Benchmarking the Inert Doublet Model for e^+e^- colliders

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Inert doublet model

- A specialized version of the 2HDM:
  - call one doublet (ϕ_D) dark
  - the other one (ϕ_S) we'll make SM-like
  - enforce a Z_2 symmetry

will interact only with other Higgses or gauge boson

$$\phi_D \to -\phi_D, \quad \phi_S \to \phi_S, \quad SM \to SM$$

- A Z_2 symmetric Lagrangian

$$V = -\frac{1}{2}\left[m_{11}^2(\phi_S^\dagger\phi_S) + m_{22}^2(\phi_D^\dagger\phi_D)\right] + \frac{\lambda_1}{2}(\phi_S^\dagger\phi_S)^2 + \frac{\lambda_2}{2}(\phi_D^\dagger\phi_D)^2 + \lambda_3(\phi_S^\dagger\phi_S)(\phi_D^\dagger\phi_D) + \lambda_4(\phi_S^\dagger\phi_D)(\phi_D^\dagger\phi_S) + \frac{\lambda_5}{2}\left[(\phi_S^\dagger\phi_D)^2 + (\phi_D^\dagger\phi_S)^2\right]$$

- only ϕ_S doublet acquires a v.e.v.

- 7 starting parameters: 1 fixed by the tadpole equation, one by the SM Higgs mass

$$M_H,\ M_A,\ M_{H^\pm},\ \lambda_2,\ \lambda_{345} \equiv \lambda_3 + \lambda_4 + \lambda_5$$

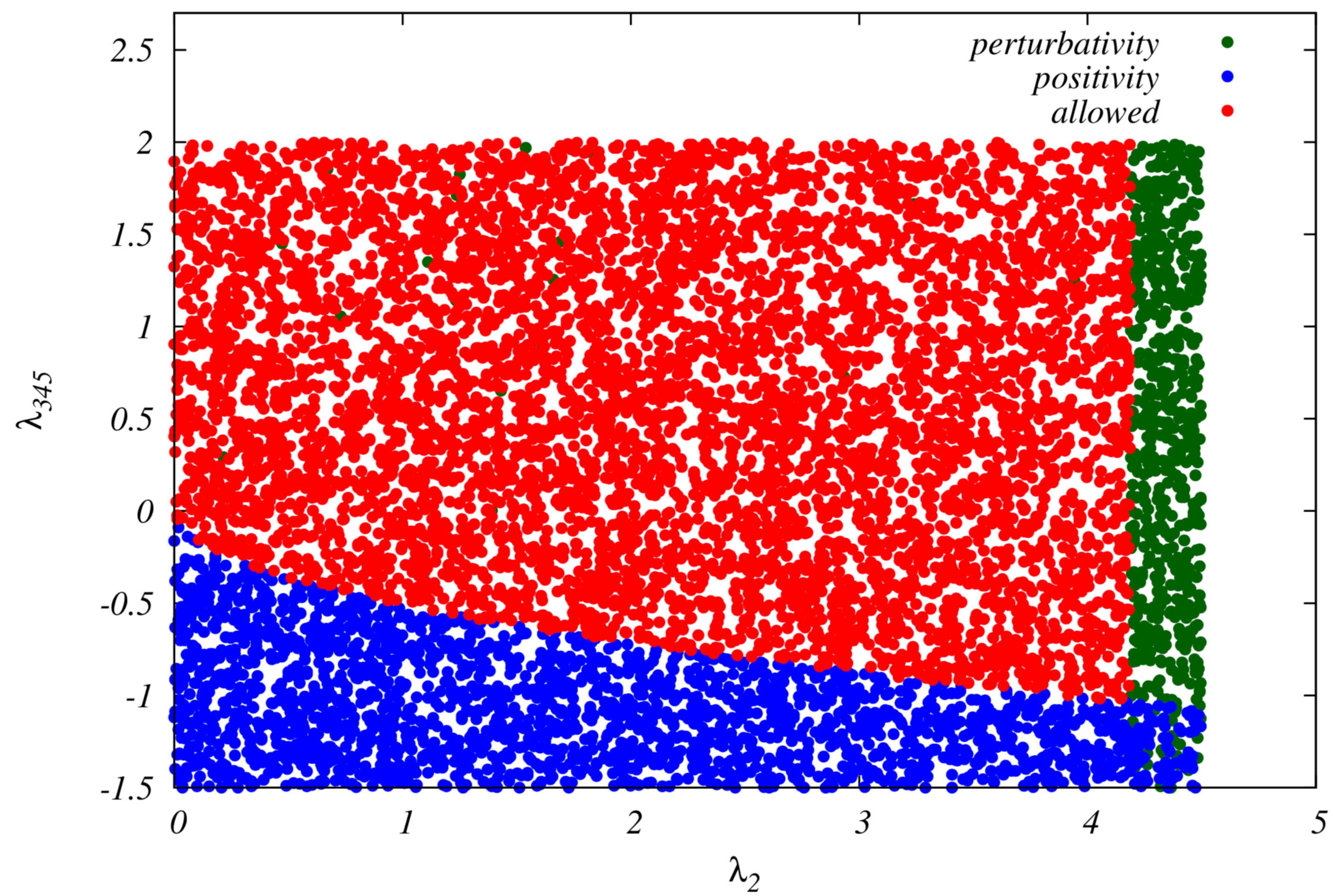
Theoretical constraints

- vacuum stability, positivity, inert vacuum

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

- perturbative unitarity, perturbativity of couplings

- m_H as a DM candidate

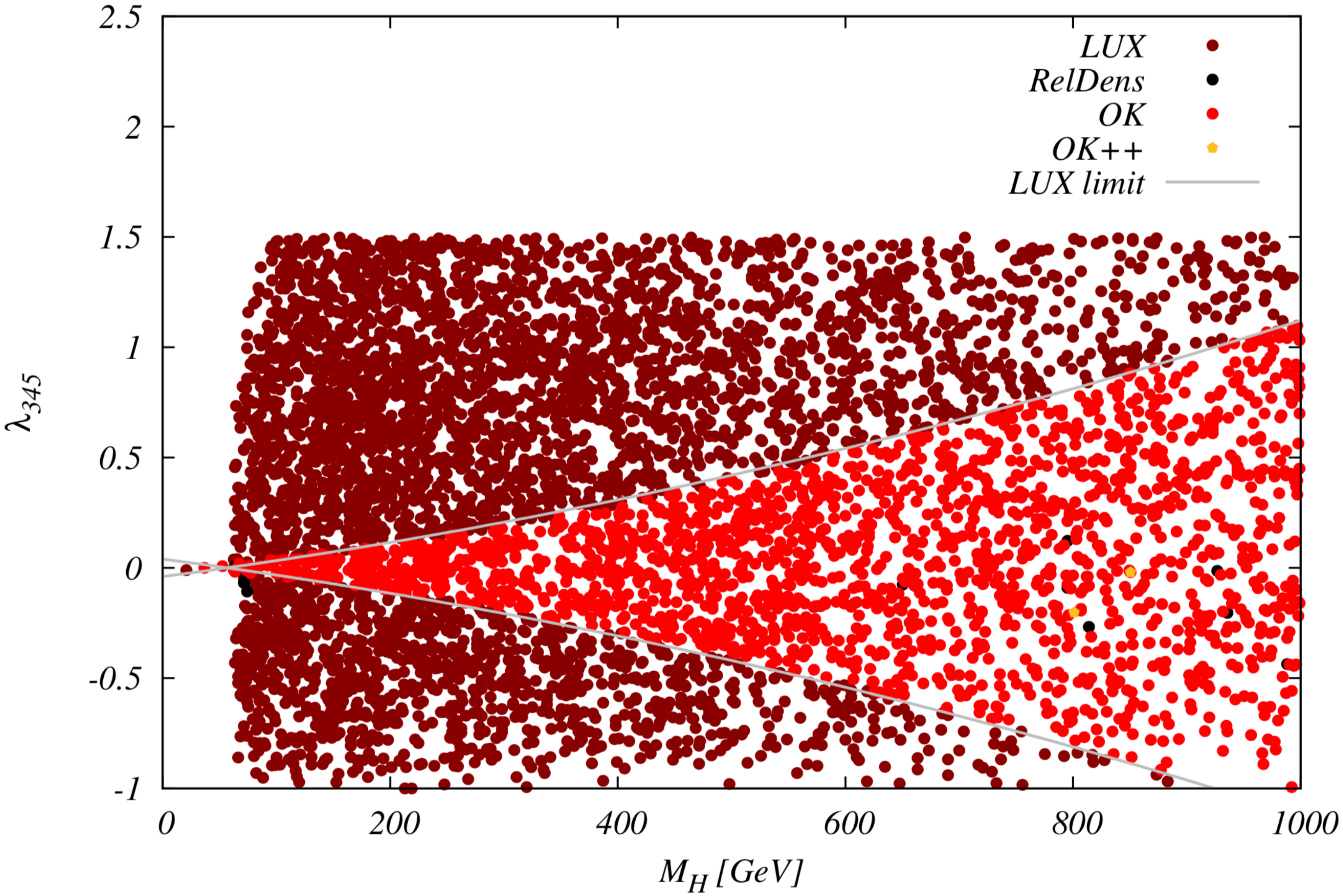


Experimental constraints

- Higgs sector properties [**HiggsBounds** & **HiggsSignals**]
- W, Z bosons total widths [**2HDMC**]
- *STU* parameters [**2HDMC**]
- no long lived charged particle ($H^\pm$)
- upper limit from DM relic density [**micrOMEGAs**]
- direct detection from Xenon1T [**micrOMEGAs**]

Impact of experimental constraints

$\lambda_{345}(\equiv \lambda_3 + \lambda_4 + \lambda_5)$



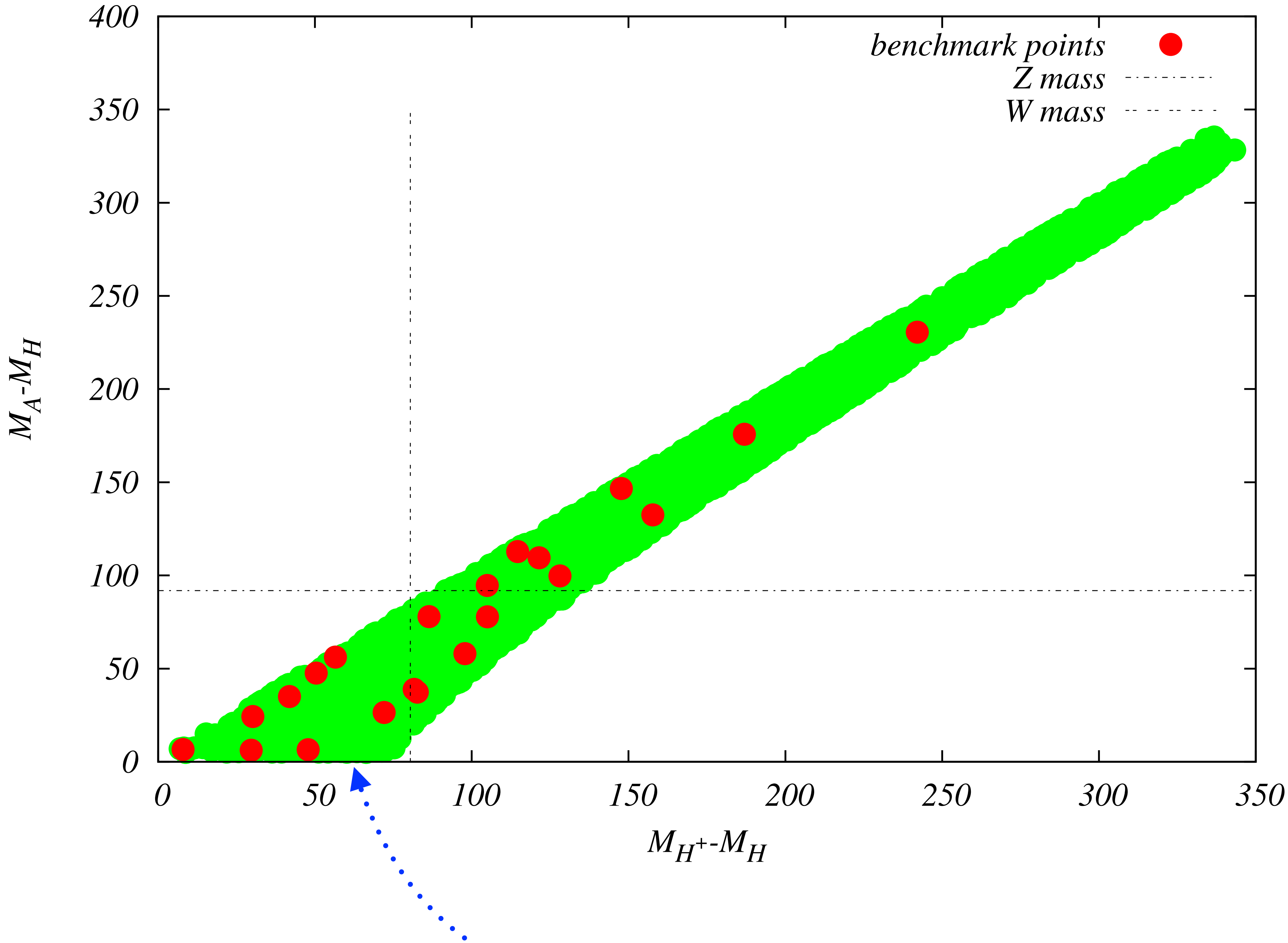
DM mass

λ_{345} controls the amount of DM in the universe

Benchmark points

- After the large scan applying enumerated theoretical and experimental constraints we selected 40 benchmark points [**arXiv:1809.07712**]
- 20 accessible at energy $\lesssim$ 500 GeV. Grouped according to which production processes are available at 250, 380 and 500 GeV e+e- collider
- 20 high mass benchmarks for $\mathcal{O}(1\ TeV)$ collider
- None of them over-closes the universe. Some have exactly required relic density
- DM candidates are usually light, around 80 GeV

Benchmark points



mainly driven by EWPO

IDM @ e+e- collider

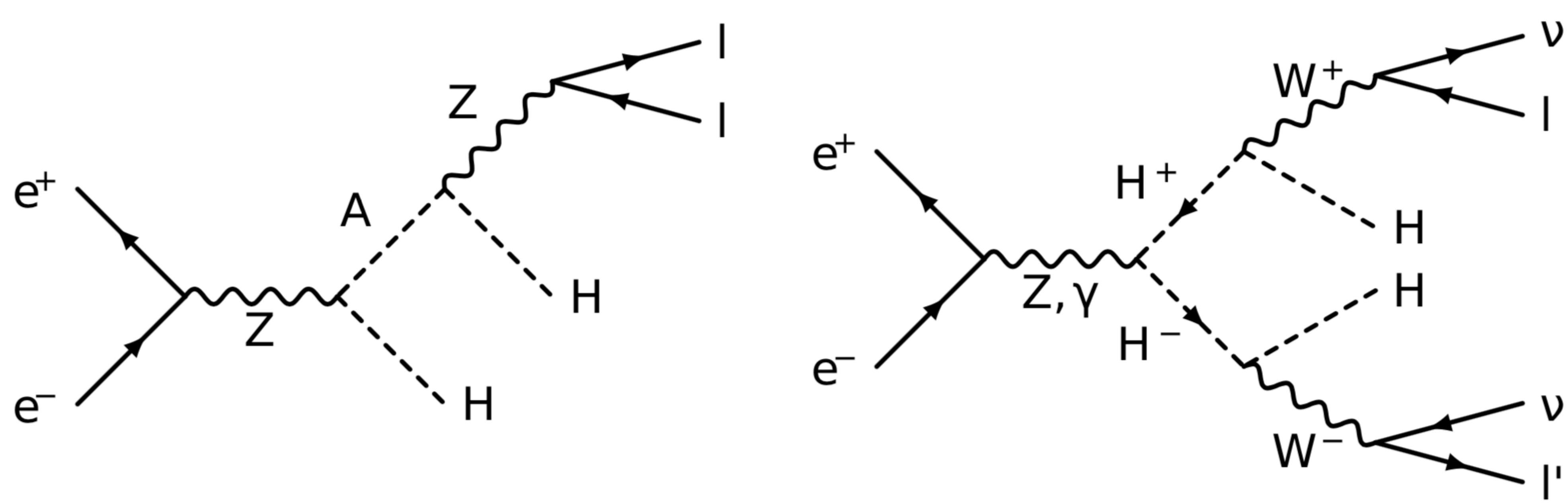
arXiv:1811.06952

- The dark sector particles (A, H, $H^{\pm}$) can be produced in pairs at e+e- collider
- For considered BMPS

$$A \to Z^{(*)}H \; (\approx 100\%) \qquad H^{\pm} \to W^{\pm}H \; (> 66\%)$$

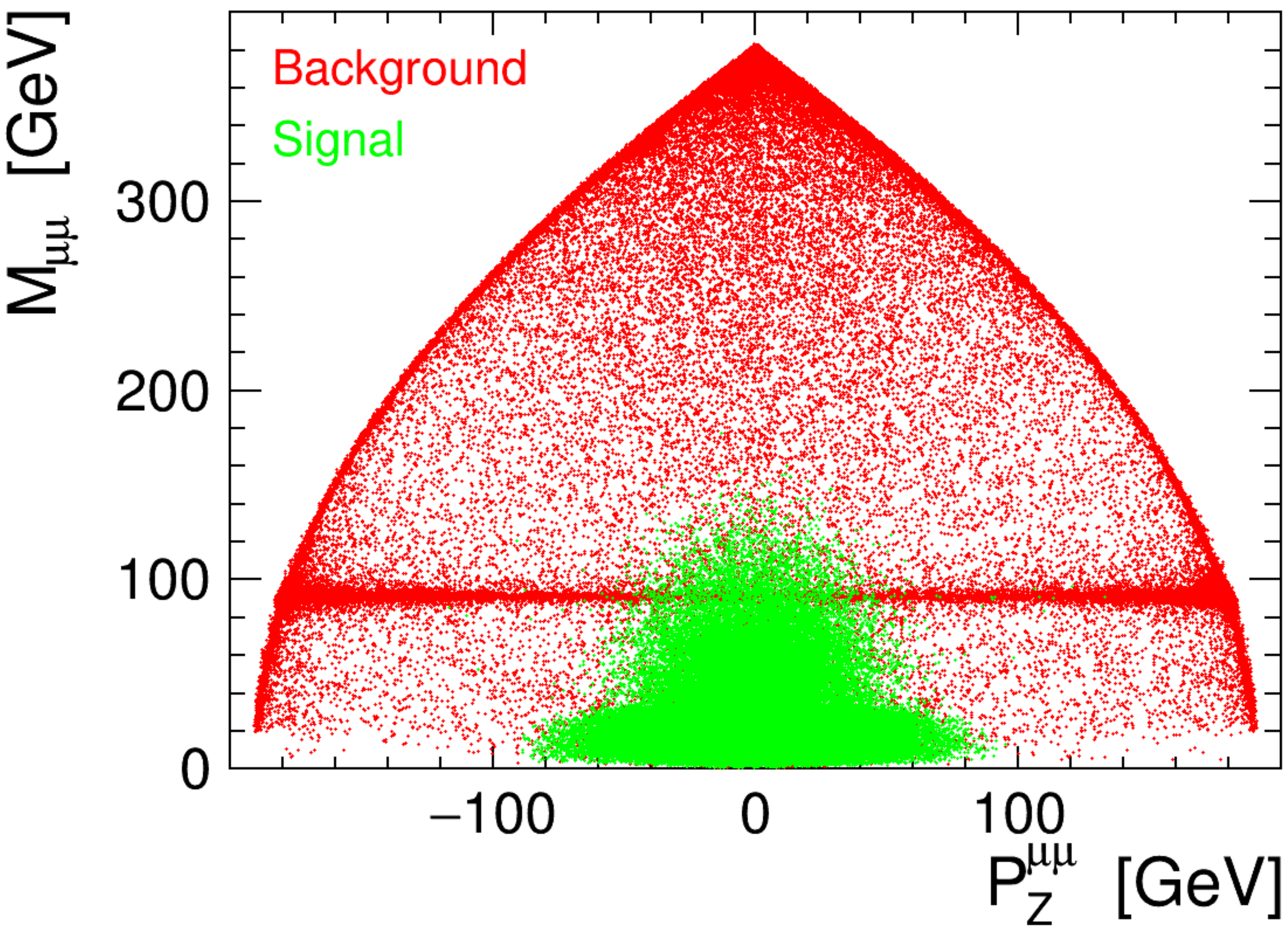
- We focus on leptonic decay, leading to

$$e^+e^- \to (AH \text{ or } H^+H^-) \to \mu^+\mu^-HH \qquad e^+e^- \to H^+H^- \to \mu^{\pm}e^{\mp}HH$$



- For simulation, we use Whizard with SARAH generated model

SM vs. IDM

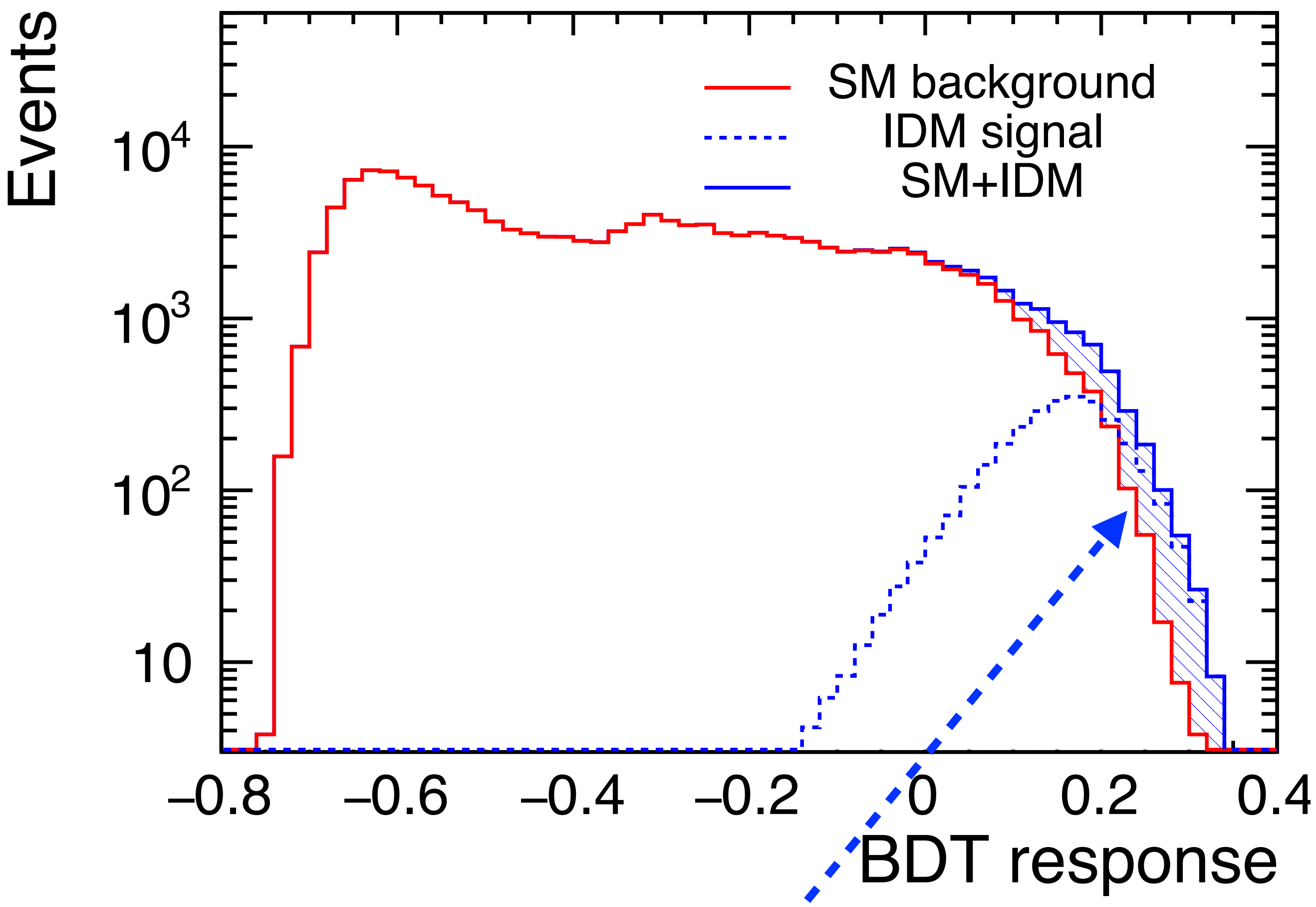


Background
Signal
$M_{\mu\mu}$ [GeV]
300
200
100
0
−100
0
100
$P_Z^{\mu\mu}$ [GeV]

Kinematic variables

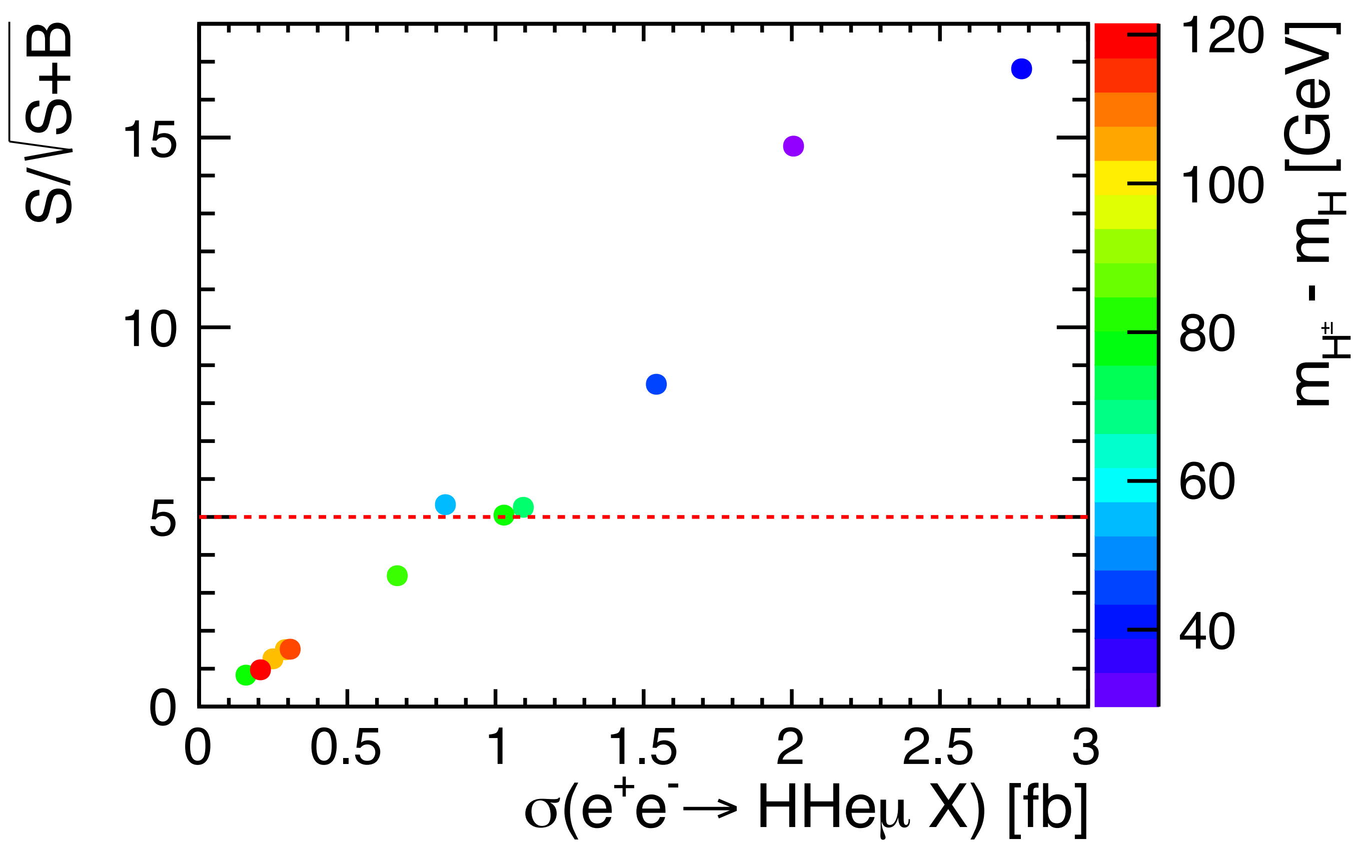
- total energy of the lepton pair, $E_{\ell\ell}$
- dilepton invariant mass, $M_{\ell\ell}$
- dilepton transverse momentum, $p_T^{\ell\ell}$
- polar angle of the dilepton pair, $\theta_{\ell\ell}$
- Lorentz boost of the dilepton pair, $\beta_{\ell\ell} = p_{\ell\ell}/E_{\ell\ell}$
- reconstructed missing (recoil) mass M_{miss} (calculated assuming nominal e^+e^- collision energy)
- ℓ^- production angle with respect to the beam direction, calculated in the dilepton center-of-mass frame, $\theta_\ell^\star$
- ℓ^- production angle with respect to the dilepton pair boost direction, calculated in the dilepton center-of-mass, $\angle^\star(\ell, \ell\ell)$

BMPs at early stages of CLIC

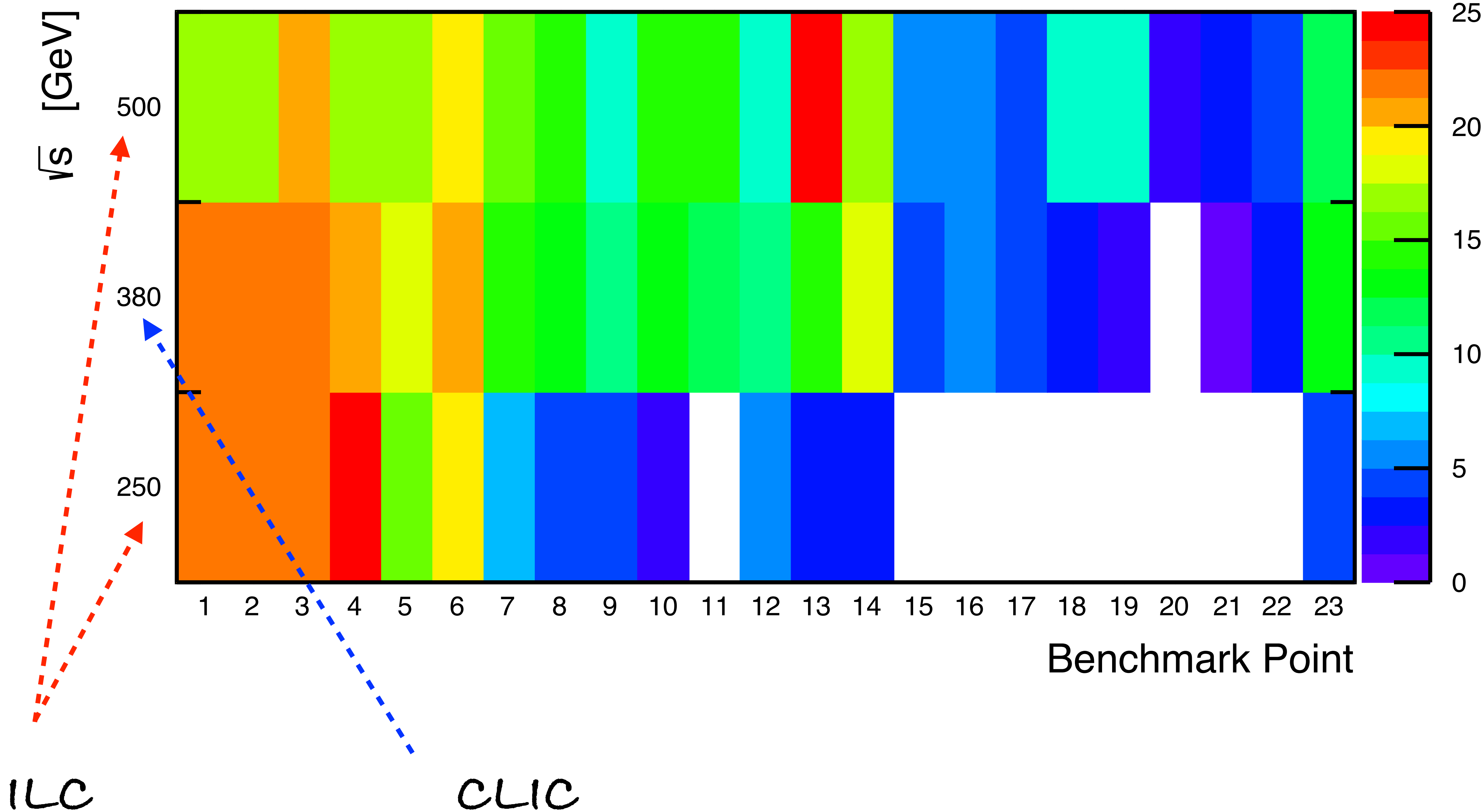


a cut on BDT response
allows to select signal enriched
phase space regions

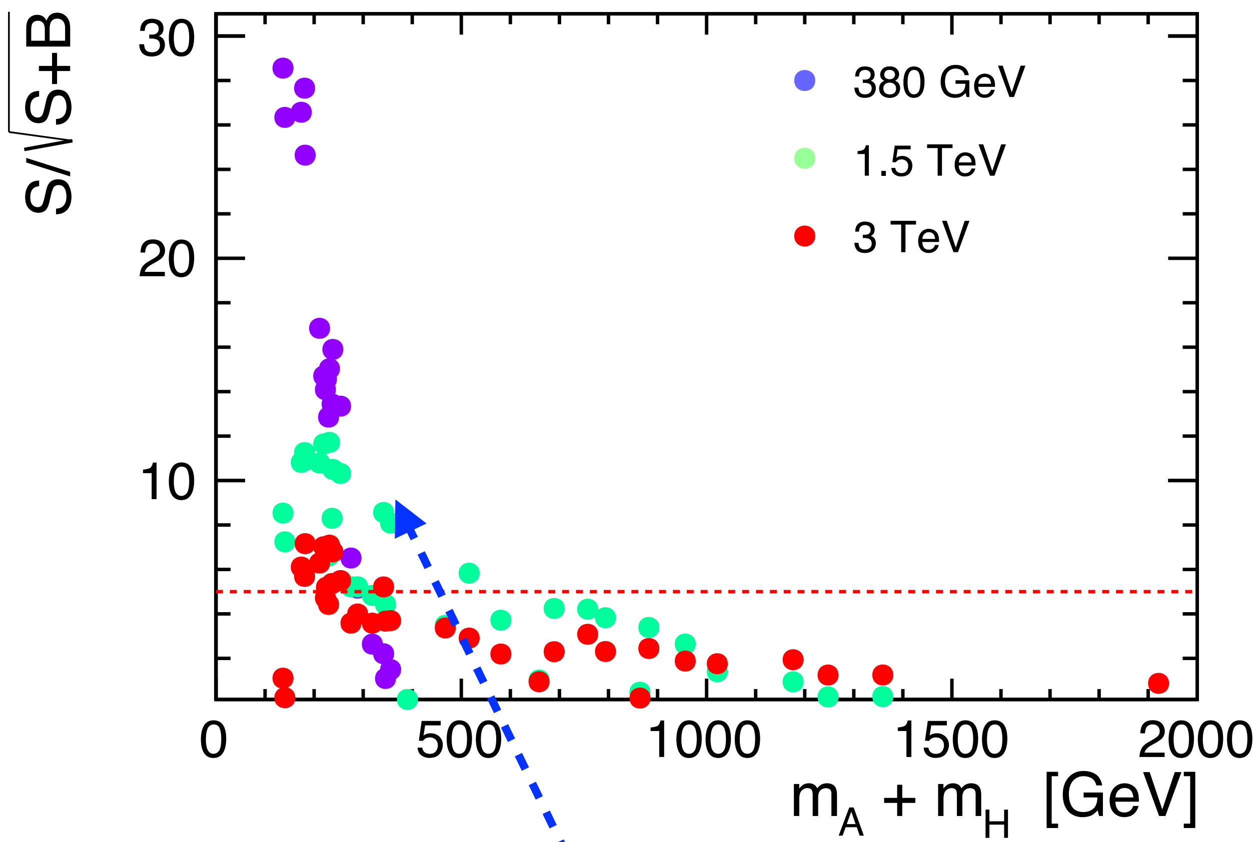
There's no magic in BDT!
Significances follow the
signal cross sections

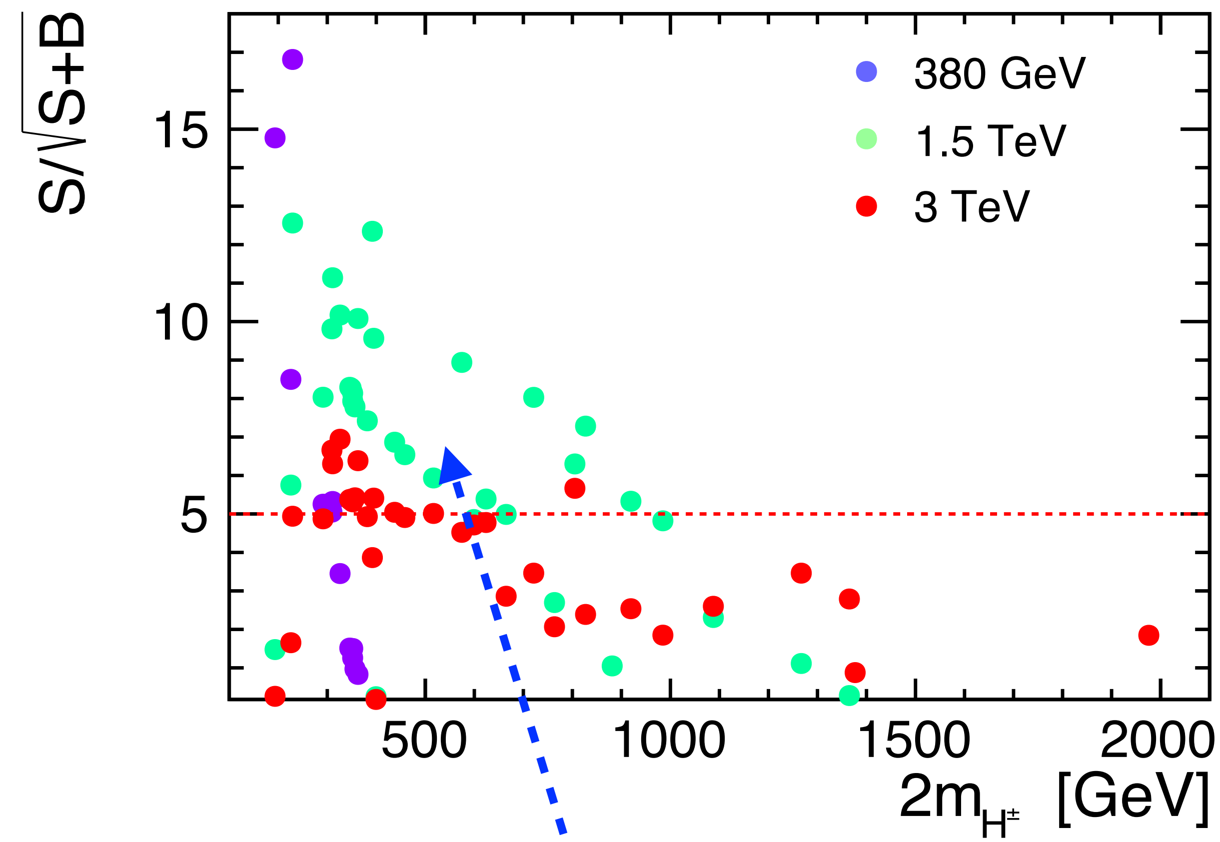


BMPs at early stages of CLIC & ILC



Significances at CLIC

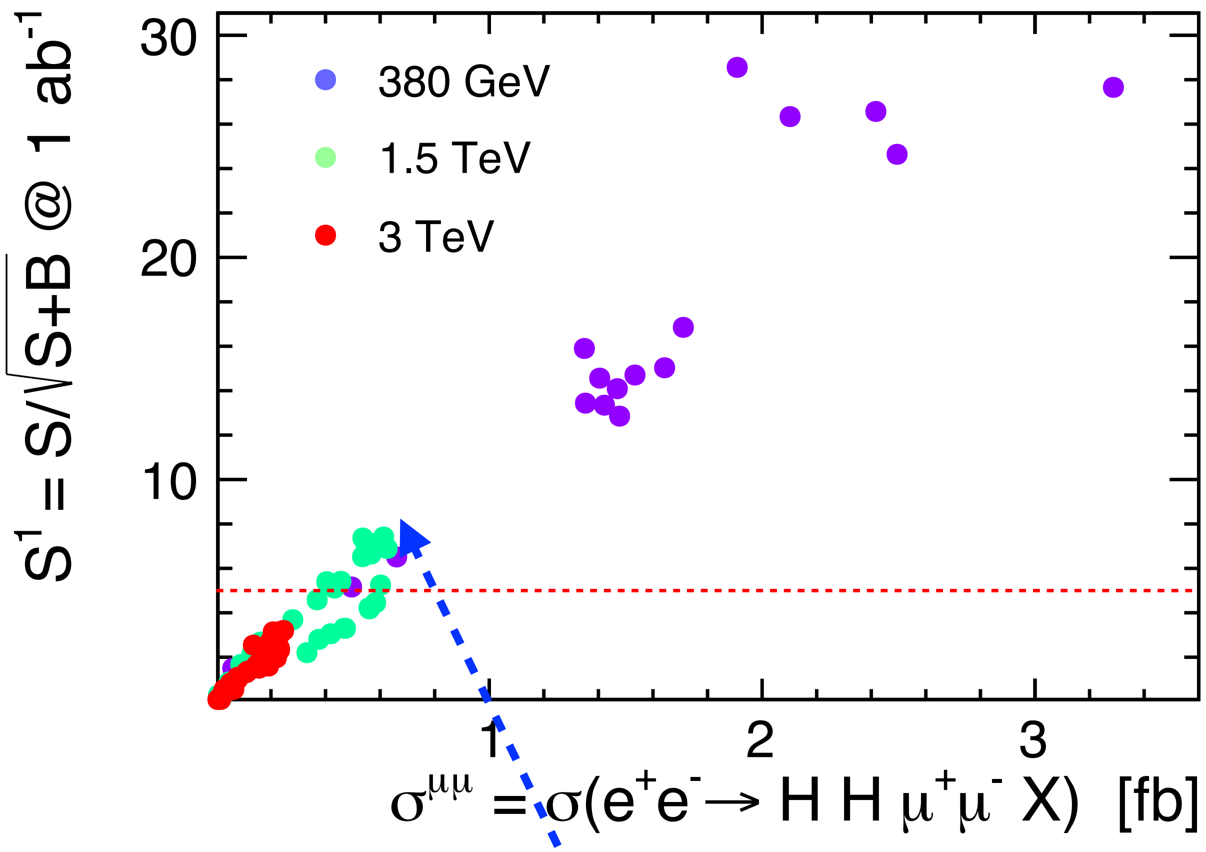


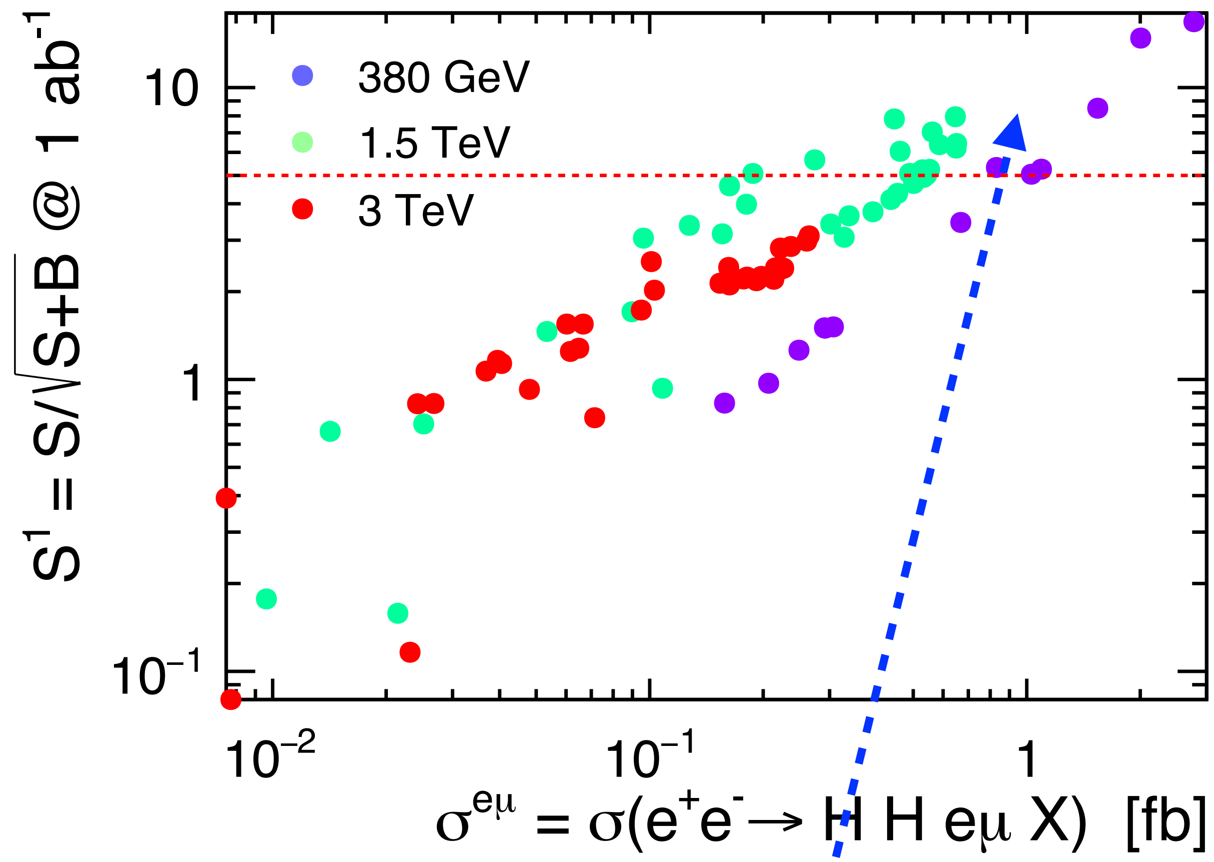


increasing energy (e.g blue to green) does not significantly increase the mass reach in this case

while here it does

Significances at CLIC (normalized to ab^{-1})





universal linear dependence on the production cross section

for this channel increasing energy increases kinematic reach

Conclusions and prospects

- Inert double model is an interesting variant of the 2HDM: less free parameters + a DM candidate
- Complementarity of collider and astrophysical observables
- A linear collider is **the** tool to study extended Higgs sectors
- We proposed a selection of benchmark points for e+e- studies: different characteristics, perfect for experimentalists to train tools or students on them
- Highlights from this work will be published in the CERN Yellow report
- Study for polarized beams is in preparation