Testing Inert Doublet at Future e^+e^- Colliders

Dorota Sokołowska

International Institute of Physics,
Universidade Federal do Rio Grande do Norte, Natal, Brazil

DARKWIN: Dark Matter and Weak Interactions Conference
Natal, Brazil, 02-13.09.2019

based on
JHEP12(2018)081, JHEP1907(2019)053
and work in progress

J. Kalinowski, J. Klamka, P. Sopicki, A.F. Żarnecki (University of Warsaw),
W. Kotlarski (TU Dresden),
T. Robens (Rudjer Boskovic Institute Zagreb)

Motivation

- **Standard Model:**
  - Higgs particle found at the LHC in 2012
    $\rightarrow$ very SM-like
  - no signal for New Physics as of 2019
  - several issues are still not explained by the SM
- **Dark Matter:**
  - if Standard Cosmological Model correct: 85% mass missing
  - only gravitational interaction observed
  - no (in)direct detection signal
  - nature of DM unknown – here we assume it is a WIMP
  - complementary approach preferred for testing DM models
  - here we focus on e^+e^- colliders

Outline

Inert Doublet Model

- particle content and parameters
- experimental and theoretical constraints
- benchmarks

Inert Scalars at Linear Colliders

- low-energy stages of ILC and CLIC
- high-energy stages of CLIC
- semi-leptonic channels at 3 TeV CLIC

Inert Doublet Model

2-Higgs Doublet Model with an exact Z_2 symmetry

$$\Phi_S = \begin{pmatrix} G^{\pm} \\ \frac{v+h+iG^0}{\sqrt{2}} \end{pmatrix}, \Phi_D = \begin{pmatrix} H^{\pm} \\ \frac{H+iA}{\sqrt{2}} \end{pmatrix}$$

- Φ_S is the SM–like Higgs doublet, with the SM-like Higgs h
- Φ_D (inert doublet) has four additional scalars H, A, $H^{\pm}$,
- a discrete Z_2 symmetry:
  Φ_S is *even*: $\Phi_S \to \Phi_S$ (also SM→SM)
  Φ_D is *odd*: $\Phi_D \to -\Phi_D$,
- Yukawa-type interactions only for Higgs doublet (Φ_S):
  Φ_D does not interact with the SM fermions
- the lightest inert particle is stable: a natural candidate for DM
- we assume H is the DM particle

$$M_H < M_A,\ M_{H^{\pm}}$$

Parameters

- The model contains seven free parameters

$$\lambda_{1,2,3,4,5}, m_{11}^2, m_{22}^2$$

- after EWSB λ_1, m_{11}^2 fixed from the SM (v, M_h)
- left with five free parameters, which we take as:
  - three inert scalar masses: M_H, M_A, $M_{H^\pm}$
  - two couplings, λ_2 and $\lambda_{345} = \lambda_3 + \lambda_4 + \lambda_5$
- inert scalars' couplings to γ, $W^\pm$ and Z determined by SM parameters

We scanned the IDM parameter space looking for scenarios consistent with current theoretical and experimental constraints, for masses up to 1 TeV.

Details in *Benchmarking the Inert Doublet Model for e^+e^- colliders*
JHEP12(2018)081 [arXiv:1809.07712]

Parameter Scan

- **Positivity of potential:**

$$\lambda_1 > 0,\ \lambda_2 > 0,\ \lambda_3 + \sqrt{\lambda_1\lambda_2} > 0,\ \lambda_{345} + \sqrt{\lambda_1\lambda_2} > 0.$$

- **Perturbativity:**

$$\lambda_i \leq 4\pi$$

- **Global minimum:**

$$\frac{m_{11}^2}{\sqrt{\lambda_1}} \geq \frac{m_{22}^2}{\sqrt{\lambda_2}}$$

- **LEP bound on charged scalar:**

$$M_{H^\pm} \geq 70\,\mathrm{GeV}$$

- **Recast LEP searches for SUSY particles:**

$$M_A \leq 100 \text{ GeV},\ M_H \leq 80 \text{ GeV},\ \Delta M(A,H) \geq 8 \text{ GeV},$$

- ***H* is the lightest inert scalar:**

$$M_H < M_A, M_H^\pm$$

- **Higgs mass from the LHC:**

$$M_h = 125.1 \text{ GeV}$$

Parameter Scan: Step 1

Step 1 - done using `2HDMC`

- **Unitarity:**
  the scalar $2 \to 2$ scattering matrix should be unitary
- **Higgs total decay width:**

$$\Gamma_{tot} \leq 9\text{MeV}$$

- **No EW bosons decays:**

$$M_{A,H} + M_{H^\pm} \geq M_W,\; M_A + M_H \geq M_Z,\; 2\,M_{H^\pm} \geq M_Z$$

- **EWPT:**
  $2\,\sigma$ (i.e. 95% C.L.) agreement with electroweak precision observables
- **No long-lived charged scalars:**

$$\tau_{H^\pm} \leq 10^{-7}\,s \Rightarrow \Gamma_{H^\pm} \geq 6.58 \times 10^{-18}\ \text{GeV}$$

Parameter Scan: Step 2 and 3

Step 2 – done using `HiggsSignals`, `HiggsBounds`:

- Higgs invisible decays
- $h \to \gamma\gamma$ signal strength and other
- reinterpreted direct (null) searches for BSM physics

Step 3 – done using `micrOMEGAs`:

- DM relic density – upper Planck limit:

$$\Omega_H h^2 \leq \Omega_{DM}\, h^2 \;=\; 0.1224$$

- $\Omega_H h^2 = \Omega_{DM}\, h^2$ if possible
- direct detection – latest results from XENON1T (2018)
- indirect detection – no new exclusions for most points

Constraints for M_H

- $M_H \leq 45$ GeV:

  excluded by at least one of $Br(h \to inv), \Gamma_{W,Z}, \Omega_{DM} h^2$

Larger DM masses are still viable:

- $45 \text{ GeV} < M_H \lesssim 57$ GeV:

  OK but $\Omega_H h^2 < \Omega_{DM} h^2$

- $57 \text{ GeV} \lesssim M_H \lesssim 75$ GeV:

  OK and $\Omega_H h^2 \leq \Omega_{DM} h^2$ (100% DM possible)

- $75 \text{ GeV} \lesssim M_H \lesssim 525$ GeV:

  OK but $\Omega_H h^2 < \Omega_{DM} h^2$

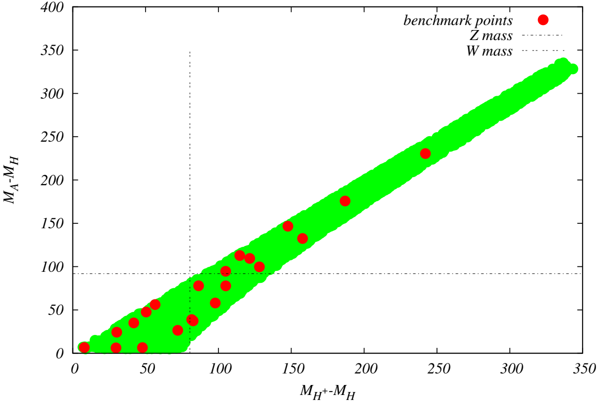
- $M_H \gtrsim 525$ GeV:

  OK and $\Omega_H h^2 \leq \Omega_{DM} h^2$ (100% DM possible)

Constraints for $M_A, M_{H^\pm}$

- from EWPT:

$$M_A < M_{H^\pm} \text{ and } M_{H^\pm} - M_A \lesssim 70\,\text{GeV}$$



- if exact relic density for heavy masses then masses almost degenerated

Constrains for λ_2, λ_{345}

self-coupling λ_2

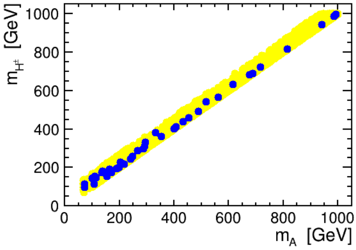
- direct constraints from positivity, perturbative unitarity
- no influence on tree-level DM annihilation, LHC physics
- possible test – self-interaction of DM? loop corrections?

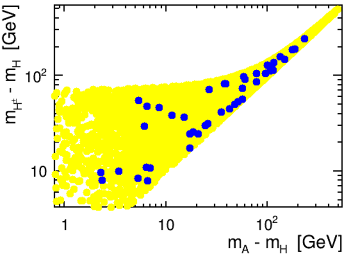
Higgs-DM coupling λ_{345}

- very strong constraints from LHC & DD & relic density
- $\lambda_{345} \sim \mathcal{O}(10^{-3})$
- after that almost no influence on collider physics
- not relevant at LC

IDM benchmark points

- about 15000 points consistent with all considered constraints found
- 41 points (21 accessible at 500 GeV) chosen for detailed study





The selection was arbitrary, but we tried to

- cover a wide range of scalar masses and mass splittings
- get significant contribution to the relic density

Detailed list of parameters for all benchmarks: backup slides

Significance of mass splittings

BP1 and BP6:

	M_H	M_A	$M_{H^\pm}$	V or V^*
BP1	72.77	107.8	114.6	$Z^*, W^{\pm *}$
BP6	72.14	109.5	154.8	$Z^*, W^\pm$

BP8 and BP15:

	M_H	M_A	$M_{H^\pm}$	V or V^*
BP8	70.91	148.7	175.9	$Z^*, W^\pm$
BP15	71.03	217.7	218.7	$Z, W^\pm$

On-shell scalar production for $\sqrt{s} = 250, 380, 500$ GeV

$\sigma(e^+e^- \to H^+H^-)$ [fb] $\sigma(e^+e^- \to AH)$ [fb]

	$\sigma(250)$	$\sigma(380)$	$\sigma(500)$			$\sigma(250)$	$\sigma(380)$	$\sigma(500)$
BP1	23.7	97.8	82.6		BP8	20	47.5	38.1
BP6	-	33.3	53.2		BP15	-	18.2	24.2

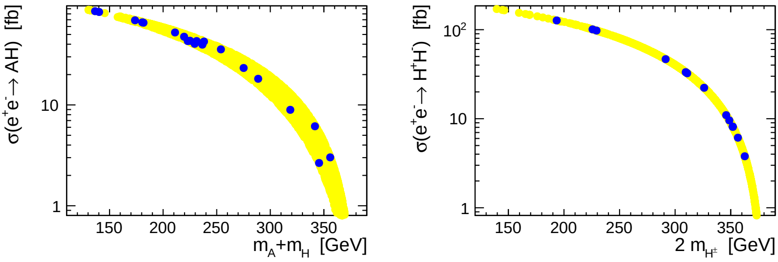
main decay channels: $H^\pm \to HW^{\pm(*)}, A \to HZ^{(*)}$

Scalar production at e^+e^- colliders

Production of IDM scalars is dominated by two processes:

$$e^+e^- \to A\ \ H \qquad\qquad e^+e^- \to H^+H^-$$

Leading-order cross sections:



(plots for $\sqrt{s} = 380$ GeV (1st stage CLIC))

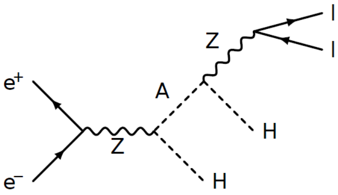
Signatures

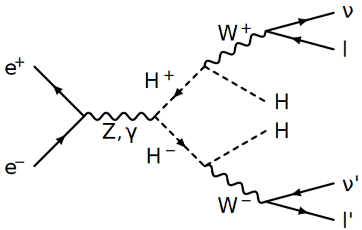
AH production process followed by the A decay $\to$ lepton pair production:

$$e^+e^- \to HA \to HHZ^{(\star)} \to HH\mu^+\mu^-,$$

H^+H^- production with decaying $H^\pm \to$ different flavour lepton pair:

$$e^+e^- \to H^+H^- \to HHW^{+(*)}W^{-(*)} \to HHl^+l'^-\nu\bar{\nu}'$$





Signal processes

We consider two possible final state signatures:

- muon pair production, $\mu^+\mu^-$, mainly from HA
- electron-muon pair production, μ^+e^- or $e^+\mu^-$, mainly from H^+H^-
- both channels include contributions from AH and H^+H^- production

Signal processes for $\mu^+\mu^-$ final state (with $\tau^\pm \to \mu^\pm\nu\nu$)

$$\begin{aligned} e^+e^- &\to \mu^+\mu^- \; HH, \\ &\to \mu^+\mu^-\nu_\mu\bar{\nu}_\mu \; HH, \\ &\to \tau^+\mu^-\nu_\tau\bar{\nu}_\mu \; HH, \;\; \mu^+\tau^-\nu_\mu\bar{\nu}_\tau \; HH, \\ &\to \tau^+\tau^- \; HH, \;\; \tau^+\tau^-\nu_\tau\bar{\nu}_\tau \; HH. \end{aligned}$$

Signal processes for $e^\pm\mu^\mp$ final state (with $\tau^\pm \to \mu^\pm\nu\nu, e^\pm\nu\nu$)

$$\begin{aligned} e^+e^- &\to \mu^+\nu_\mu \, e^-\bar{\nu}_e \; HH, \;\; e^+\nu_e \, \mu^-\bar{\nu}_\mu \; HH, \\ &\to \mu^+\nu_\mu \, \tau^-\bar{\nu}_\tau \; HH, \;\; \tau^+\nu_\tau \, \mu^-\bar{\nu}_\mu \; HH, \\ &\to e^+\nu_e \, \tau^-\bar{\nu}_\tau \; HH, \;\; \tau^+\nu_\tau \, e^-\bar{\nu}_e \; HH, \\ &\to \tau^+\,\tau^- \; HH, \;\; \tau^+\nu_\tau \, \tau^-\bar{\nu}_\tau \; HH, \end{aligned}$$

Analysis strategy

Tools used:

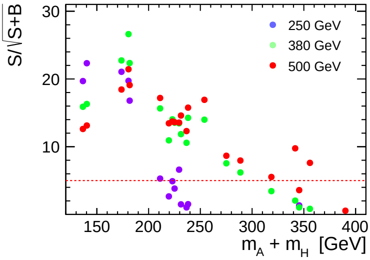
- signal and background samples from WHizard 2.2.8
- based on dedicated IDM model implementation in SARAH
- parameter files for benchmark scenarios from SPheno 4.0.3
- Boosted Decision Tree classification algorithm in TMVA toolkit
- BDT classifier with 8 input variables used for selection of signal events

Analysis for CLIC in *Exploring Inert Scalars at CLIC* (arXiv:1811.06952), *The CLIC Potential for New Physics* (arXiv:1812.02093)

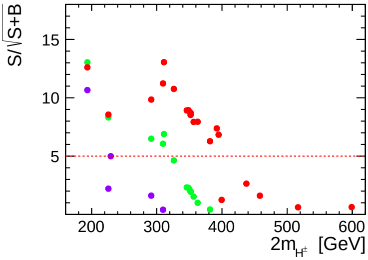
$\sqrt{s} = 250, 380, 500$ GeV

Depending on the scalar masses, many benchmarks are already accessible at first stages of ILC and CLIC:

AH signature $(\mu^+\mu^-)$



H^+H^- signature $(\mu^\pm e^\mp)$



for all $\sqrt{s}$ we take 1000 fb^{-1}

Discovery reach for $\sqrt{s} = 250, 380, 500$ GeV:

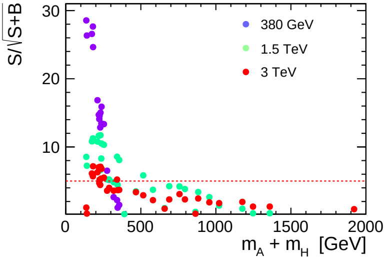
- neutral scalar production: $M_A + M_H < 220, 300, 360$ GeV
- charged scalar production: $M_{H^\pm} < 110, 160, 200$ GeV

$\sqrt{s} = 1.5, 3$ TeV

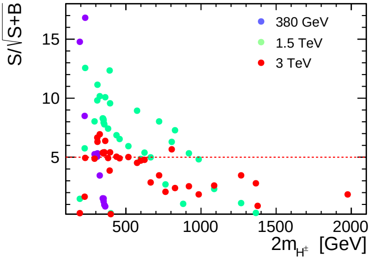
Same analysis procedure applied for CLIC Stage 2 & 3:

$2500\,\text{fb}^{-1}$ at $1.5\,\text{TeV}$ and $5000\,\text{fb}^{-1}$ at $3\,\text{TeV}$

AH signature ($\mu^+\mu^-$)



H^+H^- signature ($\mu^\pm e^\mp$)

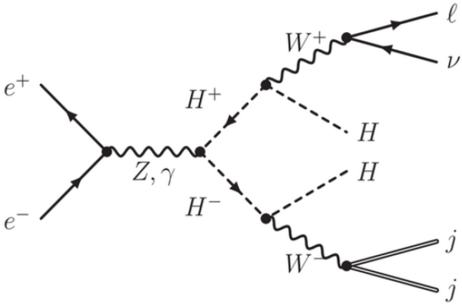


Moderate increase in discovery reach for 1.5 TeV:

- neutral scalar production: $M_A + M_H < 550\,\text{GeV}$ (360 GeV @ 500 GeV)
- charged scalar production: $M_{H^\pm} < 500\,\text{GeV}$ (200 GeV @ 500 GeV)

No significant gain from going to 3 TeV.

Semi-leptonic channels



Main SM background: $qq\ell\nu, qq\ell\ell$

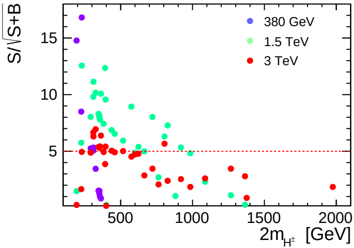
- significantly larger branching ratio:

$$\mathrm{Br}(W^\pm \to \ell\nu) \approx 2\%, \quad \mathrm{Br}(W^\pm \to qq) \approx 20\%$$

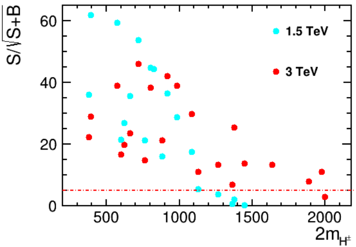
- leads to larger cross-sections!

Semi-leptonic channels

Leptonic signature



Semi-leptonic signature



- significant improvement compared to leptonic channels
- only one benchmark with very small $M_{H\pm} - M_H$ still inaccessible

Summary

- The IDM – a simple model with rich phenomenology
- e^+e^- colliders can test large part of the parameter space
- Low mass scenarios can be observed with high significance in the di-muon channel already at the low energy stages of CLIC and ILC, up to $M_A + M_H \sim 360\,\text{GeV}$ and $M_{H^\pm} \sim 200\,\text{GeV}$
- The discovery reach is extended to $\sim 500\,\text{GeV}$ when running at 1.5 TeV
- No real improvement in leptonic channels with 3 TeV run
- For semi-leptonic channel significant increase in discovery reach

Backup slides

Low mass IDM benchmark points

No.	M_H	M_A	$M_{H^\pm}$	λ_2	λ_{345}	$\Omega_H h^2$
BP1	72.77	107.8	114.6	1.445	-0.004407	0.1201
BP2	65	71.53	112.8	0.7791	0.0004	0.07081
BP3	67.07	73.22	96.73	0	0.00738	0.06162
BP4	73.68	100.1	145.7	2.086	-0.004407	0.08925
BP6	72.14	109.5	154.8	0.01257	-0.00234	0.1171
BP7	76.55	134.6	174.4	1.948	0.0044	0.0314
BP8	70.91	148.7	175.9	0.4398	0.0051	0.124
BP9	56.78	166.2	178.2	0.5027	0.00338	0.08127
BP10	76.69	154.6	163	3.921	0.0096	0.02814
BP11	98.88	155	155.4	1.181	-0.0628	0.002737
BP12	58.31	171.1	173	0.5404	0.00762	0.00641
BP13	99.65	138.5	181.3	2.463	0.0532	0.001255
BP14	71.03	165.6	176	0.3393	0.00596	0.1184
BP15	71.03	217.7	218.7	0.7665	0.00214	0.1222
BP16	71.33	203.8	229.1	1.03	-0.00122	0.1221
BP18	147	194.6	197.4	0.387	-0.018	0.001772
BP19	165.8	190.1	196	2.768	-0.004	0.002841
BP20	191.8	198.4	199.7	1.508	0.008	0.008494
BP21	57.48	288	299.5	0.9299	0.00192	0.1195
BP22	71.42	247.2	258.4	1.043	-0.00406	0.1243
BP23	62.69	162.4	190.8	2.639	0.0056	0.06404

High mass IDM benchmark points

No.	M_H	M_A	$M_{H^\pm}$	λ_2	λ_{345}	$\Omega_H h^2$
HP1	176	291.4	312	1.49	-0.1035	0.0007216
HP2	557	562.3	565.4	4.045	-0.1385	0.07209
HP3	560	616.3	633.5	3.38	-0.0895	0.001129
HP4	571	676.5	682.5	1.98	-0.471	0.0005635
HP5	671	688.1	688.4	1.377	-0.1455	0.02447
HP6	713	716.4	723	2.88	0.2885	0.03515
HP7	807	813.4	818	3.667	0.299	0.03239
HP8	933	940	943.8	2.974	-0.2435	0.09639
HP9	935	986.2	988	2.484	-0.5795	0.002796
HP10	990	992.4	998.1	3.334	-0.051	0.1248
HP11	250.5	265.5	287.2	3.908	-0.1501	0.00535
HP12	286.1	294.6	332.5	3.292	0.1121	0.00277
HP13	336	353.3	360.6	2.488	-0.1064	0.00937
HP14	326.6	331.9	381.8	0.02513	-0.06267	0.00356
HP15	357.6	400	402.6	2.061	-0.2375	0.00346
HP16	387.8	406.1	413.5	0.8168	-0.2083	0.0116
HP17	430.9	433.2	440.6	3.003	0.08299	0.0327
HP18	428.2	454	459.7	3.87	-0.2812	0.00858
HP19	467.9	488.6	492.3	4.122	-0.252	0.0139
HP20	505.2	516.6	543.8	2.538	-0.354	0.00887

Low mass benchmark points [Points from arXiv:1809.07712]

No.	M_H	M_A	$M_{H^\pm}$	HA	$H\,H^+$	AH^+	H^+H^-	AA	onshell
BP1	72.77	107.803	114.639	322	304	169	132	0.4	
BP2	65	71.525	112.85	1022	363	322	140	0.1	
BP3	67.07	73.222	96.73	909	504	444	242	0.1	
BP4	73.68	100.112	145.728	377	165	115	55.1	0.3	
BP6	72.14	109.548	154.761	314	144	88.9	45.1	0.4	W
BP7	76.55	134.563	174.367	173	99.0	50.8	29.2	0.4	W
BP8	70.91	148.664	175.89	144	103	42.7	28.3	0.5	W
BP9	56.78	166.22	178.24	125	116	34.4	27.1	0.6	W, Z
BP10	76.69	154.579	163.045	120	119	46.4	37.3	0.5	W
BP11	98.88	155.037	155.438	87.7	101	50.4	43.8	0.2	
BP12	58.31	171.148	172.96	113	125	34.5	30.3	0.6	W, Z
BP13	99.65	138.484	181.321	113	68.8	44.7	25.2	0.3	W
BP14	71.03	165.604	175.971	106	103	35.5	28.3	0.5	W, Z
BP15	71.03	217.656	218.738	46.9	54.6	14.2	12.8	0.4	W, Z
BP16	71.33	203.796	229.092	57.3	47.3	14.6	10.8	0.4	W, Z
BP18	147	194.647	197.403	29.6	34.0	21.3	17.9	0.1	
BP19	165.8	190.082	195.999	25.5	28.6	22.5	18.3	0.03	
BP20	191.8	198.376	199.721	17.9	21.4	20.1	16.9	0.03	
BP21	57.475	288.031	299.536	20.6	21.8	4.02	4.04	0.3	W, Z
BP22	71.42	247.224	258.382	31.3	32.5	8.05	6.90	0.4	W, Z
BP23	62.69	162.397	190.822	125	88.9	31.3	21.1	0.5	W, Z

Production cross sections in fb, at 13 TeV [UFO+Madgraph]

$>$ 1000 events in Run II for each process: all but BPs 21 and 22

High mass benchmark points [Points from arXiv:1809.07712]

No.	M_H	M_A	$M_{H^\pm}$	HA	HH^+	AH^+	H^+H^-	AA	onshell
HP1	176	291.36	311.96	8.3	8.8	4.0	3.1	0.1	W,Z
HP2	557	562.316	565.417	0.2	0.3	0.3	0.2	-	
HP3	560	616.32	633.48	0.1	0.2	0.2	0.1	0.003	
HP4	571	676.534	682.54	0.1	0.1	0.1	0.08	0.005	W,Z
HP5	671	688.108	688.437	0.07	0.1	0.09	0.07	-	
HP6	713	716.444	723.045	0.05	0.07	0.07	0.05	-	
HP7	807	813.369	818.001	0.03	0.04	0.04	0.03	-	
HP8	933	939.968	943.787	0.01	0.02	0.02	0.01	-	
HP9	935	986.22	987.975	0.009	0.01	0.01	0.009	-	
HP10	990	992.36	998.12	0.07	0.01	0.01	0.008	-	
HP11	250.5	265.49	287.226	5.8	6.3	5.7	4.0	-	
HP12	286.05	294.617	332.457	3.6	3.6	3.4	2.2	0.003	
HP13	336	353.264	360.568	1.7	2.2	2.0	1.5	0.001	
HP14	326.55	331.938	381.773	2.1	2.0	2.0	1.2	-	
HP15	357.6	399.998	402.568	1.1	1.5	1.2	1.0	0.006	
HP16	387.75	406.118	413.464	0.9	1.2	1.1	0.8	-	
HP17	430.95	433.226	440.624	0.6	0.8	0.8	0.6	-	
HP18	428.25	453.979	459.696	0.6	0.8	0.7	0.5	-	
HP19	467.85	488.604	492.329	0.4	0.5	0.5	0.4	-	
HP20	505.2	516.58	543.794	0.3	0.4	0.3	0.2	-	

Production cross sections in fb, at 13 TeV [UFO+Madgraph]

$>$ 1000 events at HL-LHC for each process: HP1, HP11-19

from T. Robens, IDM benchmarks for the LHC at 13 and 27 TeV, WG3 extended scalars subgroup open meeting

LHC: 27 TeV vs 13 TeV

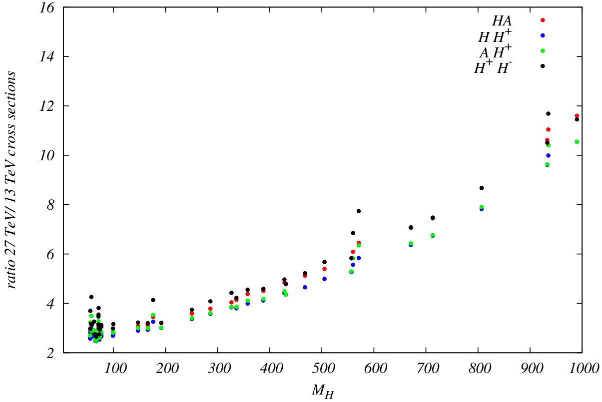
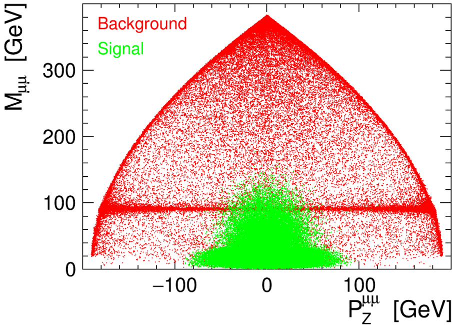


Figure: Ratio of production cross sections for the four dominant production channels at the 27 TeV HE-LHC and current center-of-mass energy of 13 TeV. While in the low energy range, cross sections are enhanced roughly by a factor $\lesssim 3$, for higher masses they can change by an order of magnitude.

Neutral scalar production @ 380 GeV

Muon pair inv. mass $M_{\mu\mu}$, vs lepton pair longitudinal momentum $P_Z^{\mu\mu}$ for BP1 scenario and SM background at 380 GeV

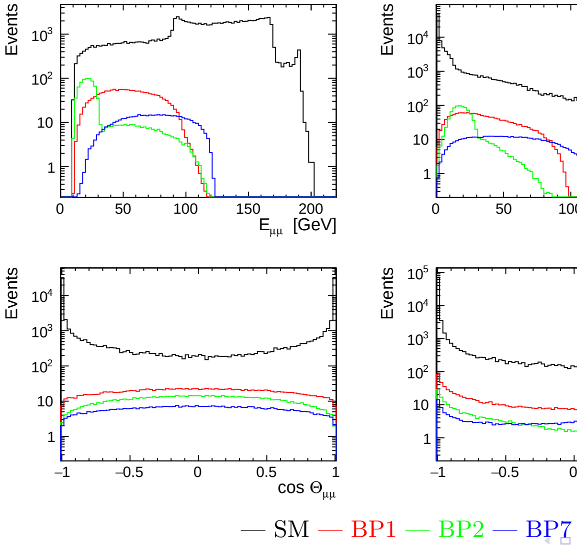


Background dominated by muon pair production $(e^+e^- \to \mu^+\mu^-)$ at nominal energy and radiative events $(e^+e^- \to \mu^+\mu^-\gamma)$

⇒ apply pre-selection cuts: $M_{\mu\mu} < 100\,\text{GeV}$ and $|P_Z^{\mu\mu}| < 140\,\text{GeV}$

Neutral scalar production @ 380 GeV (500 fb^{-1})

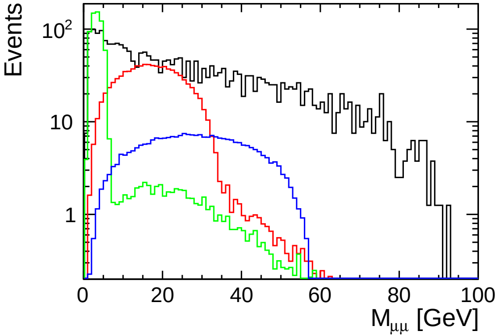
Distributions of the kinematic var. describing the leptonic final state



Cut based approach

Lepton pair invariant mass distribution after selection cuts:

- pair energy
  $E_{\mu\mu} < 100\,\mathrm{GeV}$
- transverse momentum
  $p_T^{\mu\mu} > 10\,\mathrm{GeV}$
- production angle
  $30^\circ < \Theta_{\mu\mu} < 150^\circ$
- azimuthal distance
  $|\Delta\varphi_{\mu\mu}| < \frac{\pi}{2}$



Considered IDM scenarios result in the visible event excess 15σ, 11σ and 5σ, for BP1, BP2 and BP7

Multivariate analysis

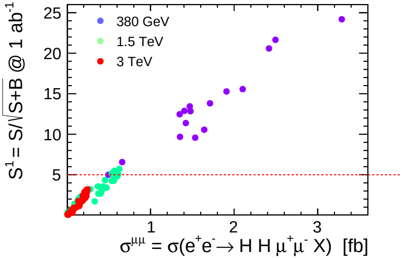
- aim: best possible discrimination between Background and Signal ($\Rightarrow$ highest significance)
- Boosted Decision Tree classification algorithm in TMVA toolkit
- BDT classifier with 8 input variables used for selection of signal events
- not all independent (system described by 5 param.)
- better significance if we use all 8:

- total energy of the muon pair, E_{ll}
- dilepton invariant mass, M_{ll}
- dilepton transverse momentum, $\mathrm{p}_{\mathrm{T}}^{ll}$
- polar angle of the dilepton pair, Θ_{ll}
- Lorentz boost of the dilepton pair, $\beta_{ll} = \mathrm{p}_{ll}/\mathrm{E}_{ll}$
- ℓ^- production angle with respect to the beam direction, calculated in the dilepton center-of-mass frame, $\Theta_l^\star$
- ℓ^- production angle with respect to the dilepton pair momentum direction, calculated in the dilepton center-of-mass frame, $\angle^\star(\ell, \ell\ell)$
- reconstructed missing (recoil) mass M_{miss} (calculated assuming nominal e^+e^- collision energy)

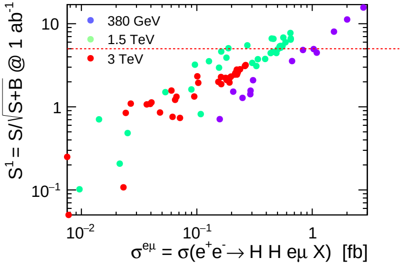
Significance vs cross-section

Significance scaled to the same integrated luminosity of $1000\,\mathrm{fb}^{-1}$
as a function of the signal channel cross section

AH signature ($\mu^+\mu^-$)



H^+H^- signature ($\mu^\pm e^\mp$)



Expected significance mainly related to the signal channel cross section!
~ 0.5 fb sufficient for the discovery...