Search for the Inert Doublet Model Signal with Dilepton and Missing Energy

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In collaboration with:

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Motivation:

- Inert Doublet Model (IDM): Two Higgs Doublet Model with Dark Matter candidate
- Dark Matter may be tested in the LHC
- Various searches with MET and leptons or jets:
  - ATLAS: e.g.[1407.7494], [1404.0051], [1309.4017], [1403.5204]
  - CMS: e.g.[1408.2745], [1402.4770], [1303.2985]
- Dilepton + MET channel relatively clean
- IDM is one of the simplest DM scenarios
  - SM-like Higgs
  - DM in agreement with data

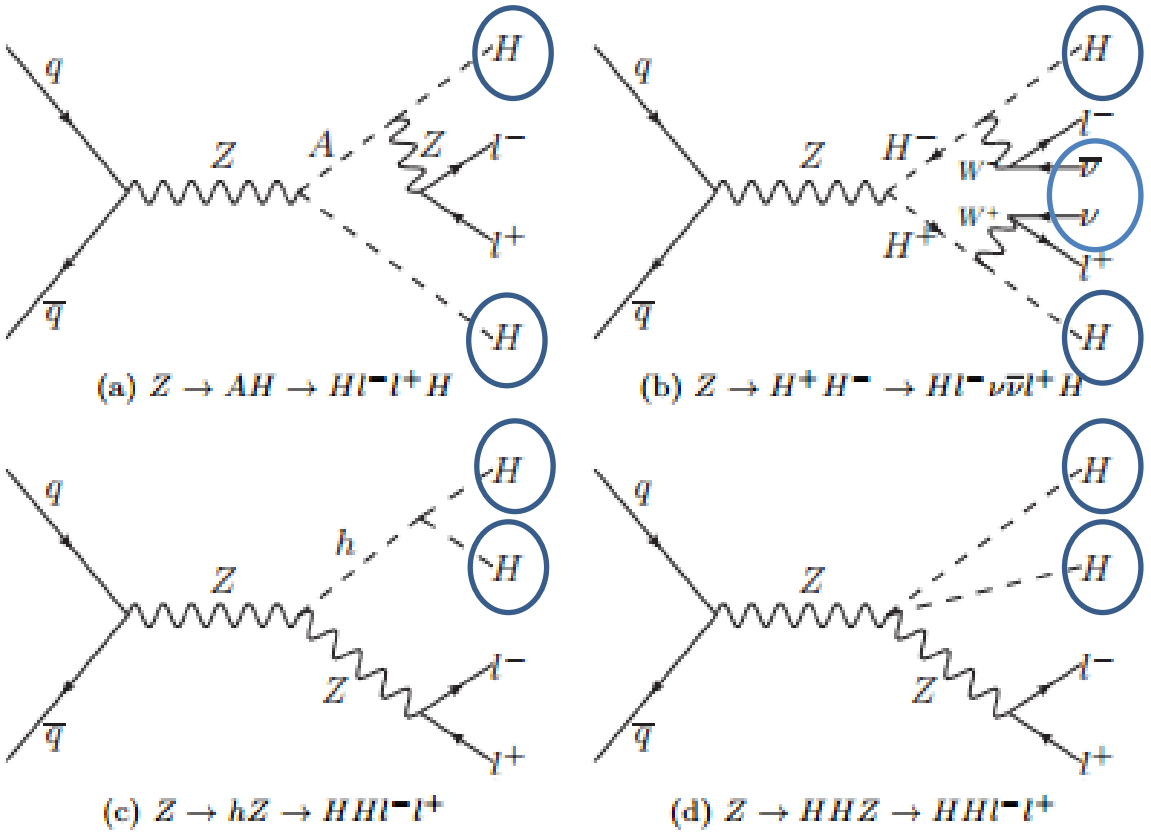
see talk by Bogumiła Świeżewska

Inert Doublet Model

$$\begin{aligned}\mathcal{L}_H^{\mathrm{IDM}} =& D^\mu \Phi_S^\dagger D_\mu \Phi_S + D^\mu \Phi_D^\dagger D_\mu \Phi_D + \frac{1}{2}\left[m_{11}^2 \Phi_S^\dagger \Phi_S + m_{22}^2 \Phi_D^\dagger \Phi_D\right] + \\ & - \frac{1}{2}\left[\lambda_1 \left(\Phi_S^\dagger \Phi_S\right)^2 + \lambda_2 \left(\Phi_D^\dagger \Phi_D\right)^2\right] - \lambda_3 \left(\Phi_S^\dagger \Phi_S\right)\left(\Phi_D^\dagger \Phi_D\right) + \\ & - \lambda_4 \left(\Phi_S^\dagger \Phi_D\right)\left(\Phi_D^\dagger \Phi_S\right) - \frac{1}{2}\lambda_5 \left[\left(\Phi_S^\dagger \Phi_D\right)^2 + \left(\Phi_D^\dagger \Phi_S\right)^2\right] + \mathcal{L}_Y^{\mathrm{IDM}}\end{aligned}$$

- Only 5 free parameters (M_H, M_A, M_{H+}, λ_2, λ_{345}) + M_h
- No mixing between states
- 4 dark particles, 1 DM candidate (H) due to exact Z_2 symmetry
- Dark sector communicates with SM only through vector bosons and Higgs portal

Our signal: 2l+MET



[0909.3094]

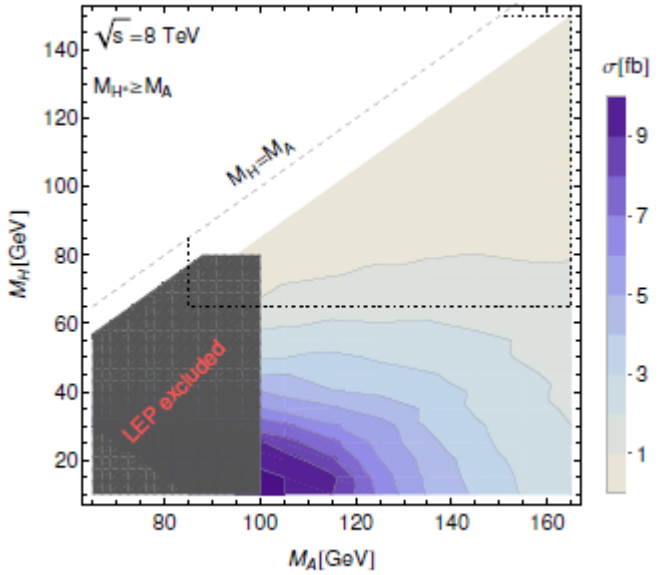
What was done previosly

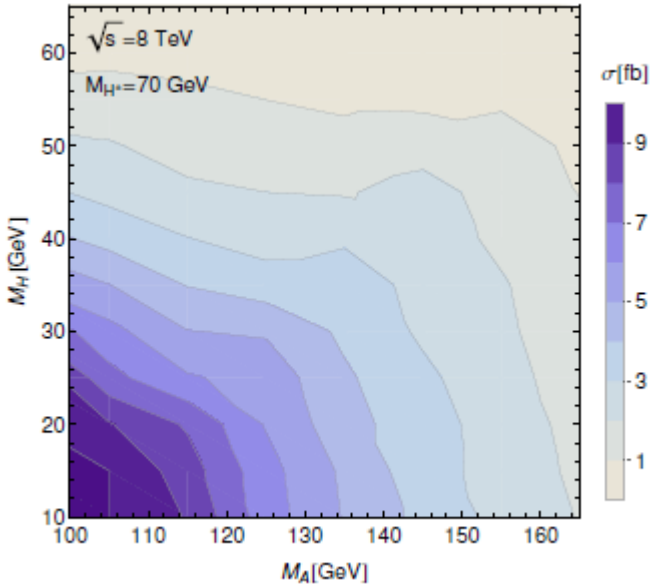
- The phenomenological studies of l^+l^-+MET signal from IDM proposed by Dolle, Miao, Su, Thomas [0909.3094]
- P. Swaczyna's MSc Thesis [2013]: automated scan of parameter space
  - Event generation in Pythia
  - For 8 TeV
  - Tested for DM in mass range 10-150 GeV
  - A in mass range 65-170 GeV
  - Two scenarios: $M_{H+} \geq M_A$ and $M_{H+} = 70$ GeV
  - Automated cut optimization

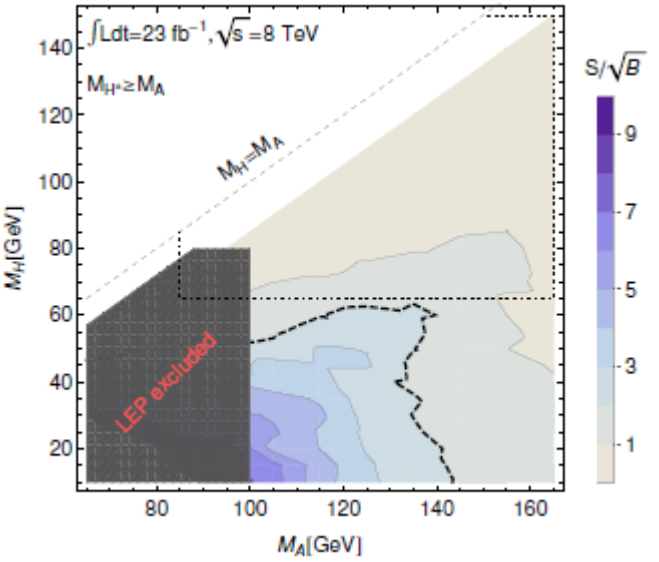
Parameter cuts:

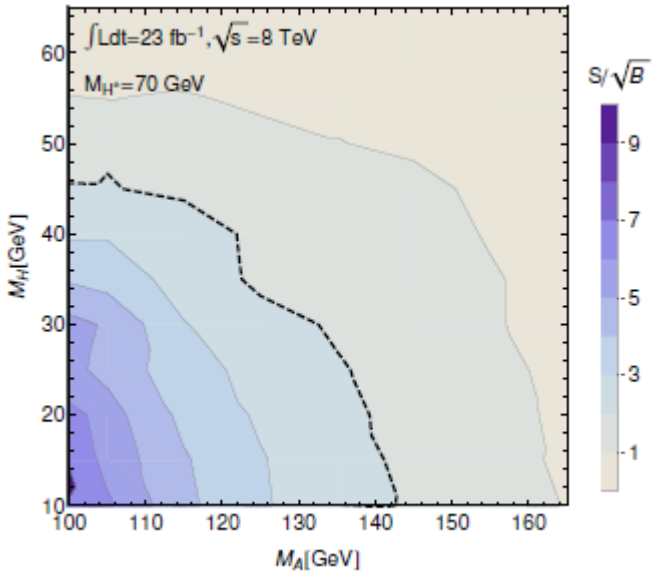
- Level I [as in 0909.3094]:
  - Two leptons with oposite charge
  - $p_{Tl} \geq 15\text{GeV}$ and $\eta_l \leq 2.5$
  - $p_{Tjet} \leq 20\text{GeV}$ and $|\eta_{jet}| > 3.0$
  - Separation: $\Delta R_{ljet} > 0.4$
  - $E_{Tmiss} > 30\text{GeV}$
- Level II (optimised to maximize $S/\sqrt{B}$):
  - $M_{ll}^{min} \leq M_{ll} \leq M_{ll}^{max}$ [$M_{ll}^{max} = M_A - M_H$, $M_{ll}^{min} = 10n$;
    for $M_A - M_H \geq M_Z$: $M_{ll}^{min} = 80\text{GeV}$, $M_{ll}^{max} = 100\text{GeV}$]
  - Separation: $\Delta R_{ll} \leq \Delta R_{ll}^{max}$ [= 0.1n, n ∈ [1,40]]
  - Azimuthal angle: $\cos(\theta_{ll}) \geq \cos(\theta_{ll}^{min})$ [=-1+0.1n, n ∈ [1,20]]
  - $p_{Tl1} + p_{Tl2} + p_{Tmiss} \geq H_T^{min}$ [25n, n ∈ [1,20]]
  - $E_{Tmiss} \geq E_{tmiss}^{min}$ [20+10n, n ∈ [1,8]]
  - $p_{Tl1}, p_{Tl2} \leq p_{Tll}^{max}$ [20n, n ∈ [1,40]]

What was done previosly









Year 2013

Improvements

- Test with extended set of constraints:
  - Positivity
  - Vacuum stability (+ Inert vacuum condition)
  - Perturbativity, perturbative unitarity
  - STU and Δρ parameters
  - LEP and LHC exclusion limits

- Adding all possible channels to signal and SM background
- **This requires use of different MC generation tools**
- Specify SM bkg by final state

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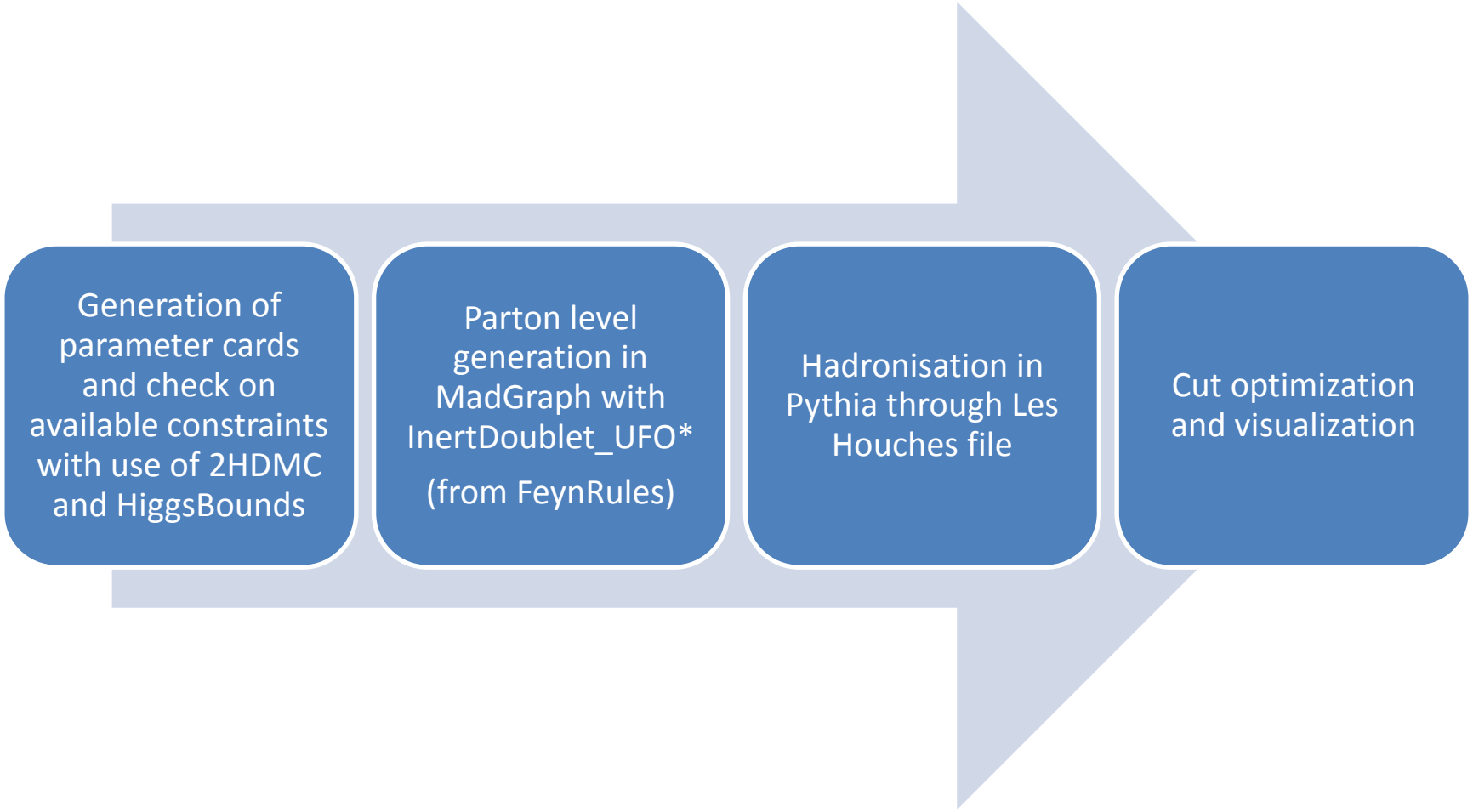
SM background

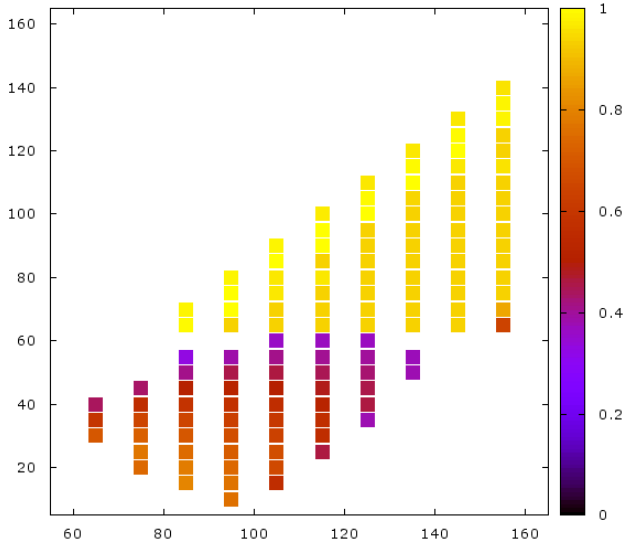
- To treat quantum interference correctly we use assignment with final state particles only
- Channels of interest:
  - llνν [WW, ZZ/γ*]
  - lljj [WZ/γ*]
  - llννb [Wt]
  - llννbb [tt]

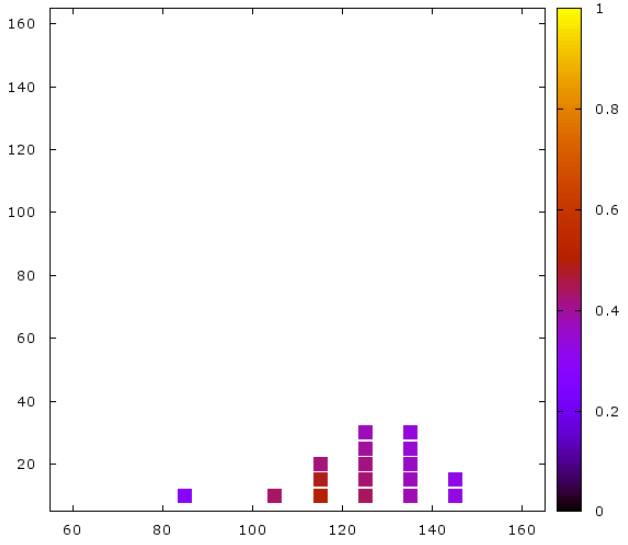
New simulation chain

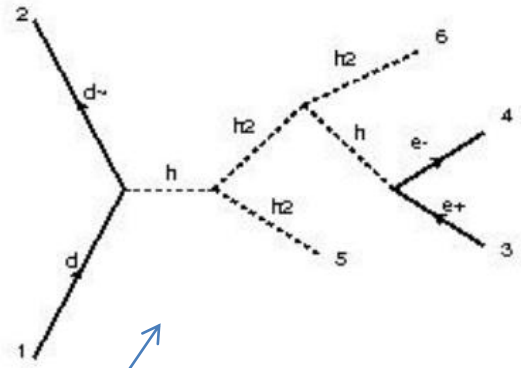


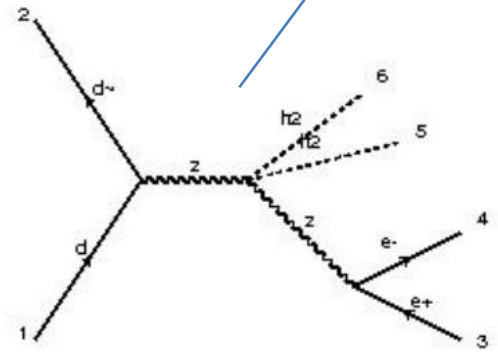
* A. Goudelis, B. Herrmann, O. Stål [1303.3010]

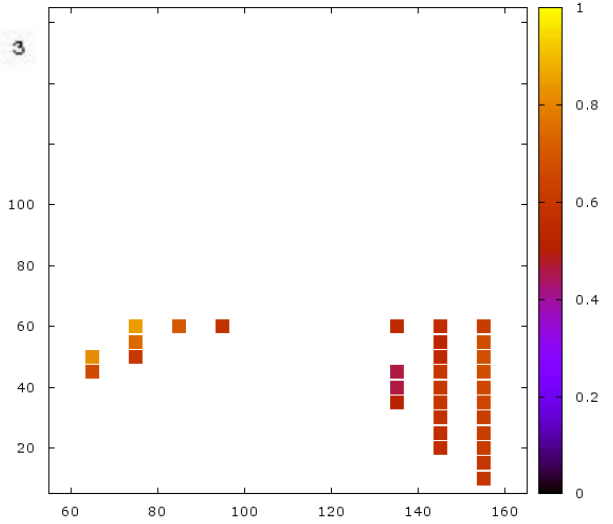
Preliminary results
- the process contributions [for $M_{H+} \geq M_A$]



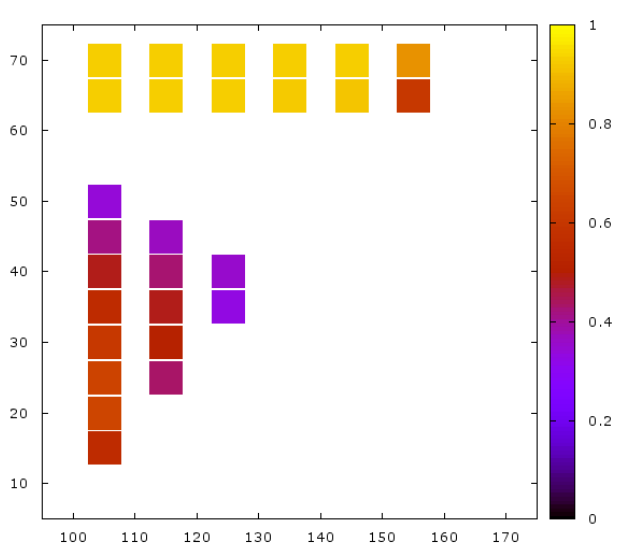


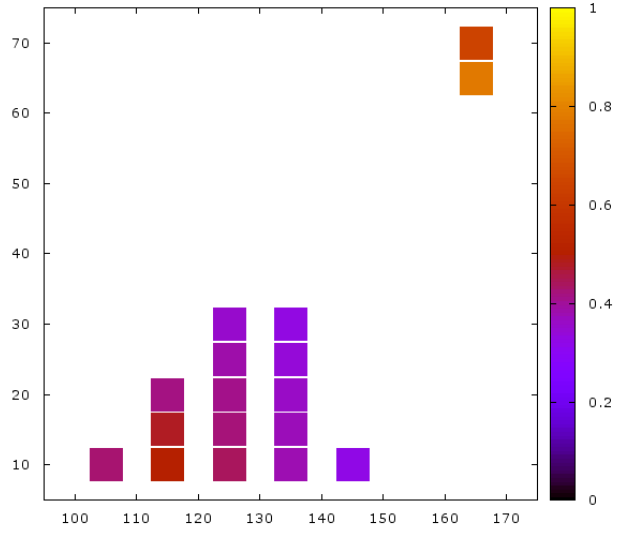


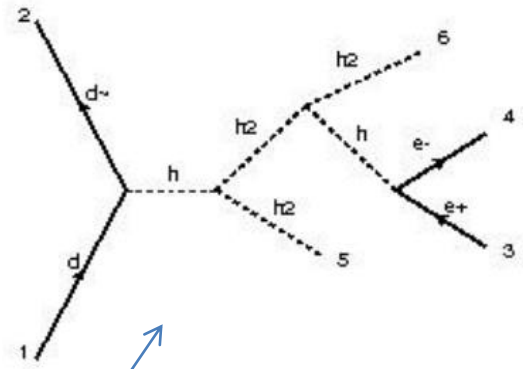


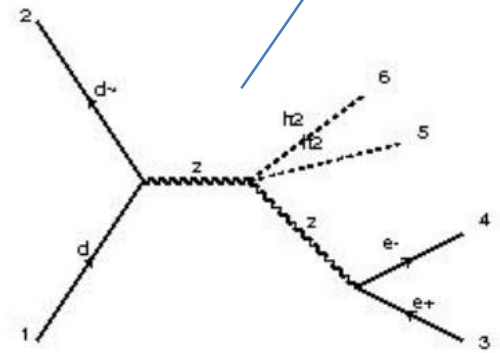


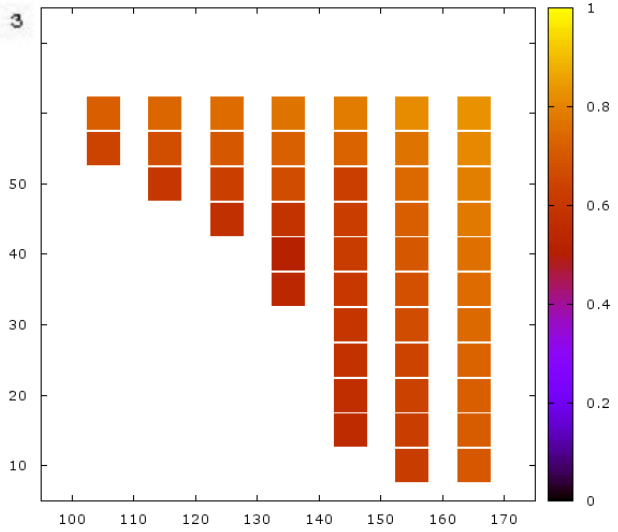
Preliminary results
- the process contributions [for M_{H+} = 70 GeV]











Outlook

- Generation of signal with llvvHH
- SM bkg requires matching with shower
- Constraints from DM searches
- Redo plots with improved event generation
- Predictions for 14 TeV LHC run

Summary

- l^+l^- + MET is a clean signal which may be used for discovery of DM from IDM in LHC
- Some parameter points have significance over 3σ

- **Work in progress**
- Dear experimentalists, please check some most promising points

Buckup

Lambda 2

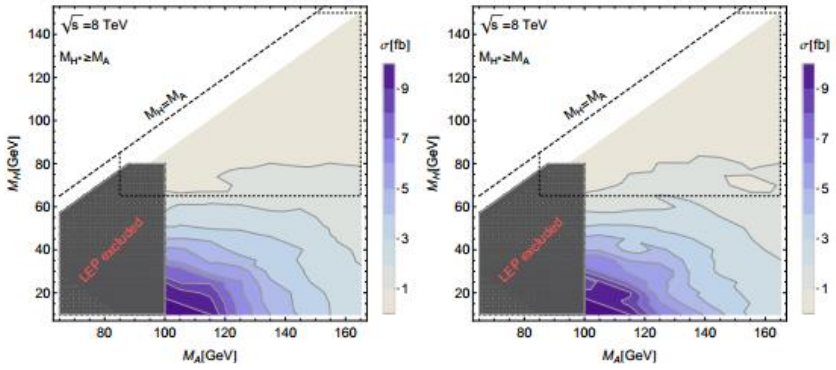


Figure 5: Plots B1 with λ_2 equal to 0.1 and 0.2.

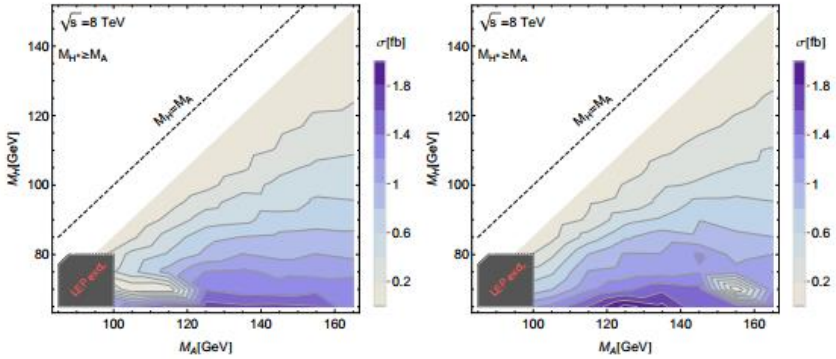


Figure 6: Plots B3 with λ_2 equal to 0.1 and 0.2.

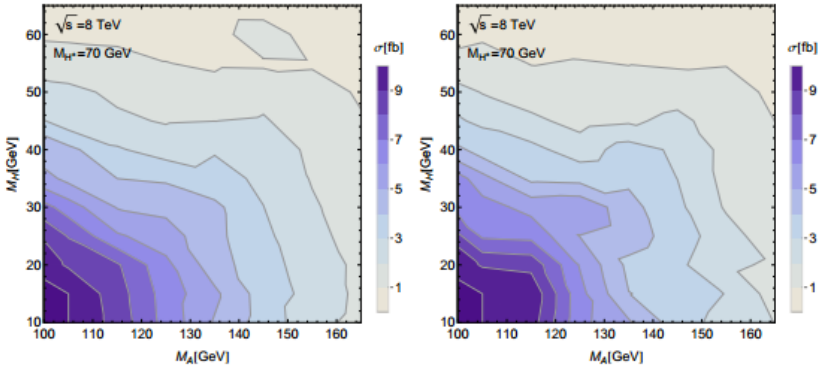


Figure 7: Plots E1 with λ_2 equal to 0.1 and 0.2.

	$\lambda_2 = 0.1$ (5000 events)			$\lambda_2 = 0.2$(5000 events)		
	σ $[10^{-10}mbn]$	$\Delta_{int}\sigma$ $[10^{-12}mbn]$	$\frac{\sigma L}{N_{events}}$	σ $[10^{-10}mbn]$	$\Delta_{int}\sigma$ $[10^{-12}mbn]$	$\frac{\sigma L}{N_{events}}$
B-1-13	5.25060	4.48507	2.415	5.22134	4.38147	2.402
B-2-17	0.72095	0.55358	0.332	0.72306	0.54749	0.333
B-3-12	7.60515	6.39751	3.498	7.56351	6.29219	3.479
E-4-20	0.26376	0.20343	0.121	0.26259	0.19973	0.121
E-5-15	1.00208	0.84778	0.461	0.99780	0.84163	0.459
E-6-11	6.46886	5.35896	2.976	6.59350	5.40612	2.999

Table 1: The cross sections (w/o cuts) given by Pythia for 6 points

InertDoublet_UFO crosscheck

Benchmark	m_h (GeV)	m_S (GeV)	δ_1 (GeV)	δ_2 (GeV)	λ_L
LH1	150	40	100	100	−0.275
LH2	120	40	70	70	−0.15
LH3	120	82	50	50	−0.20
LH4	120	73	10	50	0.0
LH5	120	79	50	10	−0.18

Benchmark	σ_{SA} (fb)	$\sigma_{H^+H^-}$ (fb)	$\sigma_{SH^\pm}$ (fb)	$\sigma_{AH^\pm}$ (fb)
LH1	289.2	69.8	503.3	125.2
LH2	628.8	163.6	1055.1	299.0
LH3	179.9	86.0	319.0	154.9
LH4	248.9	440.2	1050.3	370.1
LH5	465.5	93.3	352.9	302.3

-	σ_{HA} [fb]	$\sigma_{H^+H^-}$ [fb]	$\sigma_{HH^\pm}$ [fb]	$\sigma_{AH^\pm}$ [fb]
LH1	271.0	63.4	435.0	107.8
LH2	588.6	150.0	907.6	257.1
LH3	168.o	78.6	275.9	133.4
LH4	232.7	409.7	902.7	317.9
LH5	435.2	85.3	305.3	261.3

Table 3: Cross sections of IDM final states calculated with MadGraph5 with energy 14 TeV. Crosscheck with Table II of 0909.3094.