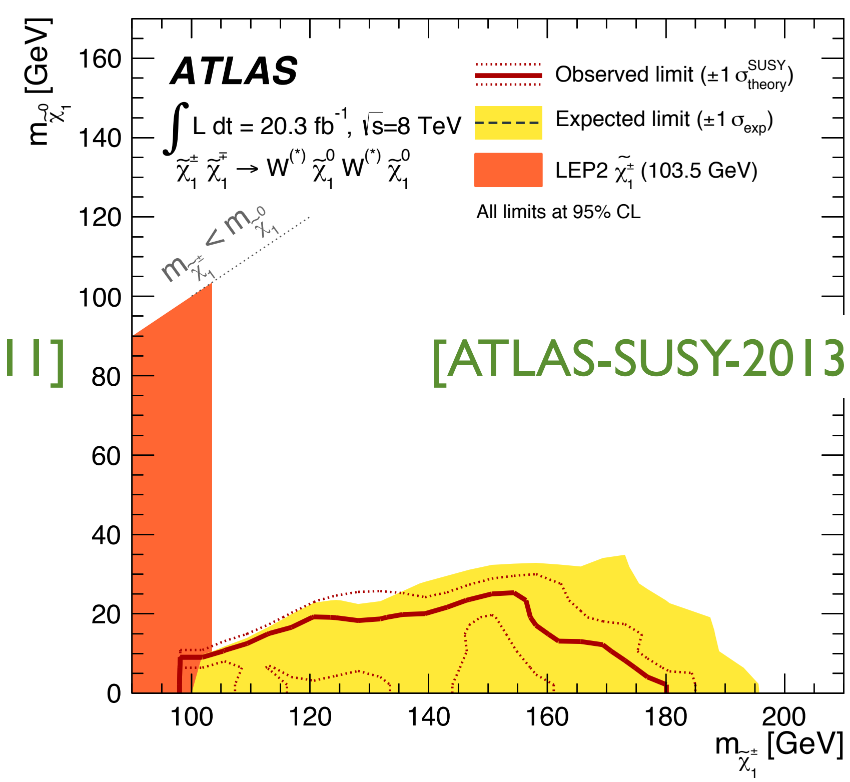
[ATLAS-SUSY-2013-11]

histograms of kinematic quantities



[CMS-SUS-13-011]

limit plots



[ATLAS-SUSY-2013-11]

Public analysis database

[BD, Fuks, Kraml, et al., arXiv:1407.3278]

- we started to build a public database of LHC analyses in the MadAnalysis 5 framework can easily be used to constrain generic new physics scenarios

- instructions on how to install and run MadAnalysis 5 on event files using LHC analyses as well as available analyses and corresponding validation notes are listed at: http://madanalysis.irmp.ucl.ac.be/wiki/PhysicsAnalysisDatabase

ATLAS analyses, 8 TeV

Analysis	Short Description	Implemented by	Code	Validation note	Status
ATLAS-SUSY-2013-05 (published)	stop/sbottom search: 0 leptons + 2 b-jets	G. Chalons	Inspire	PDF (figures)	done
ATLAS-SUSY-2013-11 (published)	EWK-inos, 2 leptons + MET	B. Dumont	Inspire	PDF (source)	done
ATLAS-HIGG-2013-03 (published)	ZH->ll+invisible	B. Dumont	Inspire	PDF (source)	done

CMS analyses, 8 TeV

Analysis	Short Description	Implemented by	Code	Validation note	Status
CMS-SUS-13-011 (published)	stop search in the single lepton mode	B. Dumont, B. Fuks, C. Wymant	Inspire [1]	PDF (source)	done
CMS-SUS-13-012 (published)	gluino/squark search in jet multiplicity and missing energy	S. Bein, D. Sengupta	Inspire	PDF (source)	done
CMS-SUS-13-016 (PAS)	search for gluinos using OS dileptons and b-jets	D. Sengupta, S. Kulkarni	Inspire	PDF (source)	done

- more analyses to come: validation is a tedious and lengthy process!

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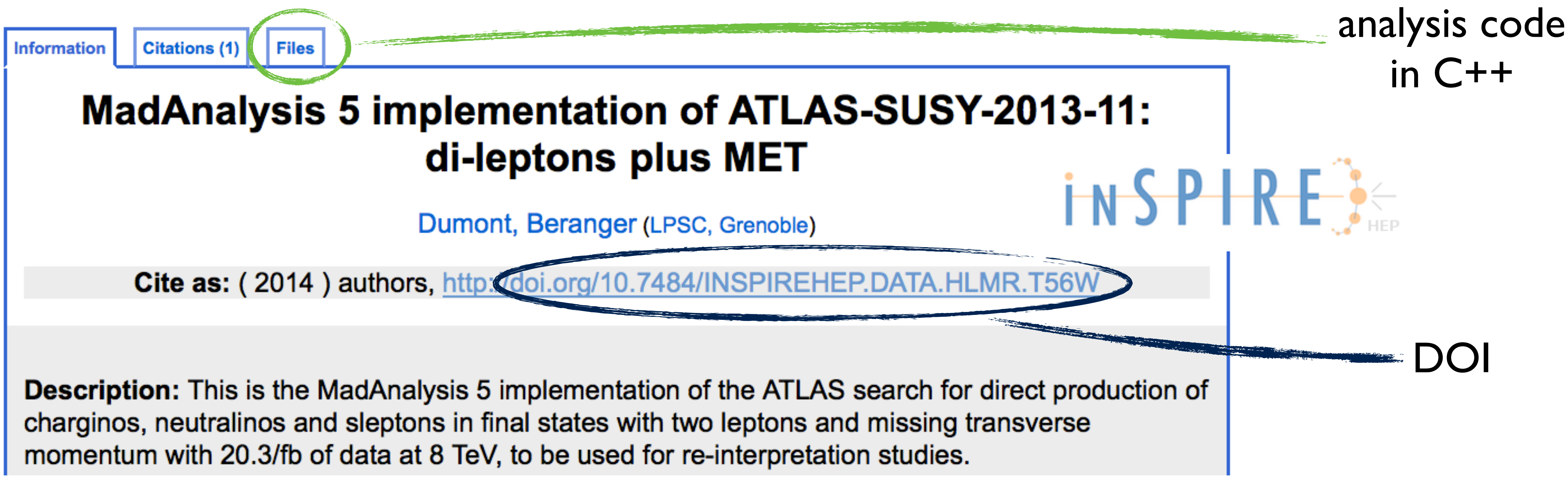
Public analysis database (2)

[BD, Fuks, Kraml, et al., arXiv:1407.3278]

- analyses are submitted to INSPIRE and are given a DOI, hence are searchable and citable
  example:



Information | Citations (1) | Files

MadAnalysis 5 implementation of ATLAS-SUSY-2013-11: di-leptons plus MET

Dumont, Beranger (LPSC, Grenoble)

Cite as: (2014) authors, http://doi.org/10.7484/INSPIREHEP.DATA.HLMR.T56W

Description: This is the MadAnalysis 5 implementation of the ATLAS search for direct production of charginos, neutralinos and sleptons in final states with two leptons and missing transverse momentum with 20.3/fb of data at 8 TeV, to be used for re-interpretation studies.

- in this way everyone can contribute to the database and have their efforts rewarded by citations

Deriving limits

[BD, Fuks, Kraml, et al., arXiv:1407.3278]

- we also provide a statistical tool for deriving limits: exclusion_CLs.py
- it derives exclusion under the CL_s prescription based on n_s, n_{obs}, n_b, and Δn_b
  (can also return the upper limit on the model cross section at 95% CL)
- in case of multiple signal regions: the best expected signal region is selected for the exclusion

XML .info file
(provided on INSPIRE
along with the analysis code)

```
<analysis id="atlas_susy_2013_11">
  <lumi>20.3</lumi> <!-- in fb^-1 -->

  <region type="signal" id="MT2-90 emu">
    <nobs>21</nobs>
    <nb>23.3</nb>
    <deltanb>3.7</deltanb>
  </region>

  ... ... ...

</analysis>
```

→

execution of exclusion_CLs.py
(reads the .info file,
the acceptance×efficiency from MA5 output,
and the signal cross section)

```
[dumont@lpsc4008x pad]$ ./exclusion_CLs.py \
> atlas_susy_2013_11 C1C1_noslep_100.0_0.0.list 0 0.606
The best expected signal region is "WWa emu".
It has: nobs = 70, nb = 73.6 \pm 7.9, nsignal = 28.79.

This signal is excluded at the 98.9% CL (CLs=0.011).
```