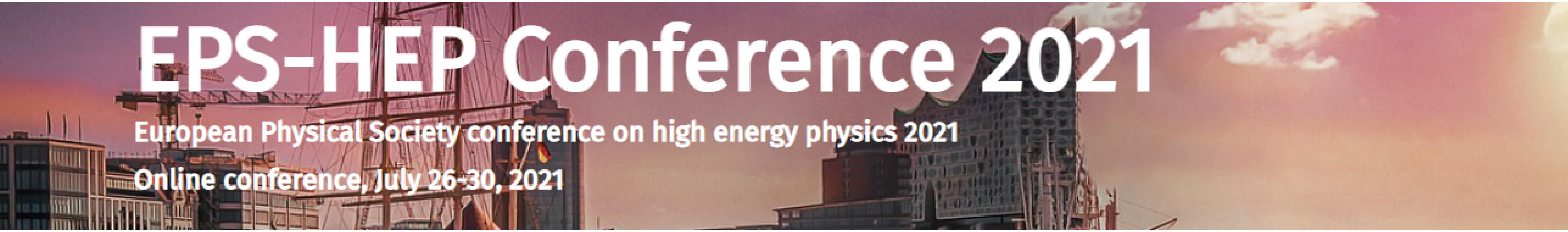
FACULTY OF PHYSICS
UNIVERSITY OF WARSAW

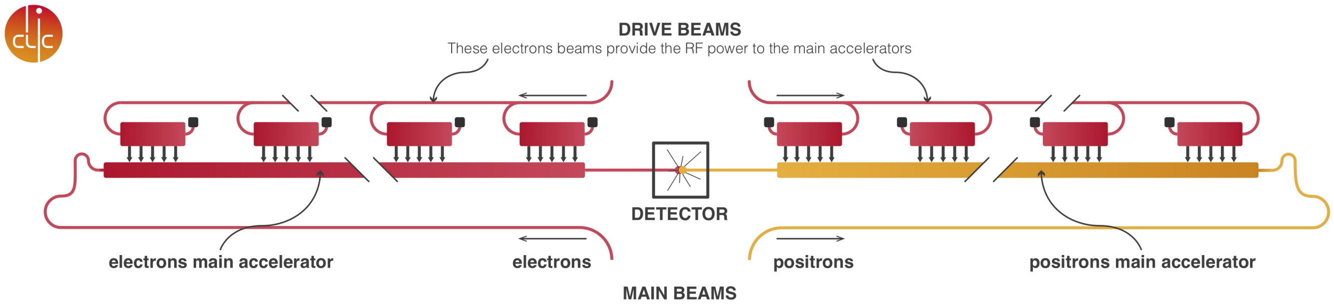
The CLIC Potential For New Physics

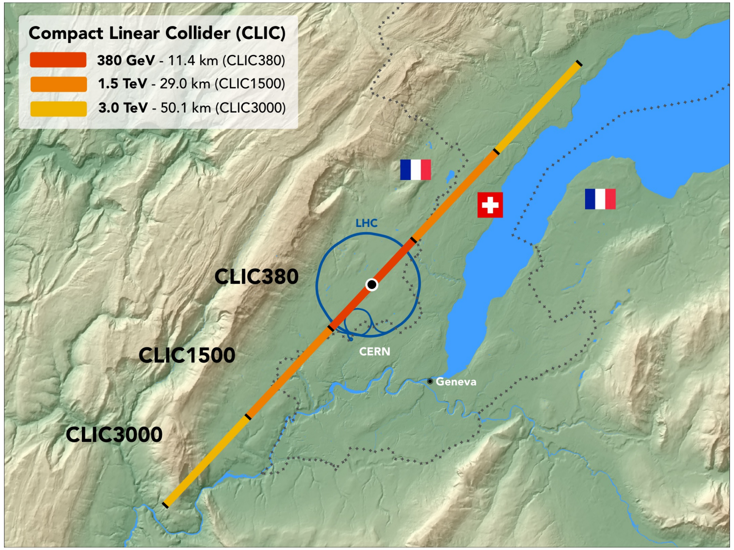


Jan Klamka, University of Warsaw
on behalf of the CLICdp Collaboration

National Science Centre
Poland

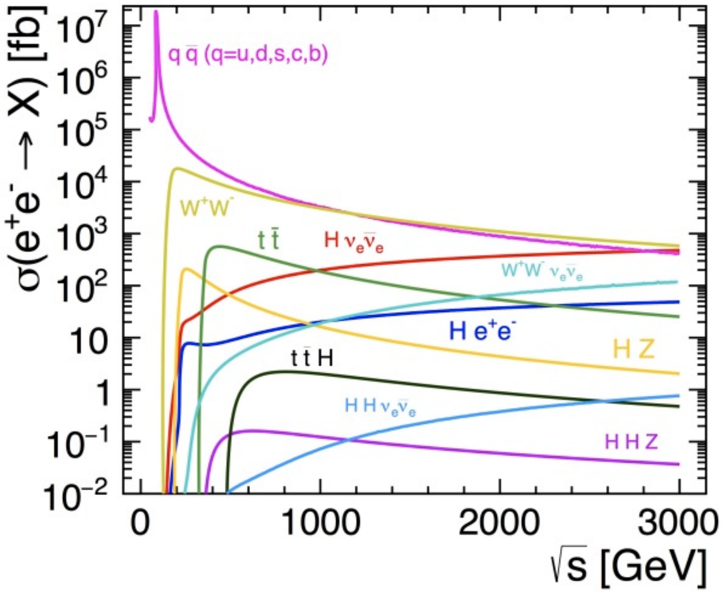
Compact Linear Collider





3 TeV

- Novel **two-beam** acceleration technique
- Normal conducting technology
- High **100 MeV/m** gradient, **12 GHz** accelerating structures
- **±80% electron beam** polarisation
- Implementation in 3 stages



380 GeV stage:

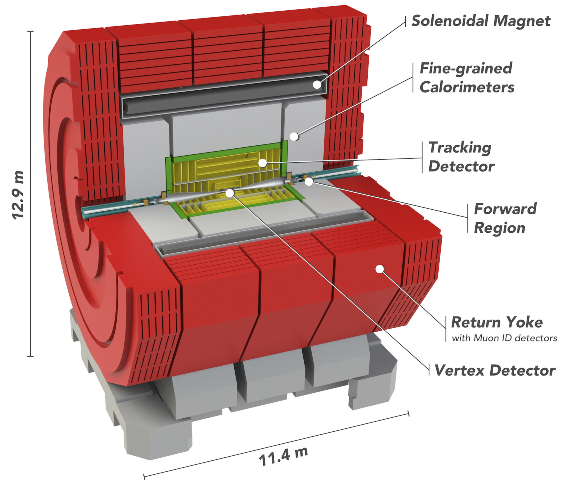
- presicion **Higgs** measurements
- presicion **top** measurements
- **top** threshold scan

1.5 TeV, 3 TeV stages:

- **Higgs** self-coupling
- **top** Yukawa coupling
- more precision measurement: indirect **BSM** constraints

+ direct new physics searches at high energies

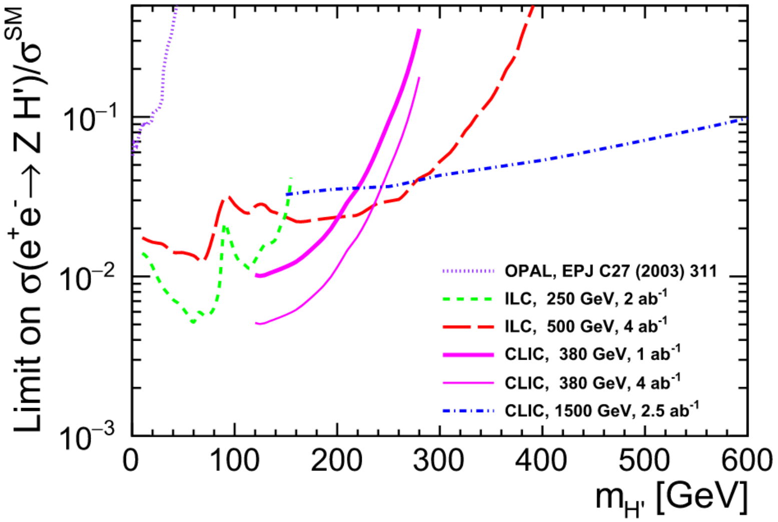
Dedicated **detector concept** optimised for **particle-flow** approach



Invisible scalar decays

BR(H_{SM} → inv.) < 1% (95% CL.)

(380 GeV, 1 ab^{-1})



Higgs Portal

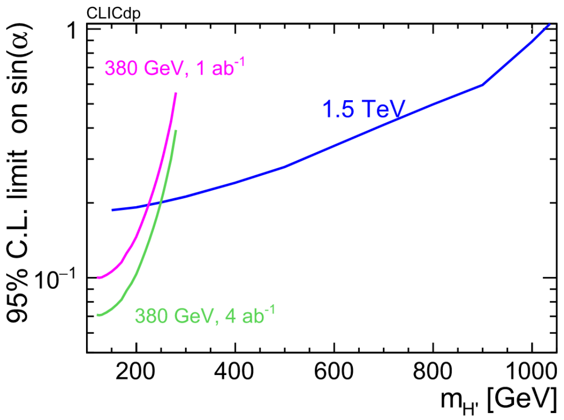
SM-like Higgs field

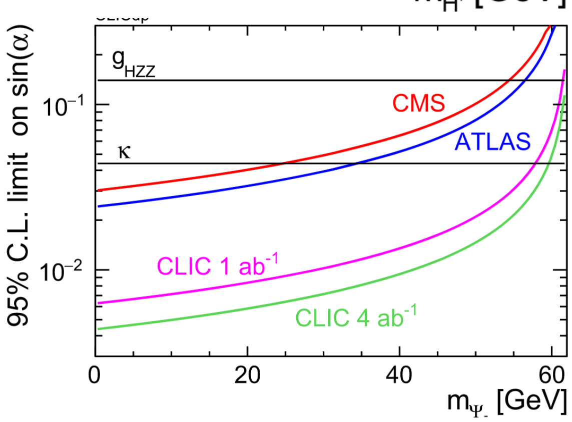
125 GeV state

$$\begin{pmatrix} H \\ H' \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h \\ \phi \end{pmatrix}$$

new scalar field

Interpretaion in terms of
Vector-fermion DM Model

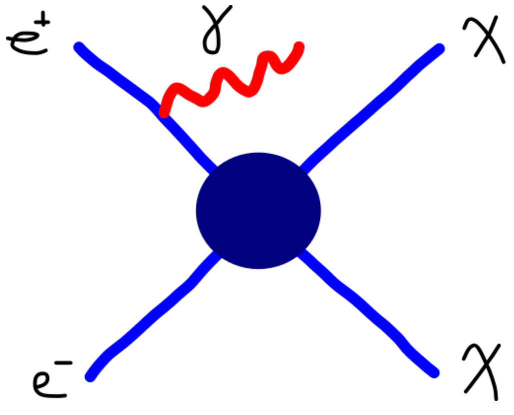




Much better constraints than current from ATLAS and CMS

Eur. Phys. J. Plus (2021) 136: 160

DM searches - mono-photon channel

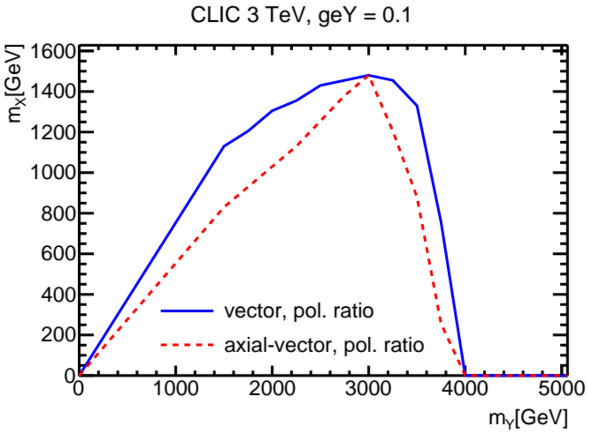


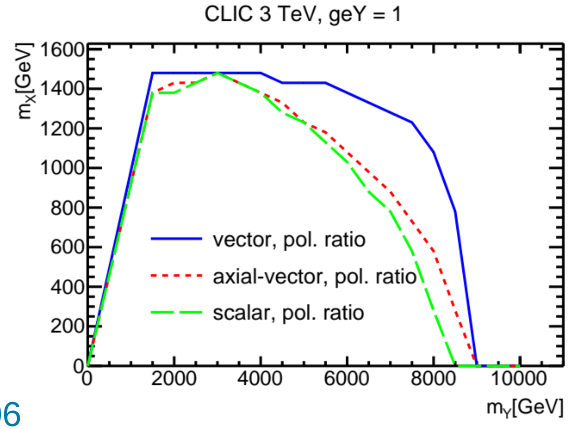
Most general approach for DM search

Simplified DM Models framework

Vector, **axial-vector** and **scalar** mediators

Coupling **geY = 0.1, 1**





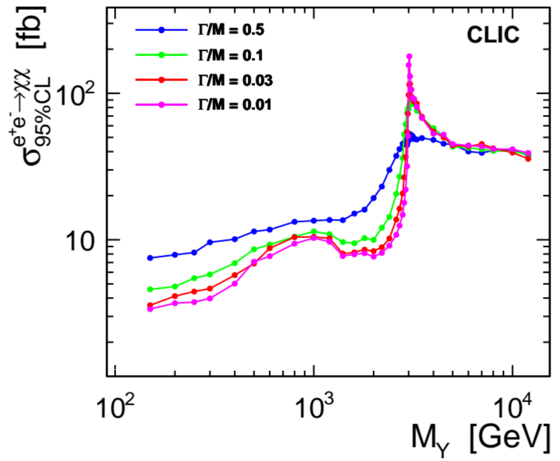
+80%, **-80%** and **no** beam **polarisation** considered
Best limits using: $\sigma(Pe{=}-80\%)/\sigma(Pe{=}+80\%)$
(sys. uncert. cancel)

Discrimination between vector and axial-vector mediators, with $m_Y = 3.5\,\mathrm{TeV}$, $m_X = 1\,\mathrm{TeV}$
WIMP mass determination with **1% accuracy**

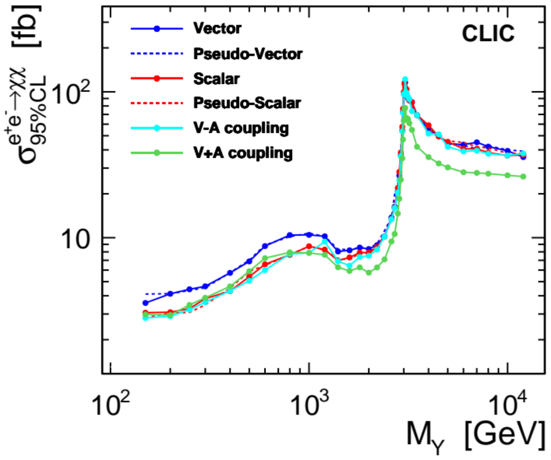
arXiv:2103.06006

Mono-photon – light mediator

arXiv:2107.11194



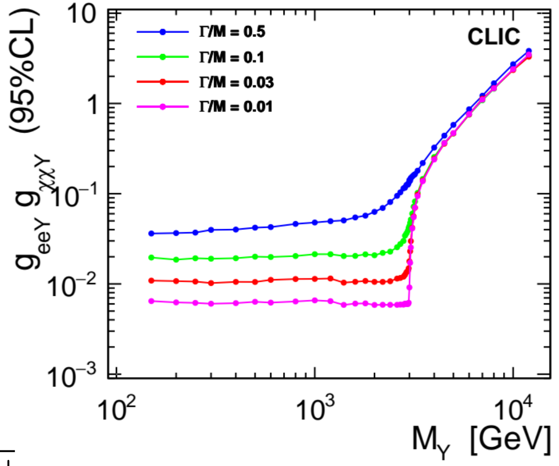
Light fermionic DM pair-production for vector mediator



Combined limits, $\Gamma/M = 0.3$

Small **masses** and **couplings**

„Experimental” approach – limits depending on width and mass



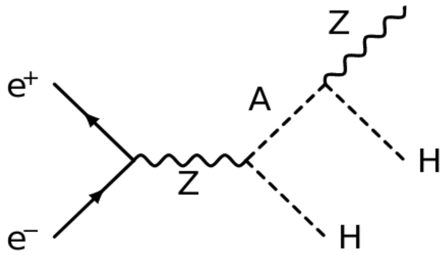
Weak dependence on the **model scenario**!

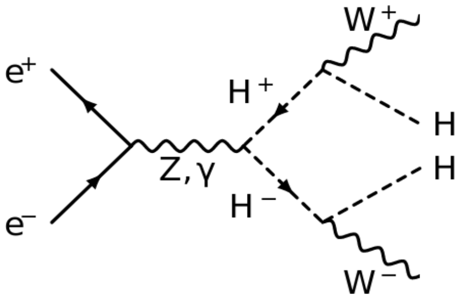
For high masses limits on EFT mass scale: **6-10 TeV**

$$\Lambda^2 = \frac{M_Y^2}{|g_{eeY}\, g_{\chi\chi Y}|}$$

Inert Doublet Model

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





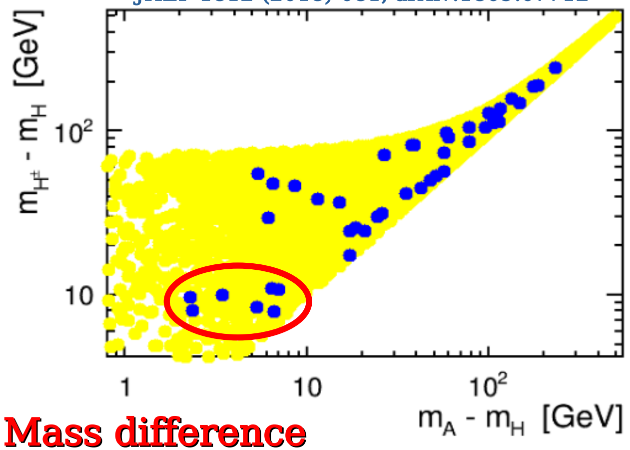
Model simplicity (one „inert” doublet, 5 free parameters)

<u>No couplings to SM fermions, stable DM candidate</u>

Considered **23 benchmark scenarios** respecting current constraints

Full simulation (5 scenarios) and **DELPHES** (23 scenarios) used for detector response

JHEP 1812 (2018) 081, arXiv:1809.07712

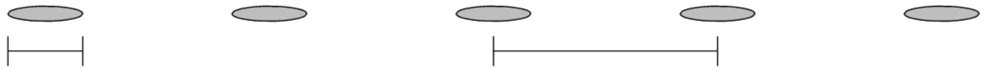


Mass difference affects virtuality of W boson!

Previously studied in JHEP07 (2019) 053

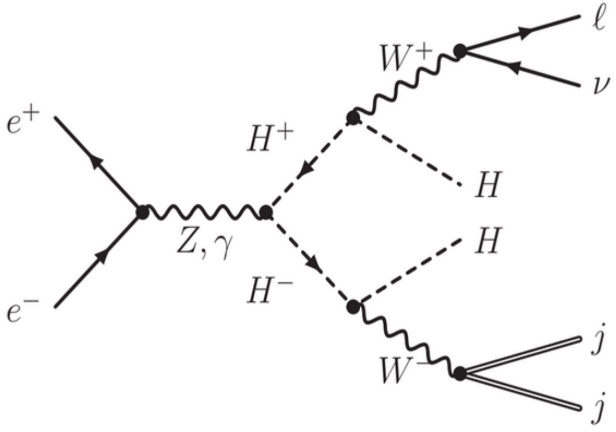
Inert Doublet Model

LCD-Note-2011-006



CLIC: 44 μm
ILC: 300 μm

CLIC: 0.5 ns, 0.15 m
ILC: 369 ns, 111 m



Huge **beam-induced backgrounds** at CLIC

$\gamma\gamma \to \boldsymbol{had.}$ most important (physics, performance)

Mitigation using timing cuts

Not existing in DELPHES CLICdet cards!

→ included in **approximate** way with **generator-level cuts**

Influence on the reconstruction if W is virtual

Inert Doublet Model

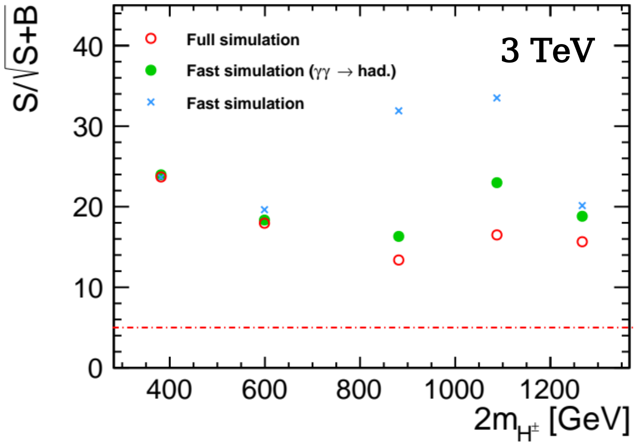
Good agreement between **full** and **fast** simulation
→ **realistic predictions** for all scenarios

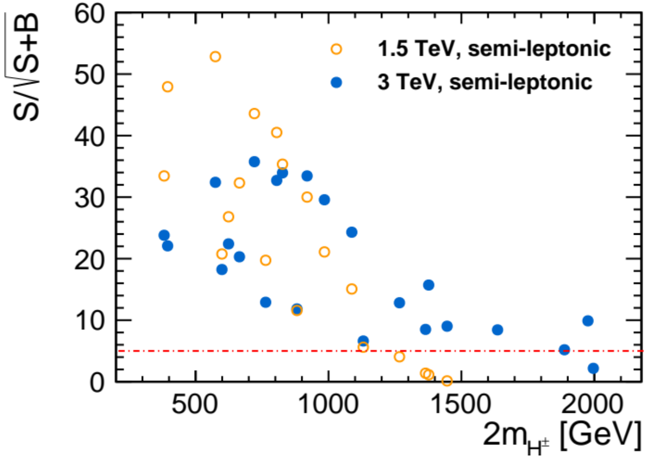
Wide range of scenarios at **1.5 TeV** and **3 TeV** CLIC analysed

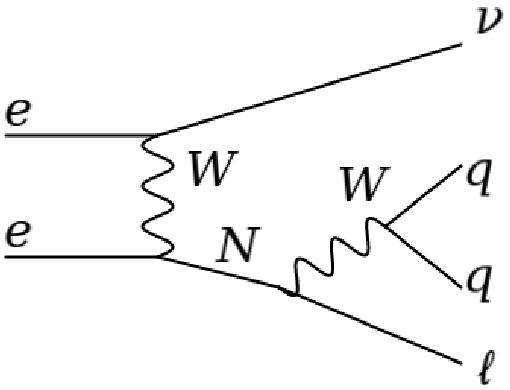
<u>Almost all scenarios could be discovered</u>

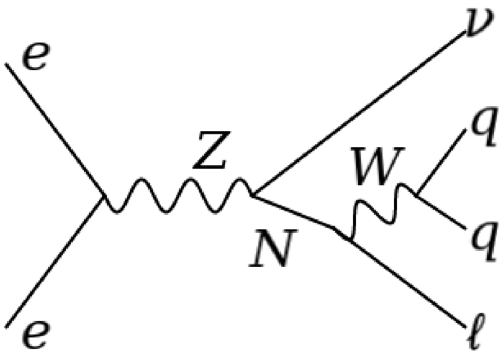
Scalars with **masses of 1 TeV accessible**
→ significant **increase** w.r.t. previous study (based on leptonic channel)

Significance reaching even **50σ**



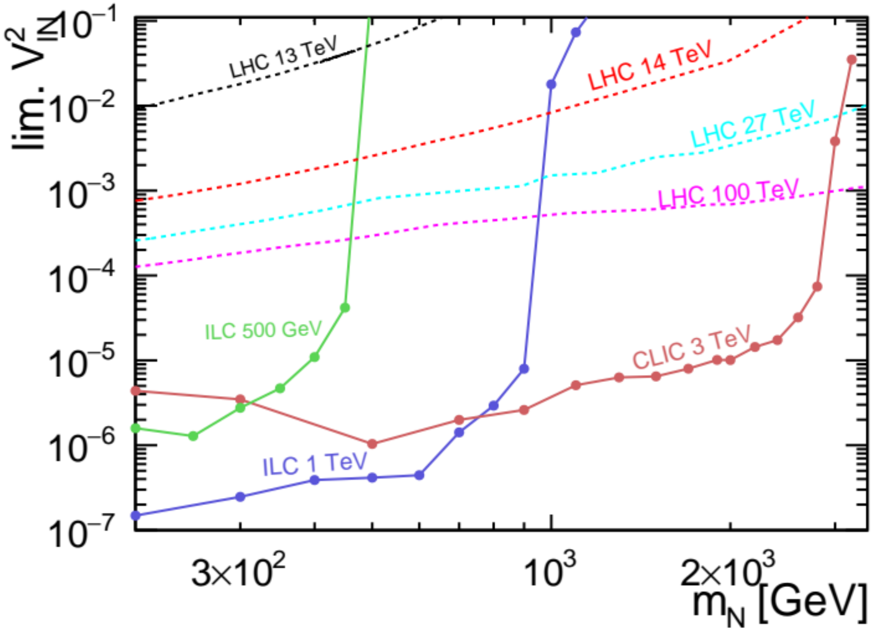






Semi-leptonic channel allows full neutrino reconstruction

Based on DELPHES simulation, with $e\gamma$, $\gamma\gamma$ backgrounds considered

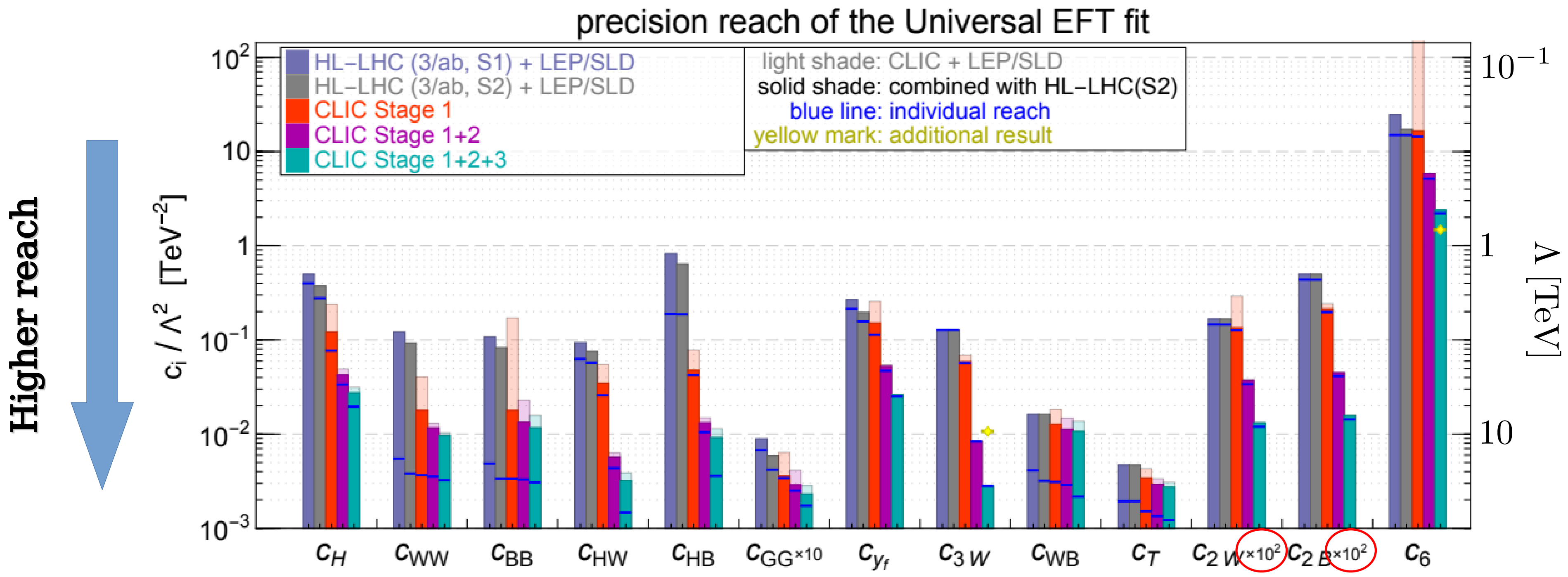


Observation expected almost up to the **kinematic limit**

Limits stronger than from **LHC** and **FCC-hh**

See the poster by Krzysztof Mękała:
https://indico.desy.de/event/28202/contributions/105536/

Global EFT fit



$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2} O_i + \mathcal{O}\left(\Lambda^{-4}\right)$$

Based on CLIC combined precision measurements of:

Higgs couplings, **top-quark observables**, **WW production** and **ee → ff**

arXiv:1812.02093

General overview

Process	HL-LHC	CLIC
Higgs mixing with heavy singlet	$\sin^2\gamma < 4\%$	$\sin^2\gamma < 0.24\%$
Higgs self-coupling $\Delta\lambda$	$\sim 50\%$ at 68% C.L.	$[-8\%, 11\%]$ at 68% C.L.
BR(H $\to$ inv.) (model-independent)		$< 1\%$ at 95% C.L.
Higgs compositeness scale m_*	$m_* > 3\,\text{TeV}$ ($> 7\,\text{TeV}$ for $g_* \simeq 8$)	Discovery up to $m_* = 10\,\text{TeV}$ ($40\,\text{TeV}$ for $g_* \simeq 8$)
Top compositeness scale m_*		Discovery up to $m_* = 8\,\text{TeV}$ ($20\,\text{TeV}$ for small coupling g_*)
Higgsino mass (disappearing track search)	$> 250\,\text{GeV}$	$> 1.2\,\text{TeV}$
Slepton mass		Discovery up to $\sim 1.5\,\text{TeV}$
RPV wino mass ($c\tau = 300\,\text{m}$)	$> 550\,\text{GeV}$	$> 1.5\,\text{TeV}$
Z$'$ mass (SM couplings)	Discovery up to 7 TeV	Discovery up to 20 TeV
NMSSM scalar singlet mass	$> 650\,\text{GeV}$ ($\tan\beta \leq 4$)	$> 1.5\,\text{TeV}$ ($\tan\beta \leq 4$)
Twin Higgs scalar singlet mass	$m_\sigma = f > 1\,\text{TeV}$	$m_\sigma = f > 4.5\,\text{TeV}$
Relaxion mass (for vanishing mixing)	$< 24\,\text{GeV}$	$< 12\,\text{GeV}$
Relaxion mixing angle ($m_\phi < m_\text{H}/2$)		$\sin^2\theta \leq 2.3\%$
Neutrino Type-2 see-saw triplet		$> 1.5\,\text{TeV}$ (for any triplet VEV)
		$> 10\,\text{TeV}$ (for triplet Yukawa coupling $\simeq 0.1$)
Inverse see-saw RH neutrino		$> 10\,\text{TeV}$ (for Yukawa coupling $\simeq 1$)
Scale $V_{LL}^{-1/2}$ for LFV $(\bar{e}e)(\bar{e}\tau)$		$> 42\,\text{TeV}$

arXiv:1812.07986

BACKUP

Invisible scalar decays

$BR(H_{SM} \rightarrow inv.) < 1\%$ (95% CL.)

(380 GeV, 1 ab^{-1})

$BR(H_{SM} \rightarrow inv.) < 0.5\%$ (95% CL.)

(380 GeV, 4 ab^{-1})

Discovery (5σ) for:

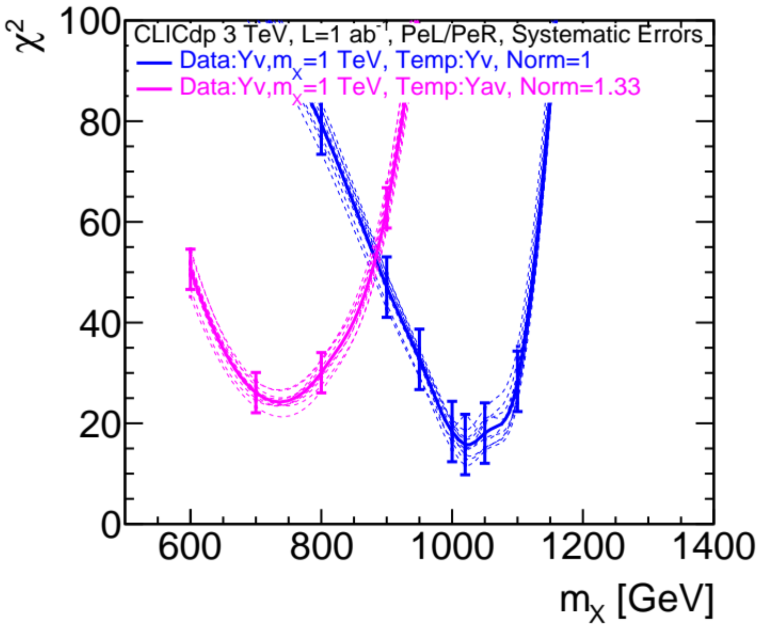
$BR(H_{SM} \rightarrow inv.) > 3\%$ (1.5%)

380 GeV, 1 ab^{-1} (4 ab^{-1})

Eur. Phys. J. Plus (2021) 136: 160

Mono-photon: model discrimination

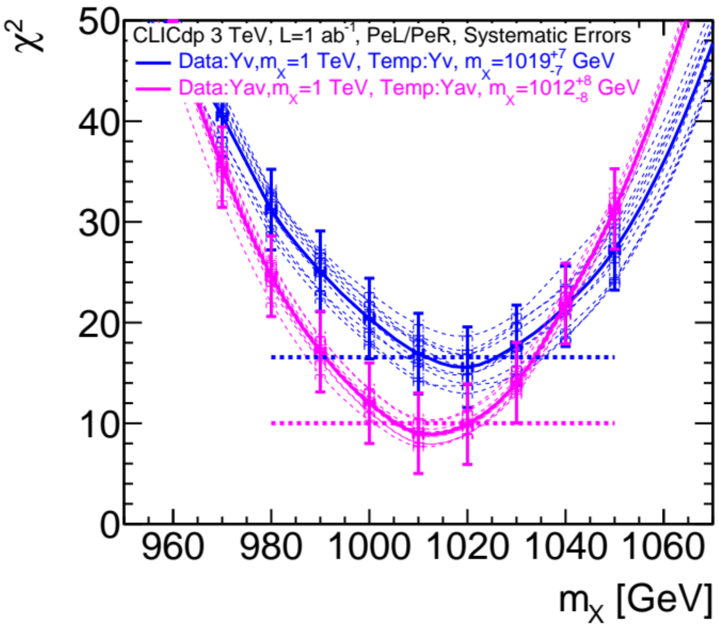
Mediator type discrimination



Pseudo-data: vector mediator (m_X = 1 TeV)

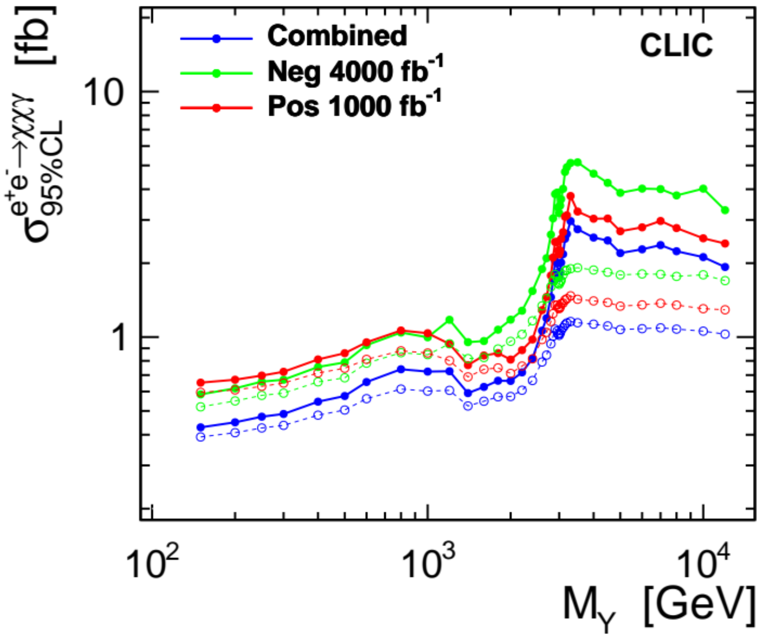
Templates: vector and axial-vector mediator

Mass determination

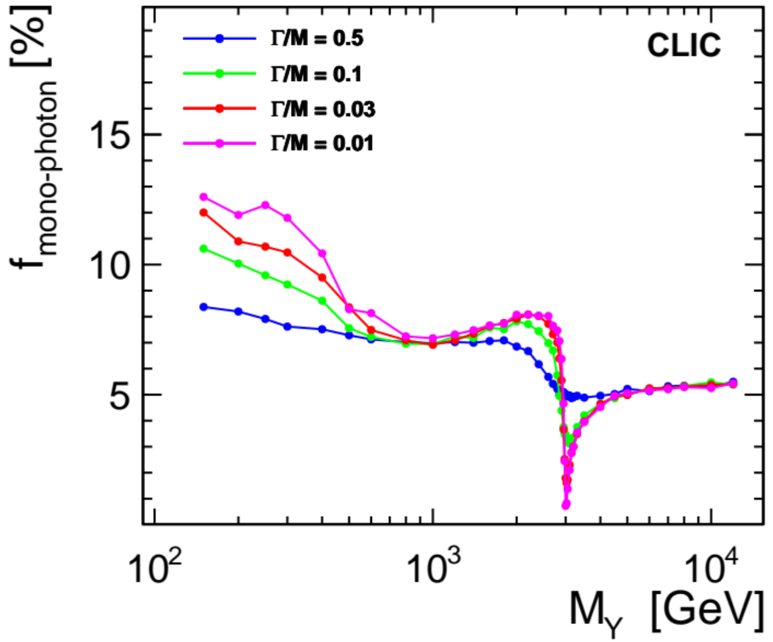


Pseudo-data: vector and axial-vector mediators (m_X = 1 TeV)

Mono-photon: light mediator

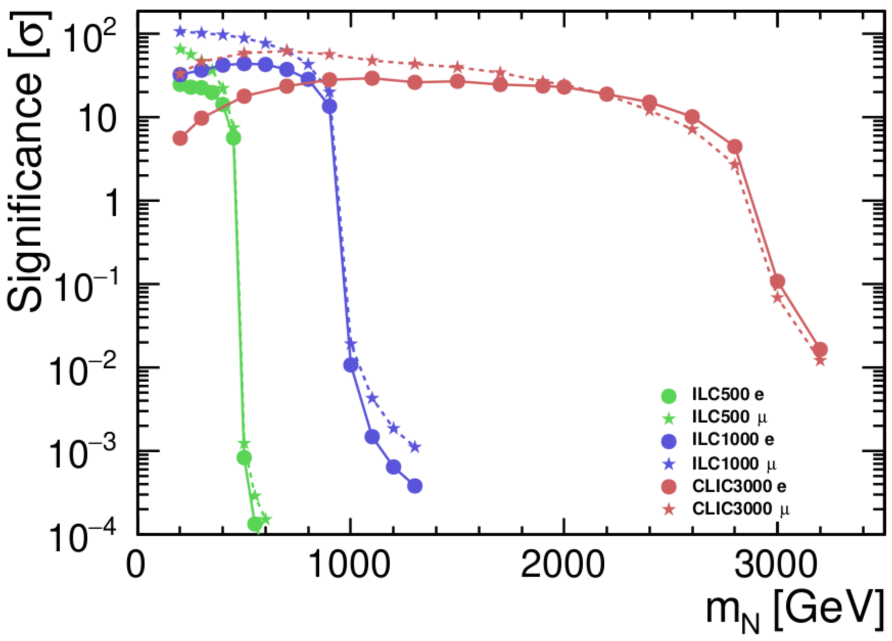


Influence of sys. uncert.

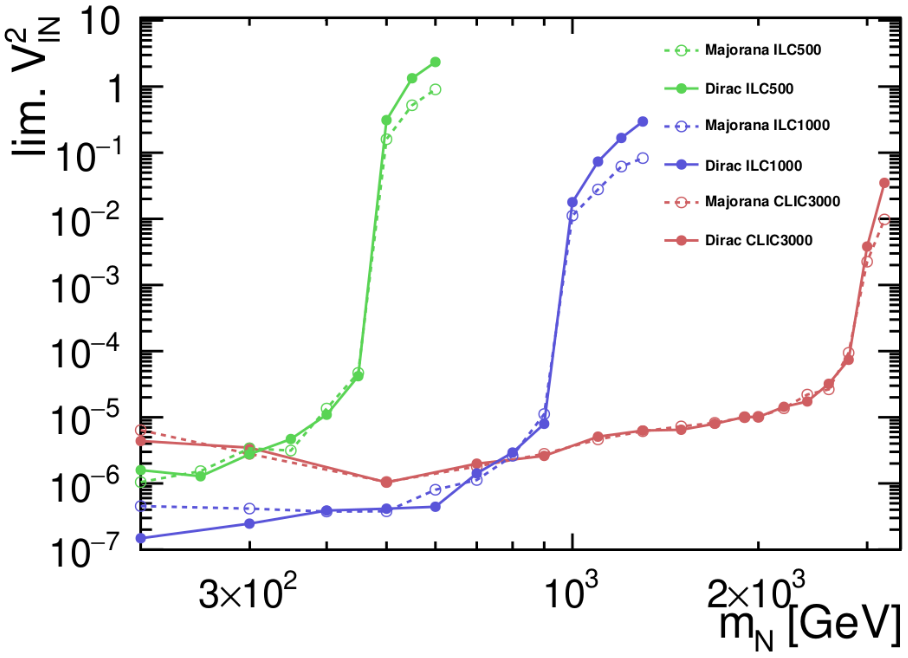


Fraction of reconstructed signal events

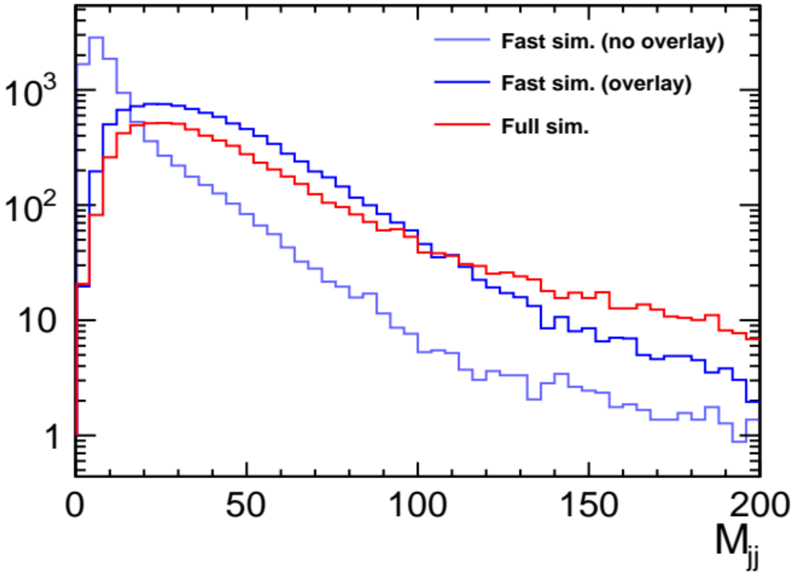
Heavy neutrinos



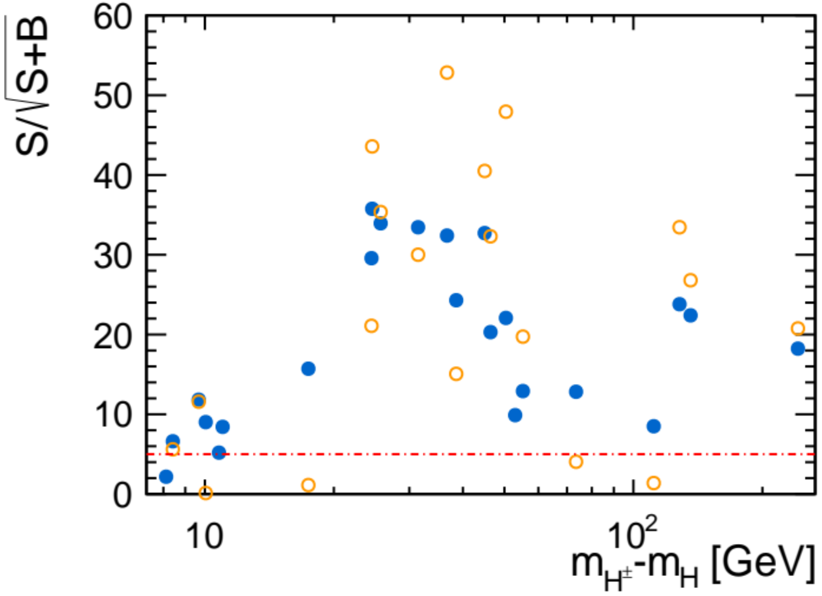
Discovery reach $(V_{lN}^2 = 0.0003)$



Dirac and Majorana masses



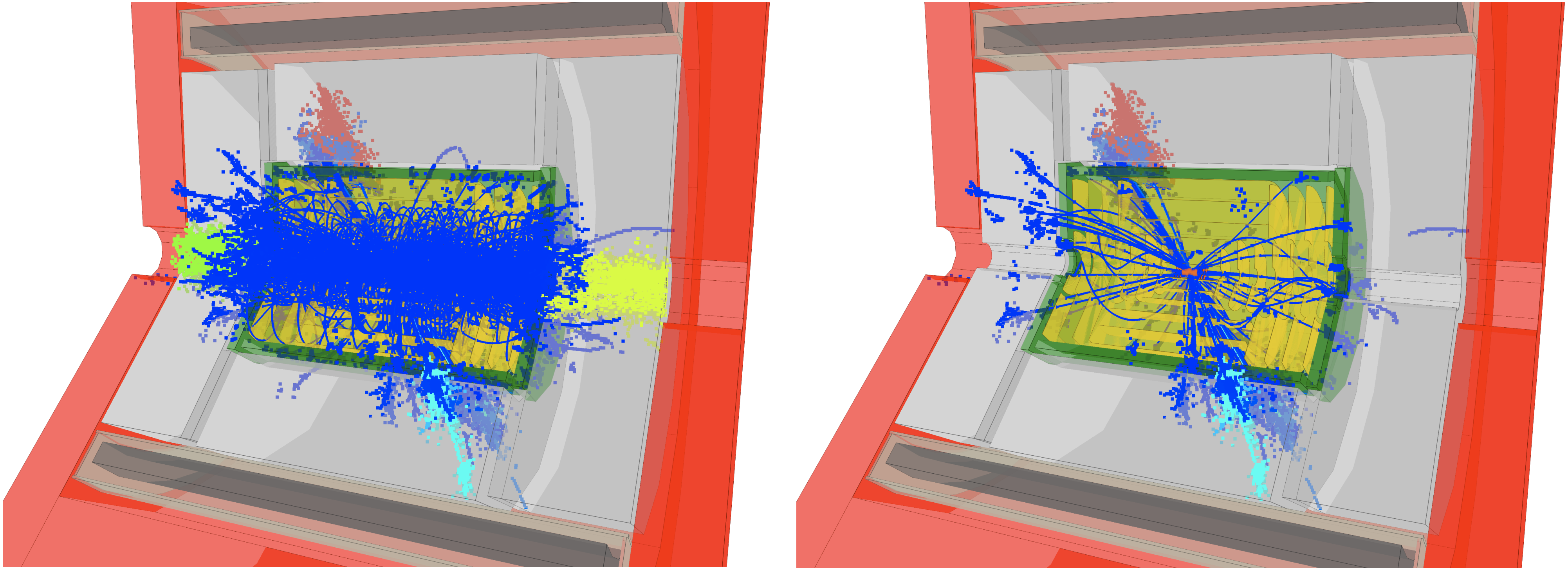
Dijet mass (signal)
Different simulation methods



Results as a function of mass splitting

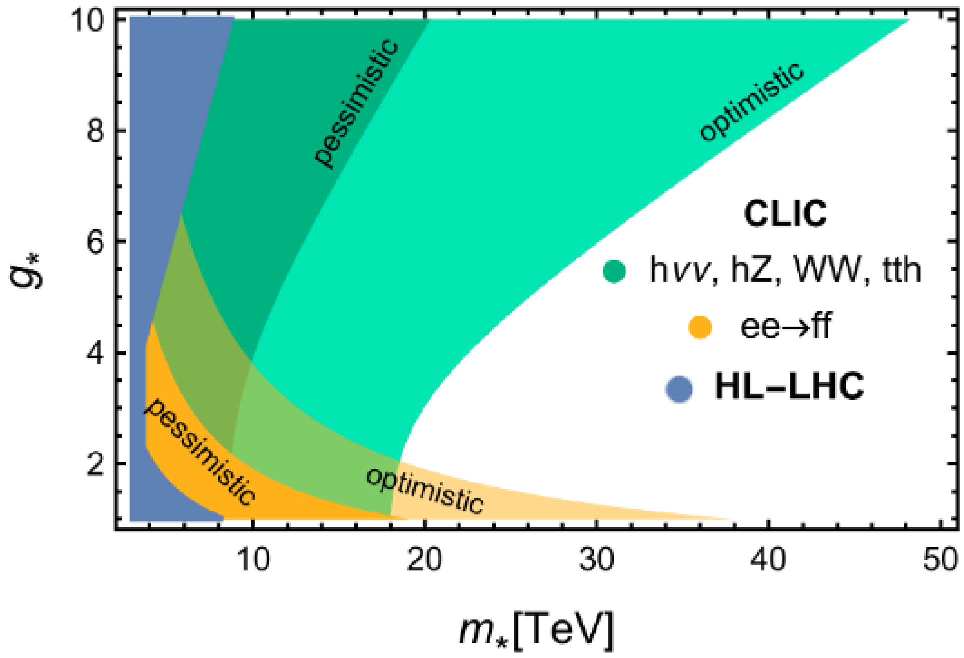
→ Scenarios with small mass splitting the most challenging

Timing cuts

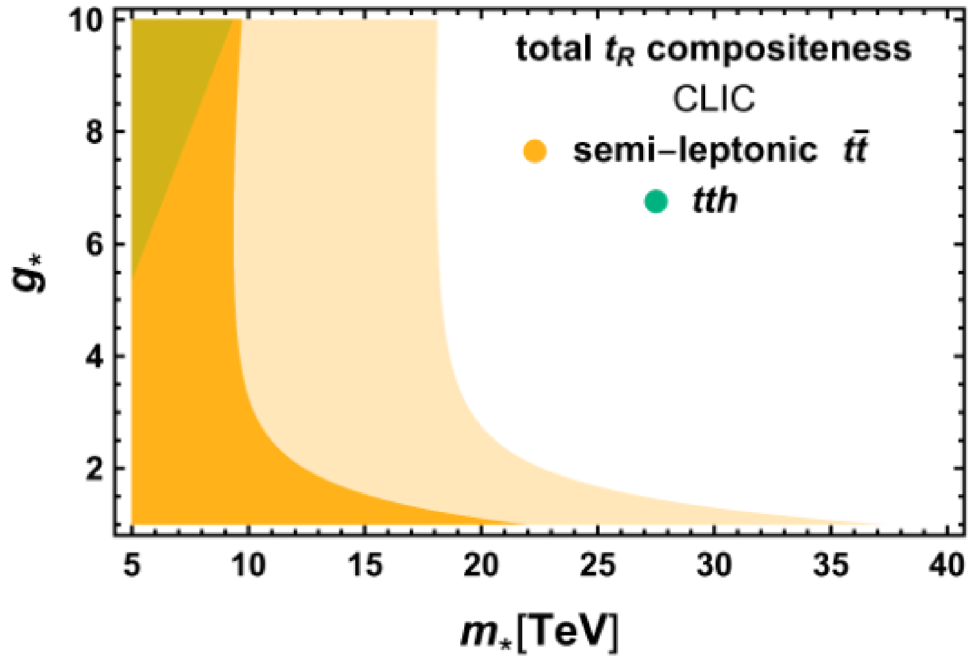


$t\bar{t}$ event before and after $\gamma\gamma \to \mathrm{had.}$ background suppression

Higgs and top compositeness



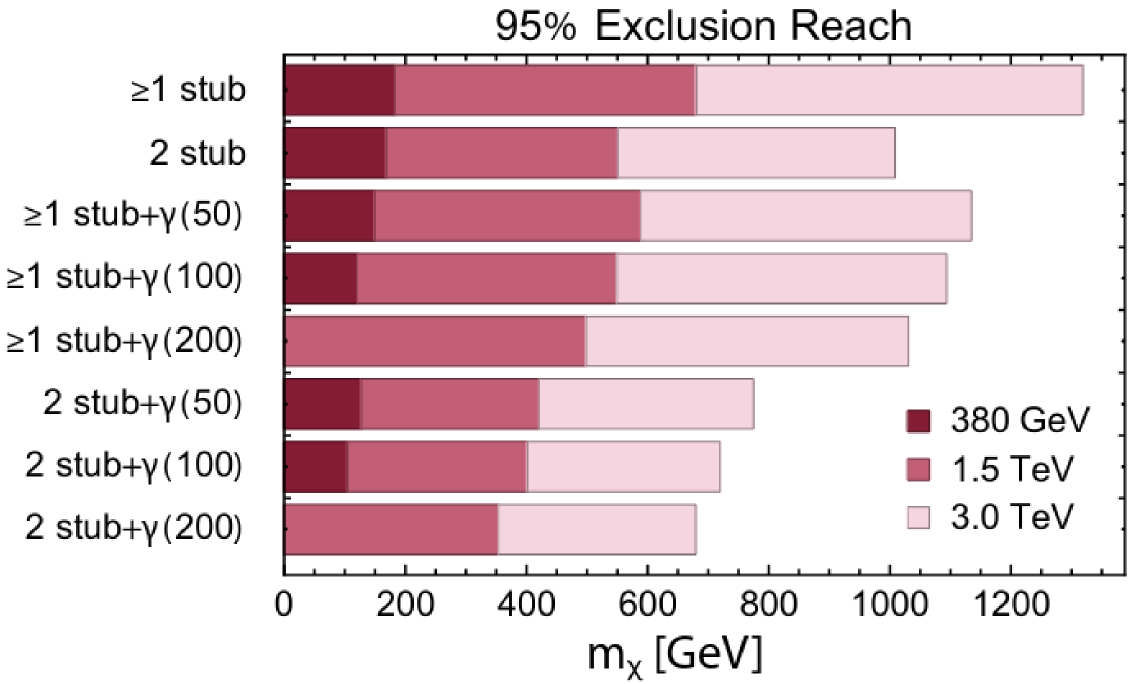
Higgs compositeness scale and coupling



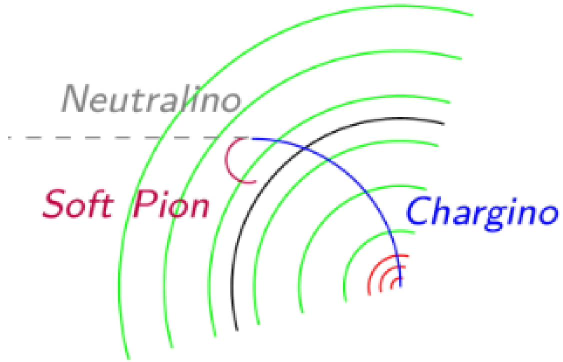
Top compositeness scale and coupling

arXiv:1812.02093

Disappearing tracks



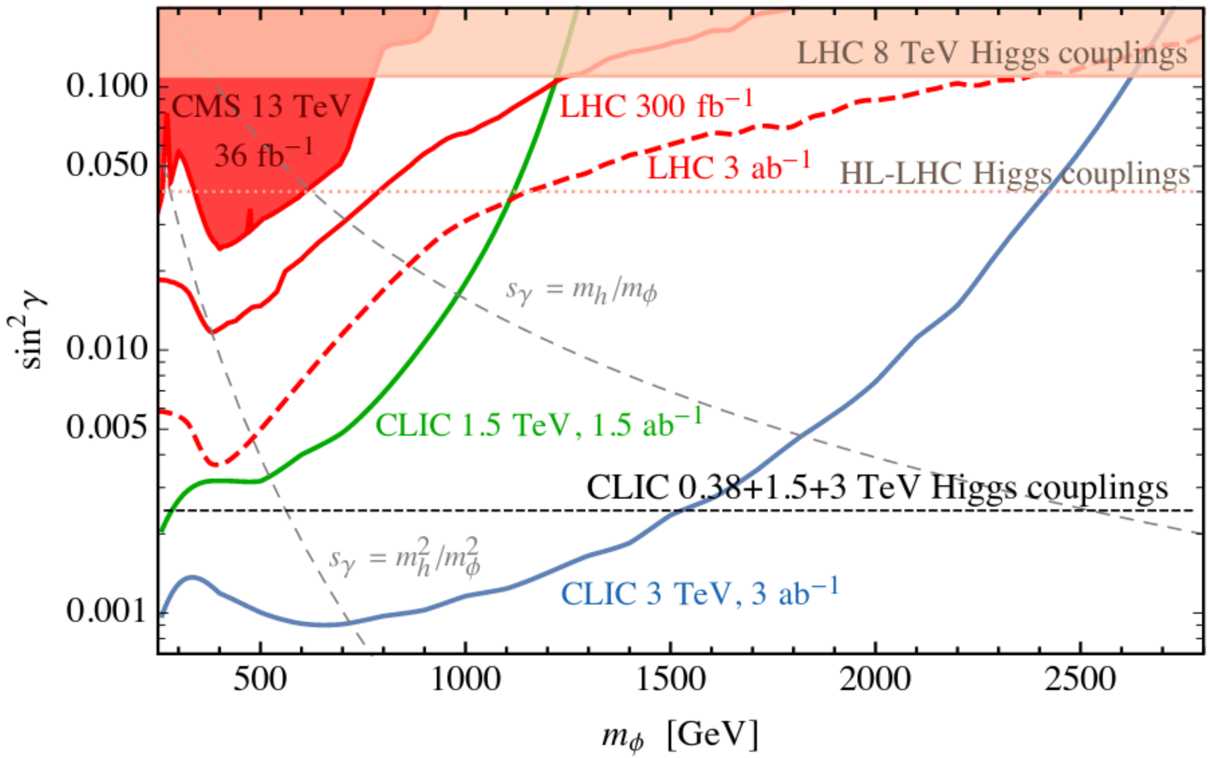
- Small mass difference between higgsino and neutralino
- At least 4 hits in tracker required



→ Reachable higgsino mass of 1.1 TeV required for exact DM relic density

arXiv:1812.02093

Heavy Scalar Singlets



Heavy scalar SM singlet mixing with the Higgs boson

Limits from **direct** production and **indirect** from Higgs couplings

arXiv:1812.02093