Searching for Inert Doublet Model scalars at high energy CLIC

Jan Klamka, Aleksander Filip Żarnecki

University of Warsaw
Faculty of Physics

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Inert Doublet Model

SM Higgs:

$$\phi_{SM} = \begin{pmatrix} \phi^+ \\ \frac{1}{\sqrt{2}}(v + h + i\xi) \end{pmatrix}$$

„Higgs boson”: h

IDM Higgs:

$$\phi_D = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}(H + iA) \end{pmatrix}$$

New particles: $H^\pm, H, A$

Inert Doublet Model

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New particles: $H^\pm, H, A$

- One of the simplest extensions of SM
- Additional scalars does not couple to fermions
- **The lightest new scalar H is stable**
  → good dark matter particle candidate
- Some theoretical and experimental constraints already exist

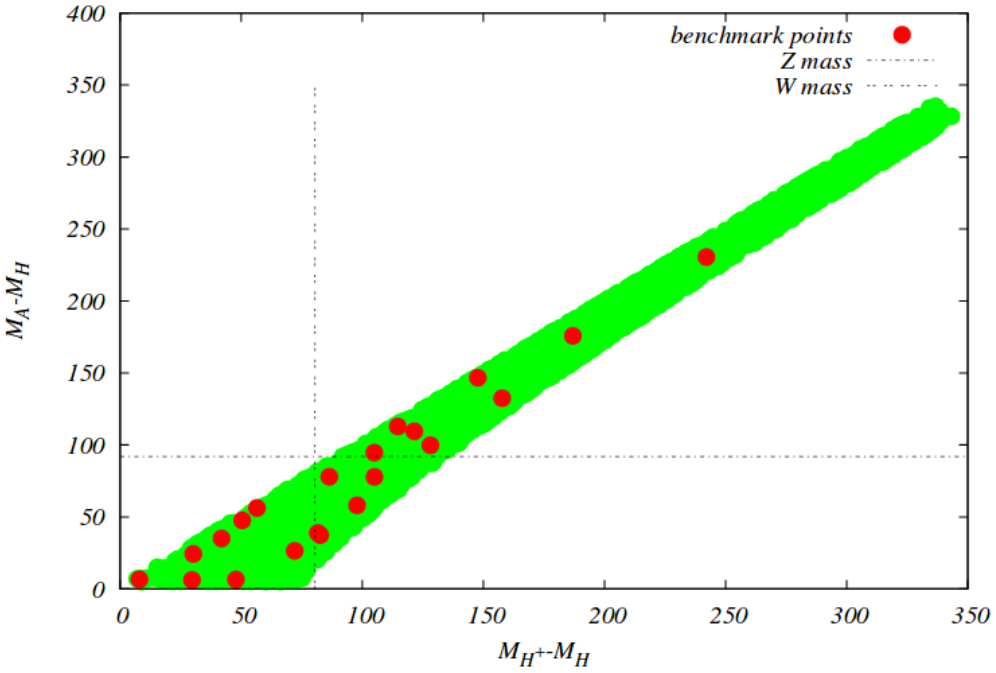
Parameters $M_{H^\pm}, M_H, M_A$ + 2 coupling constants

5 free-parameter space

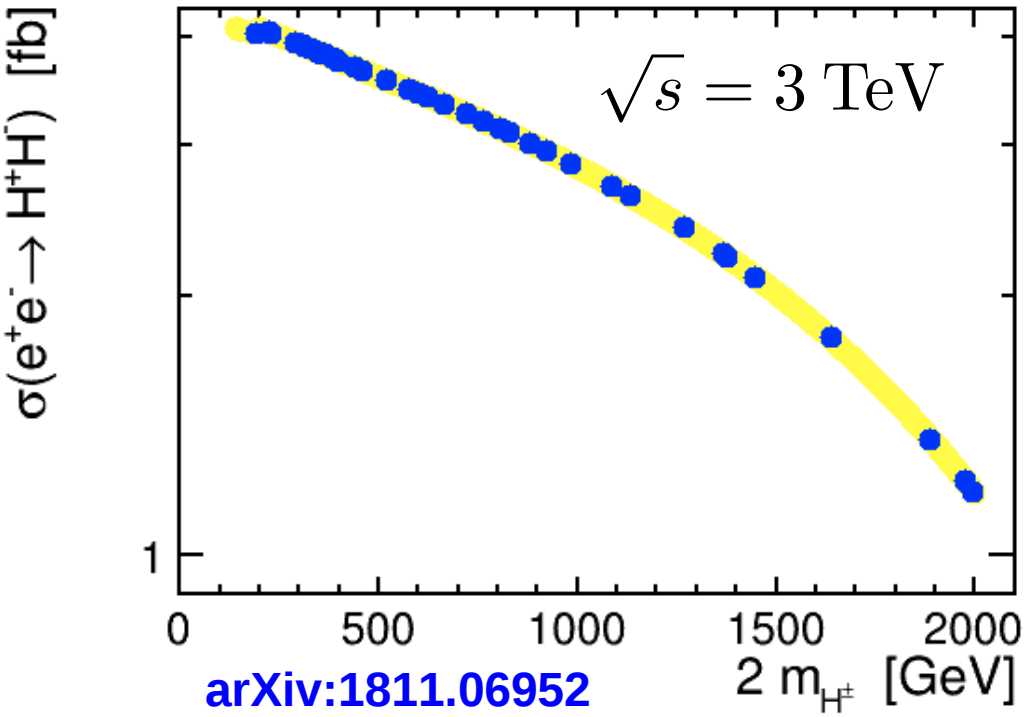
Parameter space

Considered benchmark points from:

JHEP 1812 (2018) 081, arXiv:1809.07712



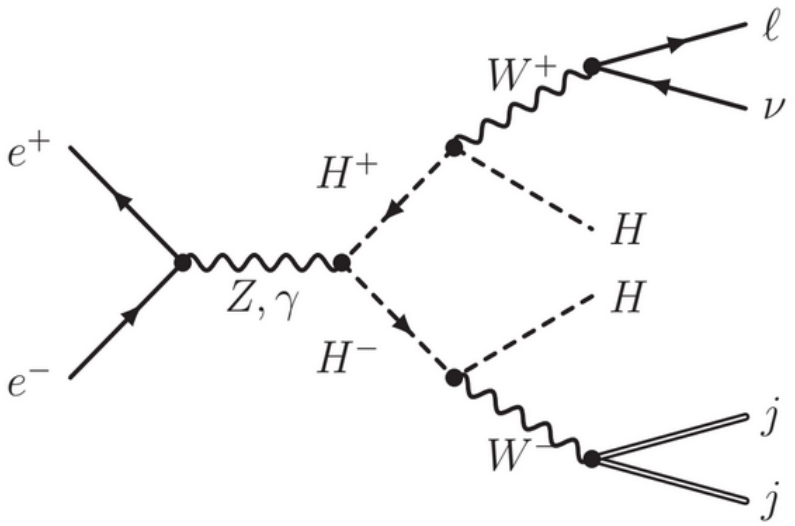
Leading-order cross sections:



arXiv:1811.06952

- Consistent with current theoretical and experimental constraints
- Masses up to 1 TeV
- Decay rates predicted from the SM parameters

Strategy

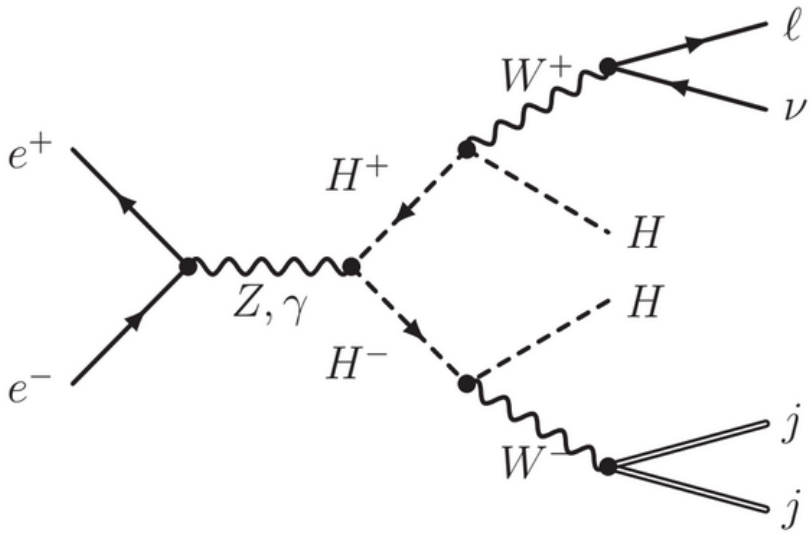


Expected **signature** of the final state:
One lepton, μ or e, and a **pair of jets**

Dominating background:

$qq\ell\nu,\ qq\ell\ell,\ qq\ell\nu\nu\nu,\ qq\ell\nu\ell\nu$

Strategy



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- Event samples generated with **Whizard 2.7.0**
- Using CLIC beam spectra for **3 TeV**
- **11 benchmark points** (BP) considered

Output → **DELPHES** fast simulation

Strategy

Reconstruction of:
- jets (VLC algorithm)
- isolated leptons
- isolated photons

} **DELPHES** (CLICdet card)

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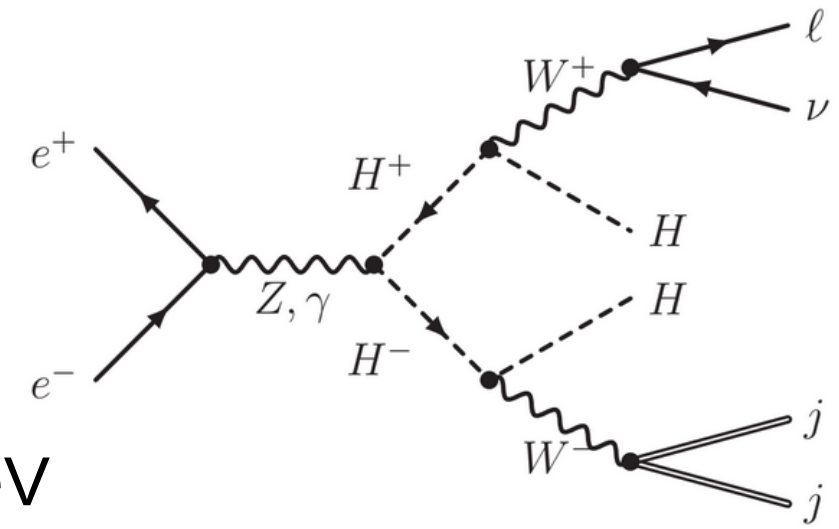
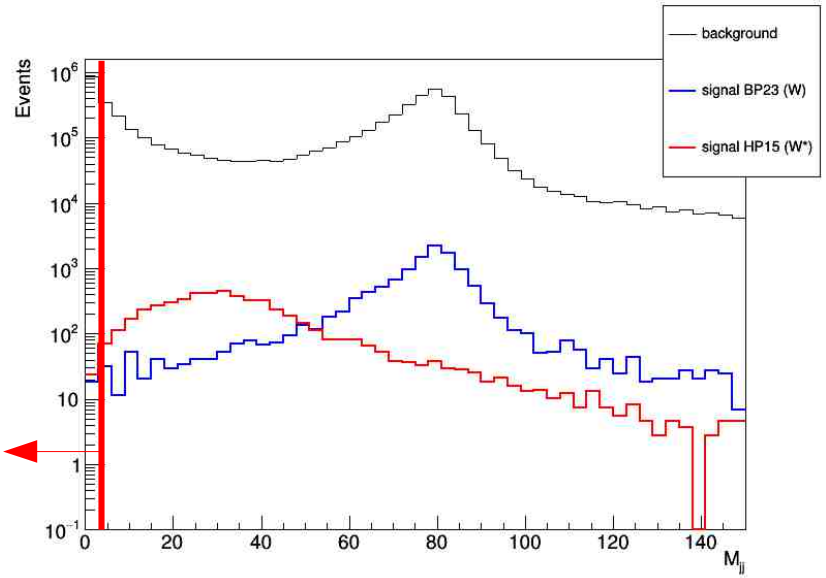
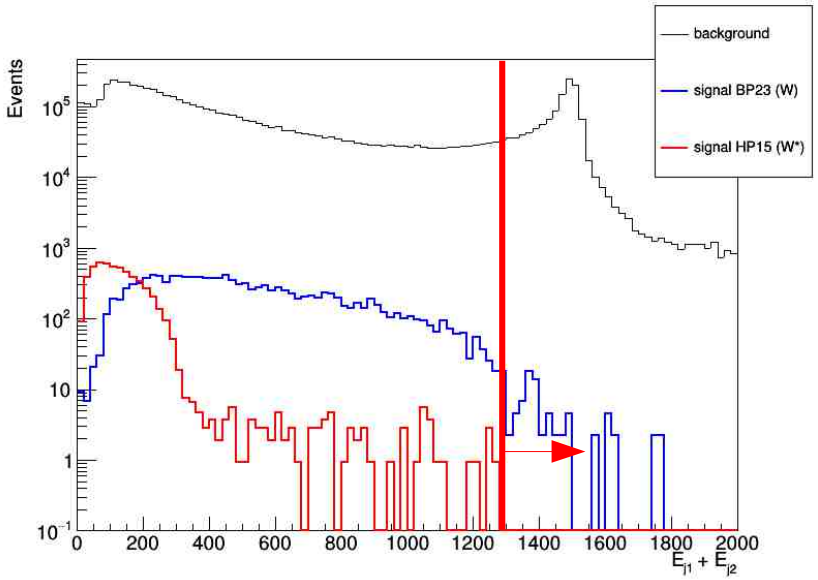


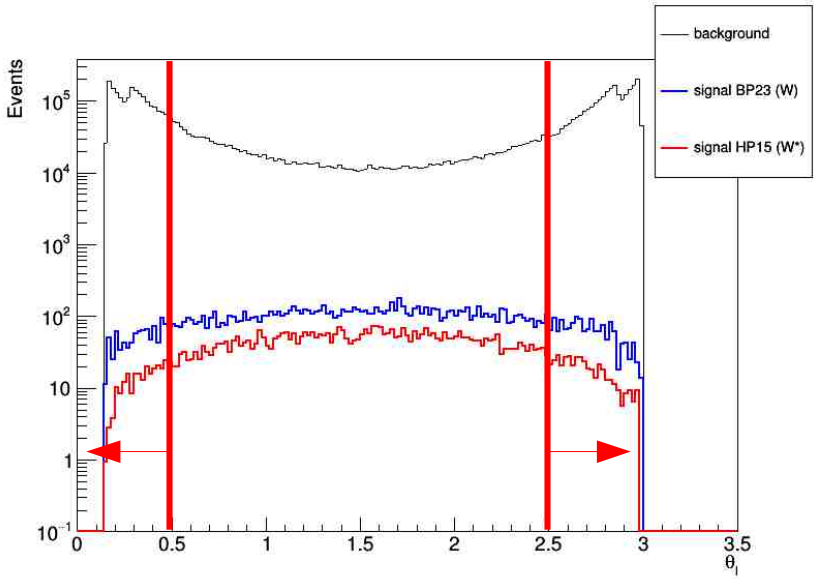
Require:
- exactly **one isolated lepton**
- **no isolated photons** over 10 GeV
- additional energy-flow objects in the detector with less than 20 GeV
- **two** exclusive **jets** (VLC: $\beta = \gamma = 1,\ R = 1.2,\ N = 2$)

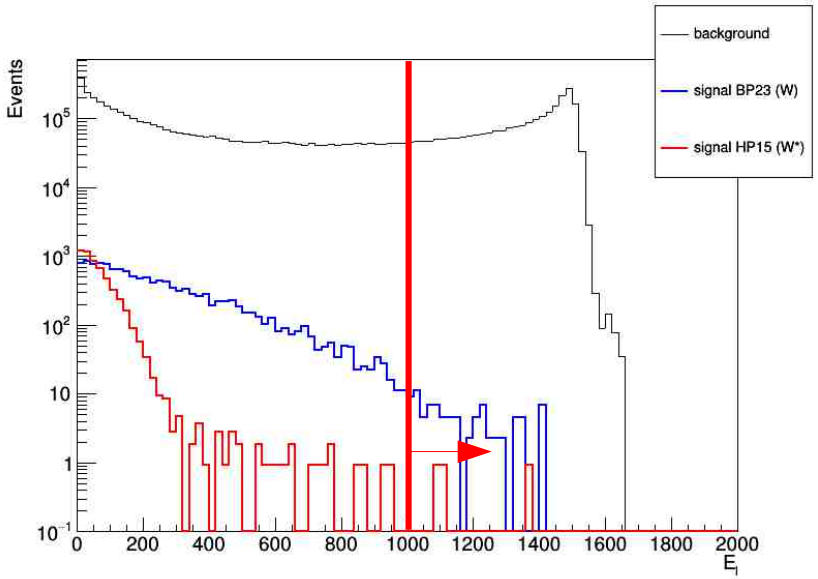
Pre-selection

Examples of the signal for **on-shell *W* (BP23)** and **off-shell *W** (HP15)**:









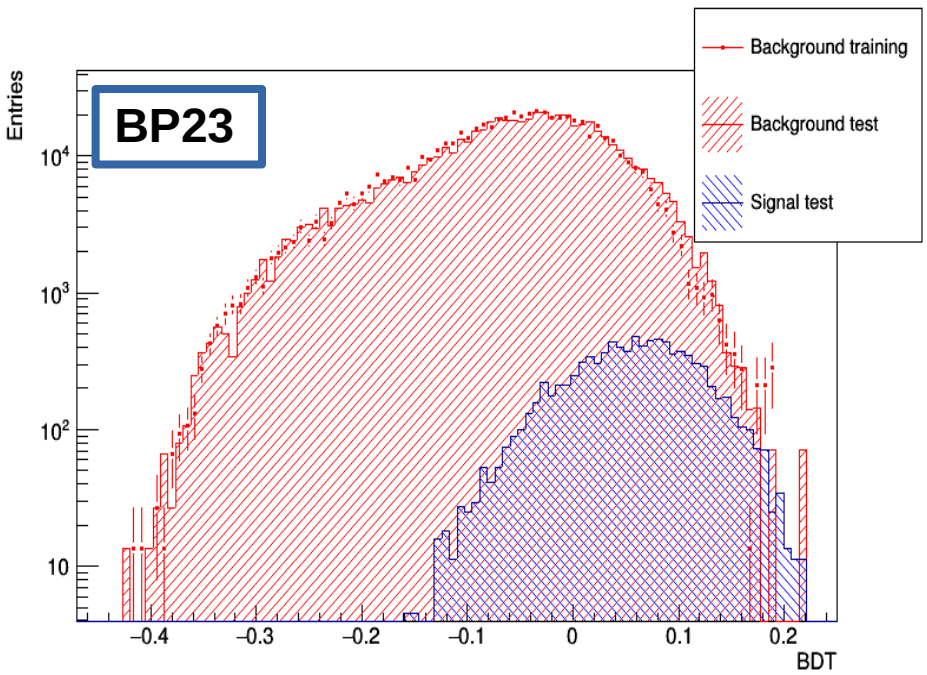
Pre-selection results

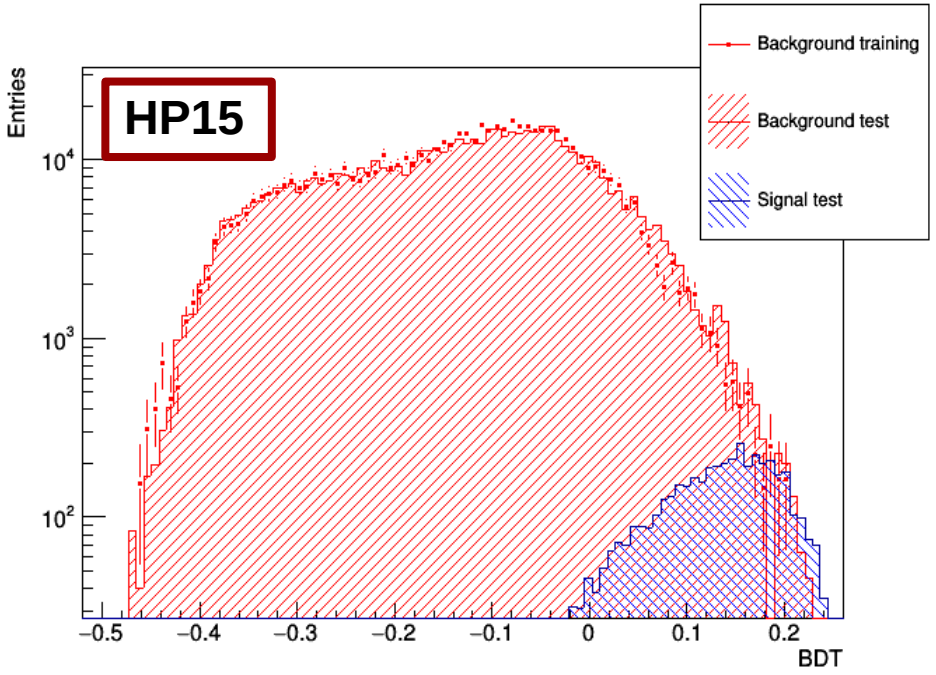
$$M_{jj} > 15\ \mathrm{GeV},\ E_\ell < 600\ \mathrm{GeV},\ p_T^\ell < 600\ \mathrm{GeV}$$
$$0.5 < \theta_W < 2.5, \quad 0.5 < \theta_\ell < 2.5$$

channel	all exp. ev.	exp. ev. after preselec.	eff.
H^+H^- (BP23)	22716	9497	41.8%
H^+H^- (HP15)	9315	4439	47.7%
tot. backg.	74877722	581367	0.78%
$qq\ell\ell$	12877040	62582	0.49%
$qq\ell\nu$	35326320	368418	1.04%
$qq\ell\nu\ell\nu$	317914	29820	9.38%
$qq\ell\nu\nu\nu$	360848	60369	16.73%
signal/backg. (BP23)	0.0003	0.016	
signal/backg. (HP15)	0.00012	0.0076	

- **Signal to background ratio** improvement
- Cut-based selection not sufficient – multivariable analysis needed

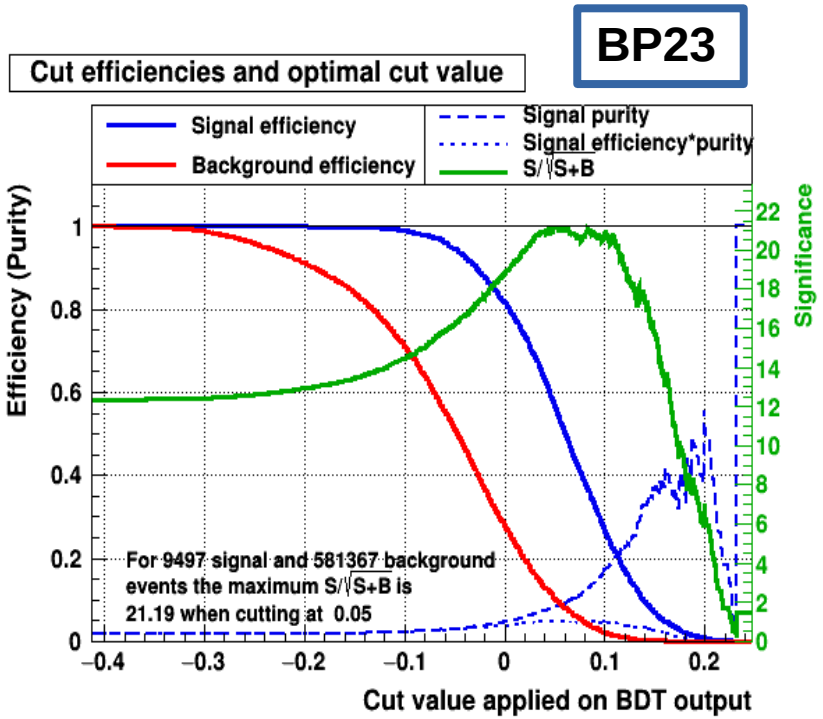
BDT analysis

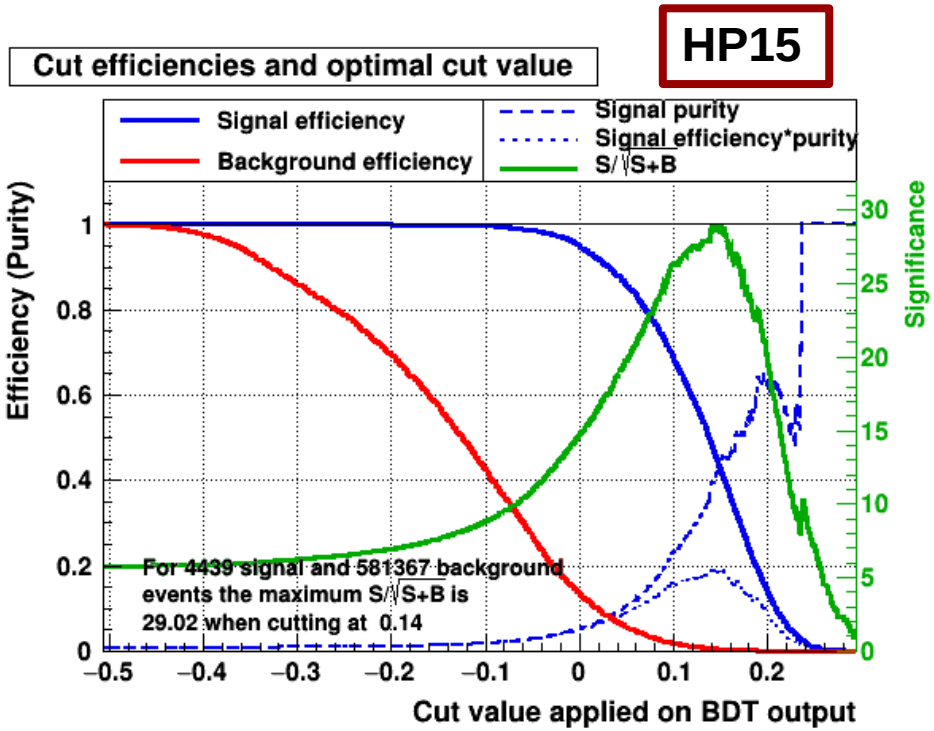




- Samples with **off-shell *W**** used for training **separately** from samples with **on-shell *W***
- Algorithm did not overtrain

BDT analysis

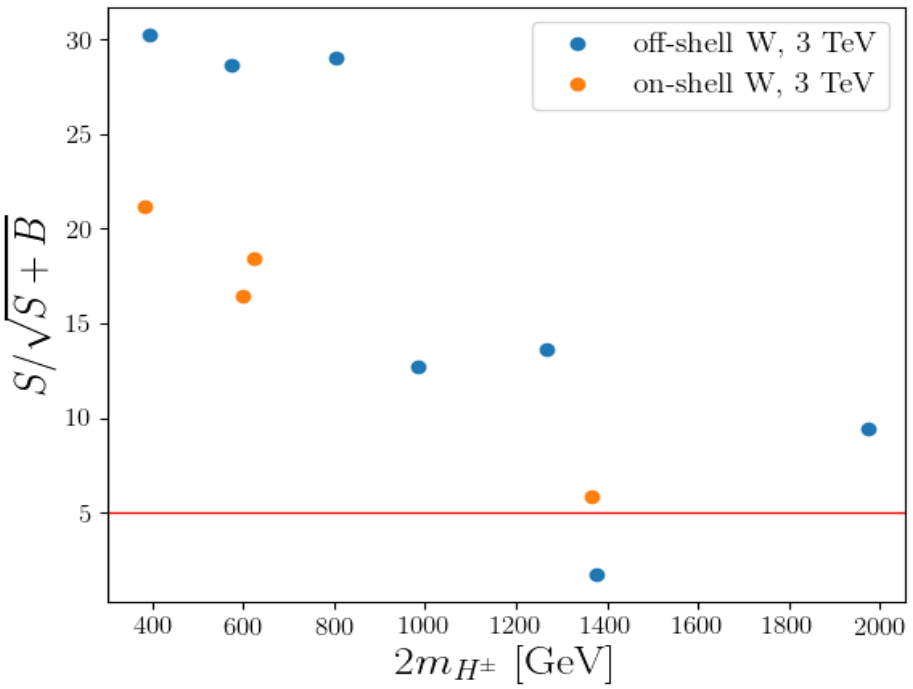




- High signal significance after BDT analysis
- Sufficient signal efficiency after cut on BDT (~20-25%)

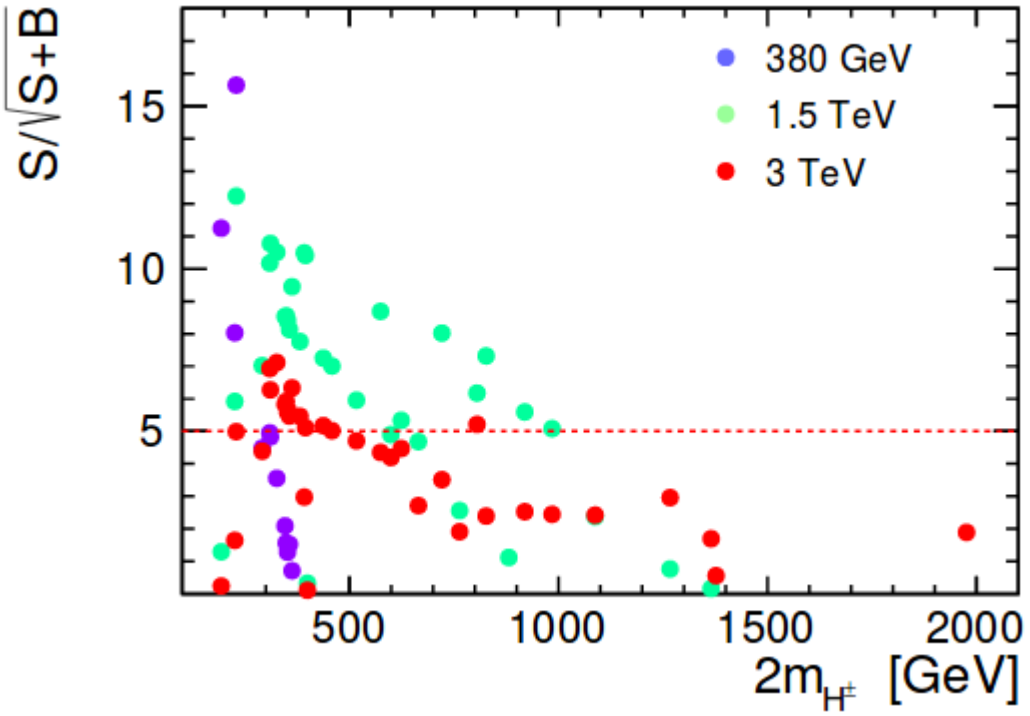
BDT results

Semi-leptonic channel results:



Full-leptonic channel results:

arXiv:1811.06952, arXiv:1812.02093



- High improvement, compared to the full leptonic channel
- Only one BP (with the lowest cross-section) below 5σ

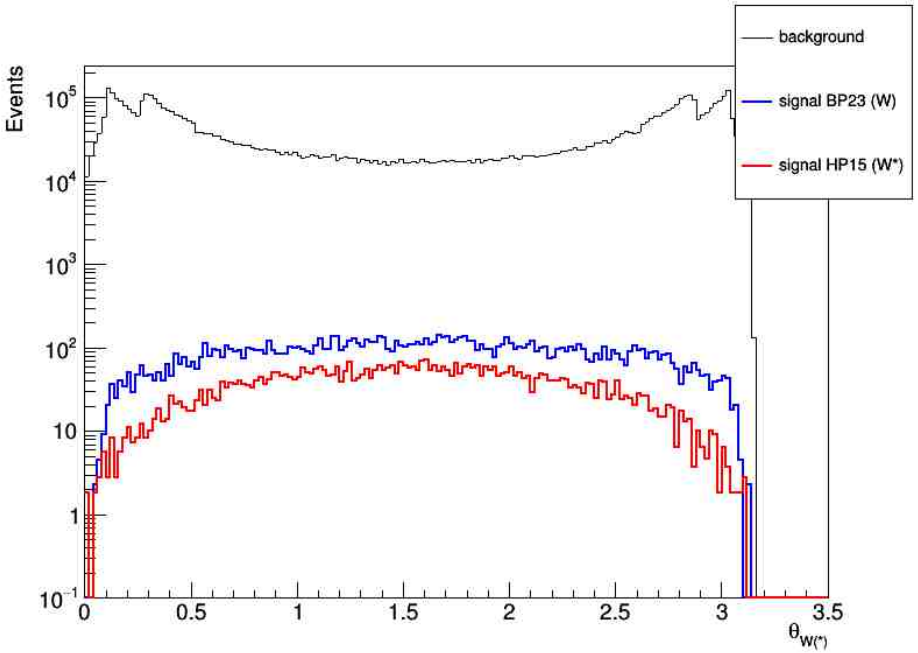
BDT results

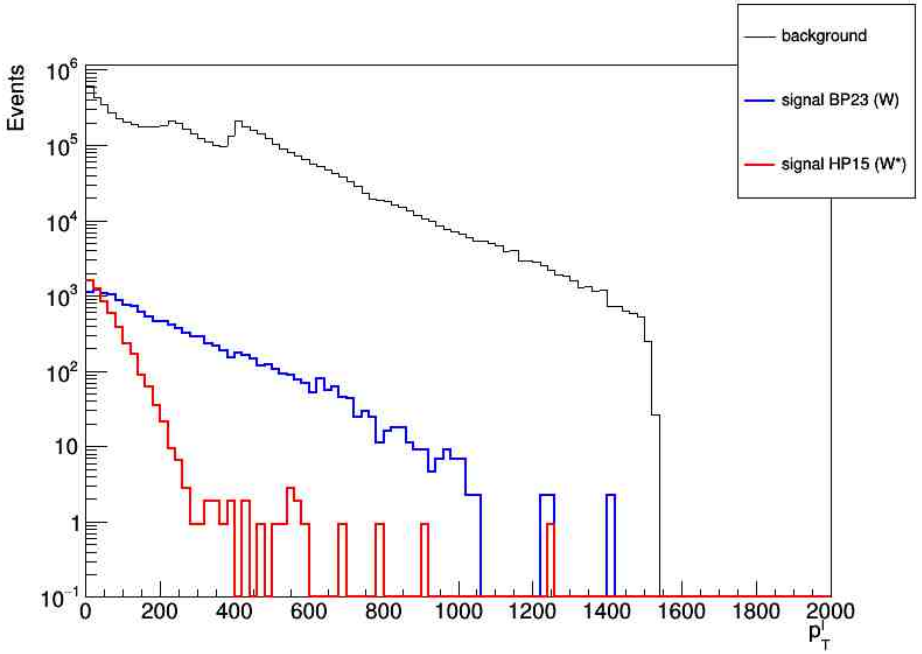
Benchmark point	$S/\sqrt{S+B}$	$2m_{H^\pm}$
on-shell W		
BP21	16.45	599.072
BP23	21.19	381.644
HP1	18.42	623.92
HP4	5.88	1365.08
off-shell W^*		
BP18	30.25	394.806
HP3	13.65	1266.96
HP5	1.72	1376.946
HP9	9.41	1975.95
HP11	28.63	574.452
HP15	29.02	805.136
HP19	12.71	984.658

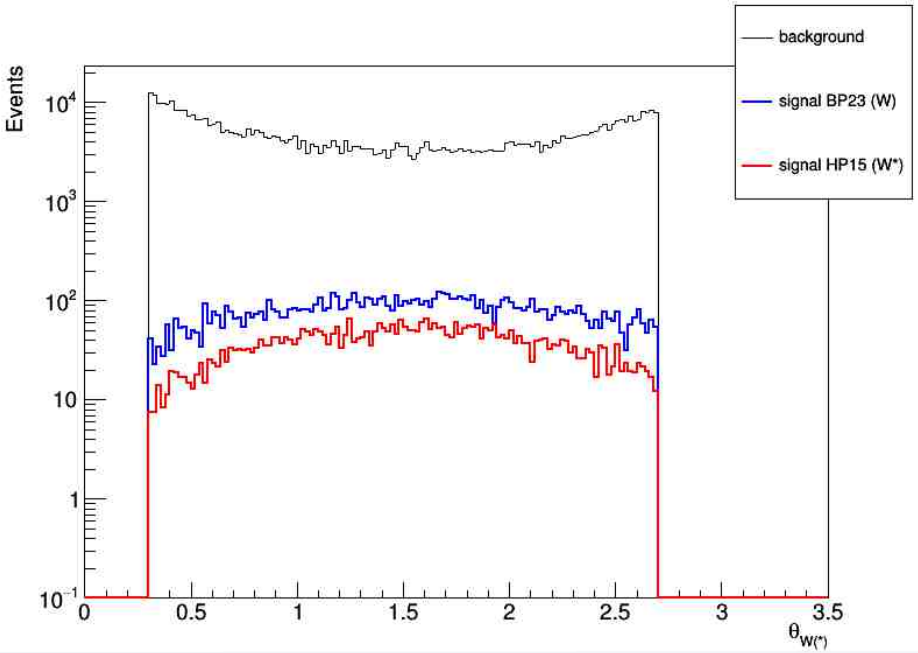
Thank you!

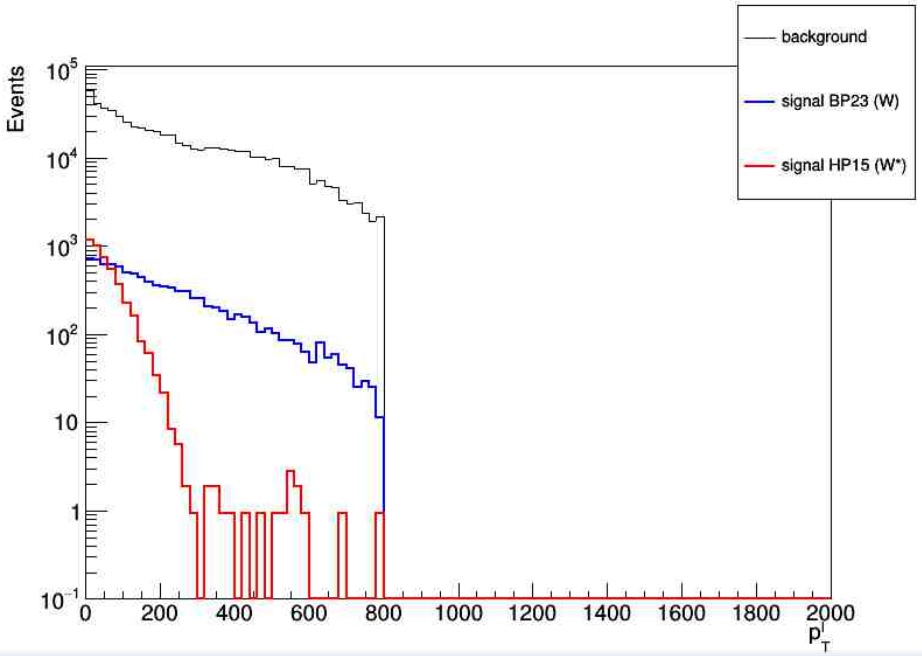
BACKUP

Pre-selection









No.	M_H	M_A	$M_{H^\pm}$	Z on-shell	W on-shell	DM >50%	λ_2	λ_{345}	$\Omega_H h^2$
222									
BP1	72.77	107.803	114.639			✓	1.44513	-0.00440723	0.12007
BP2	65	71.525	112.85			✓	0.779115	0.0004	0.070807
BP3	67.07	73.222	96.73			✓	0	0.00738	0.061622
122									
BP4	73.68	100.112	145.728			✓	2.08602	-0.00440723	0.089249
BP6	72.14	109.548	154.761		✓	✓	0.0125664	-0.00234	0.11708
112									
BP7	76.55	134.563	174.367		✓		1.94779	0.0044	0.031402
BP8	70.91	148.664	175.89		✓	✓	0.439823	0.0051	0.124
BP9	56.78	166.22	178.24	✓	✓	✓	0.502655	0.00338	0.081268
BP23	62.69	162.397	190.822	✓	✓	✓	2.63894	0.0056	0.064038
022									
BP10	76.69	154.579	163.045		✓		3.92071	0.0096	0.028141
BP11	98.88	155.037	155.438				1.18124	-0.0628	0.0027369
BP12	58.31	171.148	172.96	✓	✓		0.540354	0.00762	0.0064099
012									
BP13	99.65	138.484	181.321		✓		2.46301	0.0532	0.001255
BP14	71.03	165.604	175.971	✓	✓	✓	0.339292	0.00596	0.11841
BP15	71.03	217.656	218.738	✓	✓	✓	0.766549	0.00214	0.12225
011									
BP16	71.33	203.796	229.092	✓	✓	✓	1.03044	-0.00122	0.12214
002									
BP18	147	194.647	197.403				0.387	-0.018	0.0017718
BP19	165.8	190.082	195.999				2.7675	-0.004	0.0028405
BP20	191.8	198.376	199.721				1.5075	0.008	0.008494
001									
BP21	57.475	288.031	299.536	✓	✓	✓	0.929911	0.00192	0.11946
BP22	71.42	247.224	258.382	✓	✓	✓	1.04301	-0.00406	0.12428

No.	M_H	M_A	$M_{H^\pm}$	Z on-shell	W on-shell	DM >50%	λ_2	λ_{345}	$\Omega_H h^2$
HP1	176	291.36	311.96	✓	✓		1.4895	-0.1035	0.00072156
HP2	557	562.316	565.417			✓	4.0455	-0.1385	0.072092
HP3	560	616.32	633.48				3.3795	-0.0895	0.001129
HP4	571	676.534	682.54	✓	✓		1.98	-0.471	0.00056347
HP5	671	688.108	688.437				1.377	-0.1455	0.024471
HP6	713	716.444	723.045				2.88	0.2885	0.035152
HP7	807	813.369	818.001				3.6675	0.299	0.032393
HP8	933	939.968	943.787			✓	2.9745	-0.2435	0.09639
HP9	935	986.22	987.975				2.484	-0.5795	0.0027958
HP10	990	992.36	998.12			✓	3.3345	-0.051	0.12478
HP11	250.5	265.49	287.226				3.90814	-0.150071	0.00535
HP12	286.05	294.617	332.457				3.29239	0.112124	0.00277
HP13	336	353.264	360.568				2.48814	-0.106372	0.00937
HP14	326.55	331.938	381.773				0.0251327	-0.0626727	0.00356
HP15	357.6	399.998	402.568				2.06088	-0.237469	0.00346
HP16	387.75	406.118	413.464				0.816814	-0.208336	0.0116
HP17	430.95	433.226	440.624				3.00336	0.082991	0.0327
HP18	428.25	453.979	459.696				3.87044	-0.281168	0.00858
HP19	467.85	488.604	492.329				4.12177	-0.252036	0.0139
HP20	505.2	516.58	543.794				2.53841	-0.354	0.00887