The depleted Higgs boson:

searches for universal coupling suppression, invisible decays, and mixed-in scalars

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The depleted Higgs

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- A universal depletion factor δ suppressing all its SM couplings
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Concrete examples:

- Extension with real scalar $S \sim (\mathbf{1}, \mathbf{1}, 0)$ with invisible decays
- N such singlets (with simplifying assumptions)

With the definition

$$\kappa_{\text{inv}} \equiv \frac{\Gamma_{\text{inv}}}{\Gamma^{125}_{\text{SM}}},$$

the production cross-sections and the total width given by:

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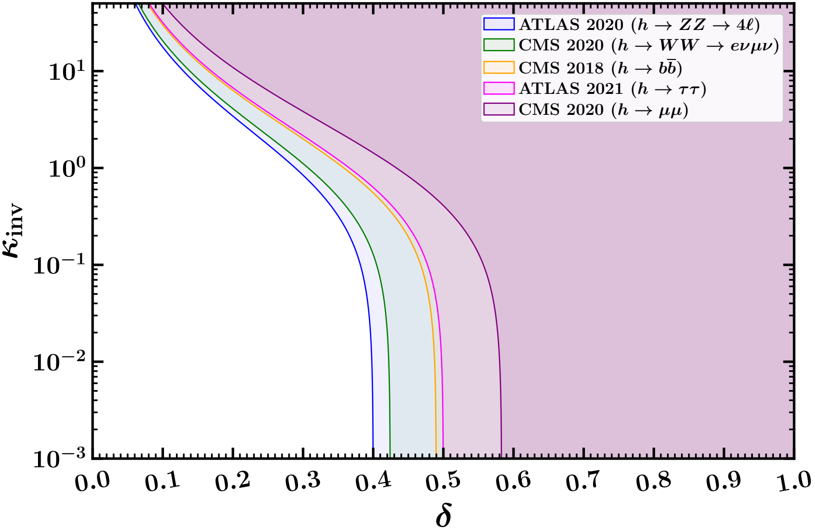
LHC probes for the observed h report:

- Signal strength modifier $\frac{\sigma\, B_j}{\sigma_{\text{SM}}\, B_{\text{SM},j}}$ in j^{th} SM final state
- Upper bound on $\frac{\sigma}{\sigma_{\text{SM}}} B_{\text{inv}}$ for invisible searches

which constrain $(\delta, \kappa_{\text{inv}})$.

Present status of the depleted Higgs



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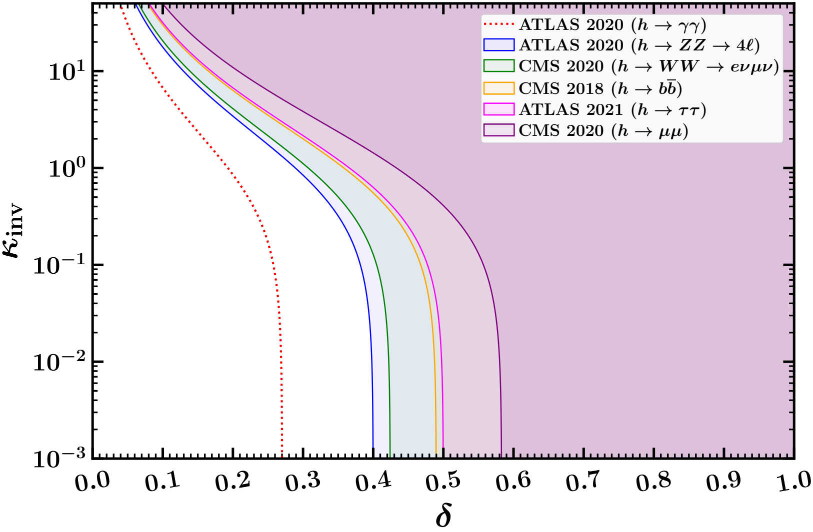

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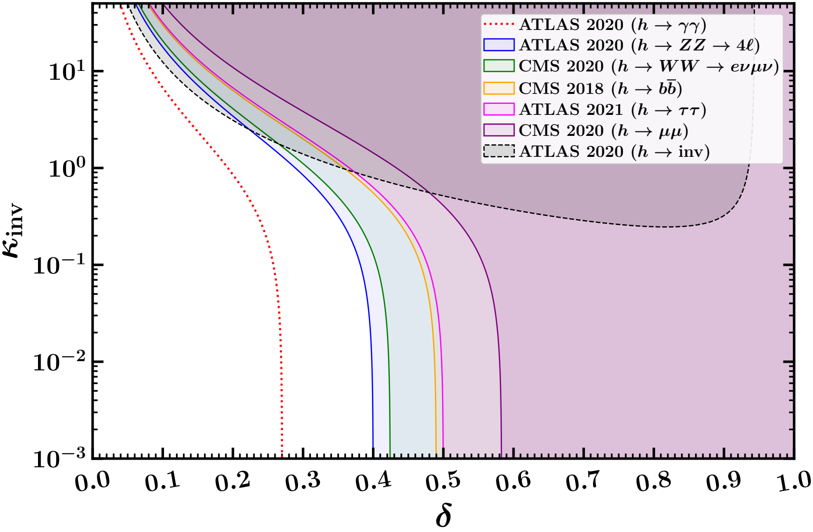

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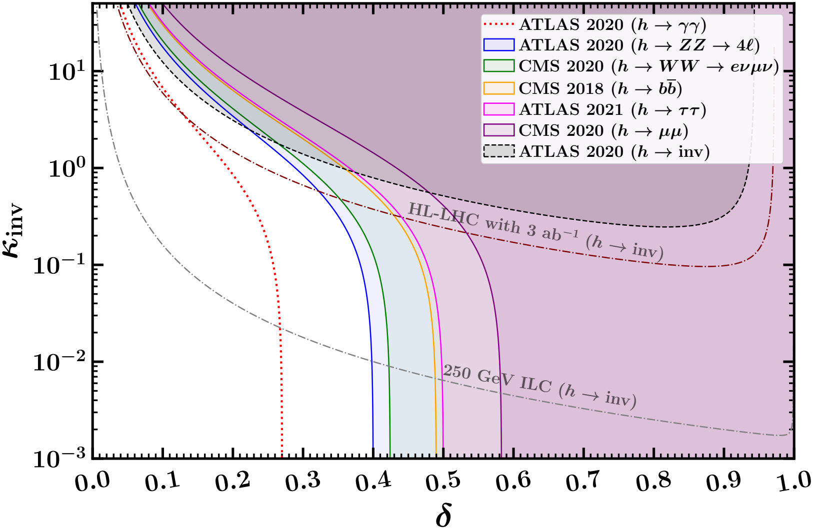

Real singlet scalar extension

Consider SM + real scalar $S \sim (\mathbf{1}, \mathbf{1}, 0)$, after EW symmetry breaking,

$$V(h_{\mathsf{SM}}, S) \supset \frac{1}{2} \begin{pmatrix} h_{\mathsf{SM}} & S \end{pmatrix} \mathcal{M}^2 \begin{pmatrix} h_{\mathsf{SM}} \\ S \end{pmatrix}$$

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Diagonalizing $\mathcal{M}^2$ leads to the physical states h, ϕ:

$$\begin{pmatrix} h_{\mathrm{SM}} \\ S \end{pmatrix} = \begin{pmatrix} \sqrt{1-\delta^2} & \delta \\ -\delta & \sqrt{1-\delta^2} \end{pmatrix} \begin{pmatrix} h \\ \phi \end{pmatrix}$$

with δ identified with the sine of the mixing angle.

h is the "depleted Higgs" with $m_h \sim 125$ GeV with

- Universal coupling suppression due to δ
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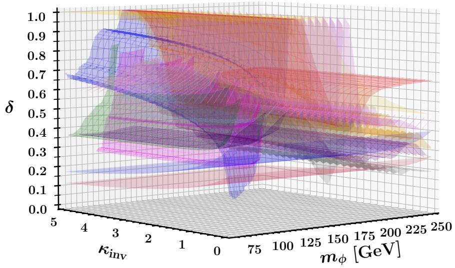
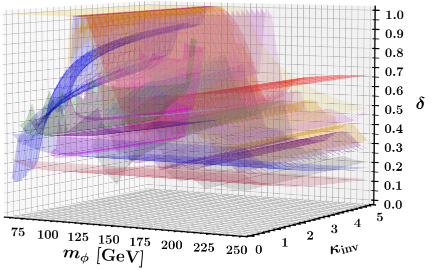
ϕ is the exotic Higgs. We assume:

- $m_\phi > m_h/2$ so that all bounds from above are applicable
- $m_\phi < 2m_h$ for simplicity and easy compatibility with PEW constraints

So $h \to \phi\phi$ and $\phi \to hh$ are kinematically forbidden.

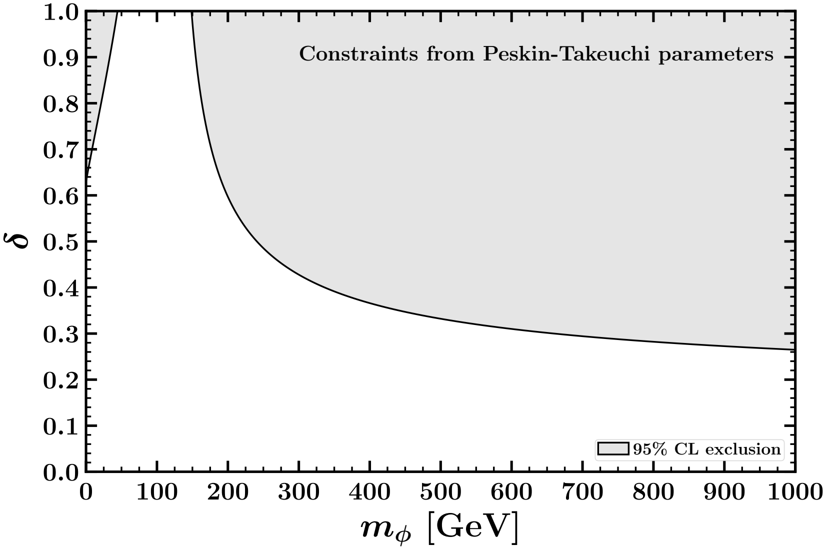
Constraints on $(\delta, \kappa_{\text{inv}}, m_\phi)$





These include constraints from:

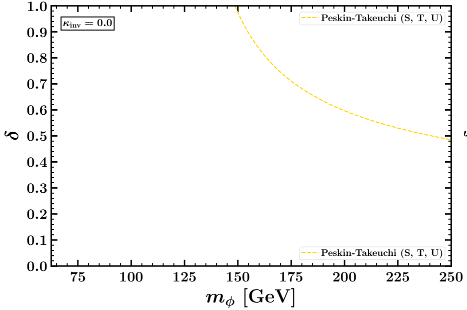
- Precision probes for the observed Higgs h (from few slides ago)
- Peskin-Takeuchi parameters
- Collider searches for additional neutral Higgs



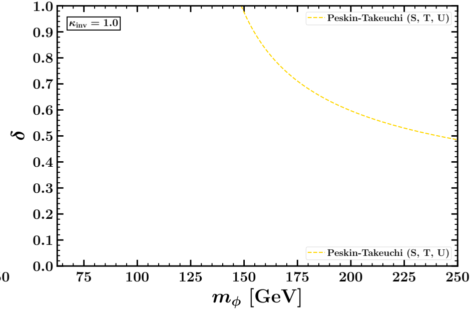
- S, T, U parameters very constraining for large m_ϕ
- Assuming $m_\phi < 2m_h \sim 250$ GeV not unreasonable

Constraints on (δ, m_ϕ)

$\kappa_{\text{inv}} = 0$



$\kappa_{\text{inv}} = 1$



- Gold dashed line: S, T, U parameters

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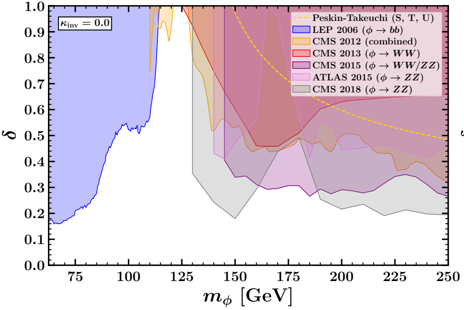

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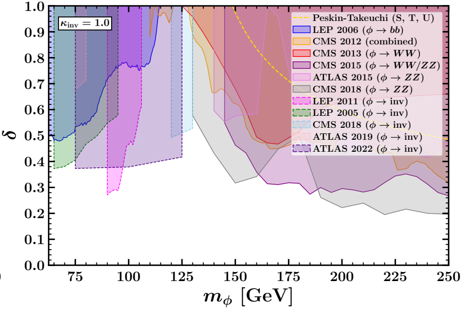

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- Shaded regions: collider searches for the exotic Higgs ϕ

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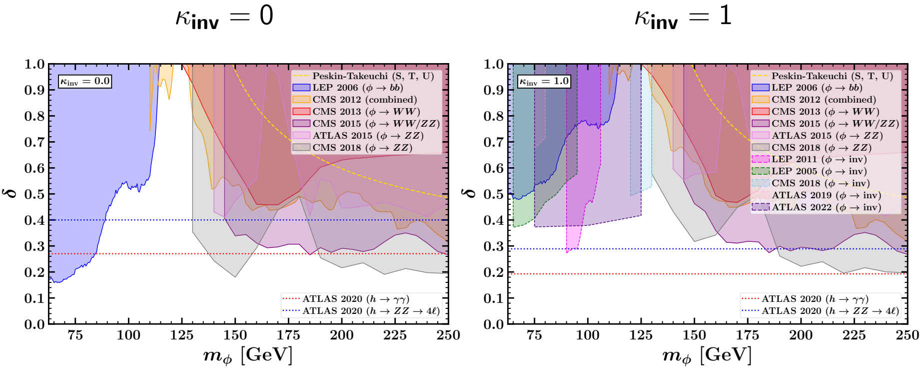

- Gold dashed line: S, T, U parameters
- Shaded regions: collider searches for the exotic Higgs ϕ
- Dotted lines: probes for the 125 GeV Higgs (often most powerful!)

Some projections for (δ, m_ϕ)

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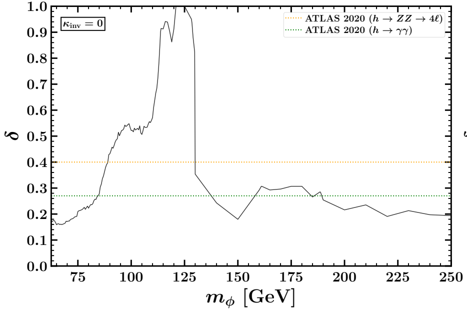

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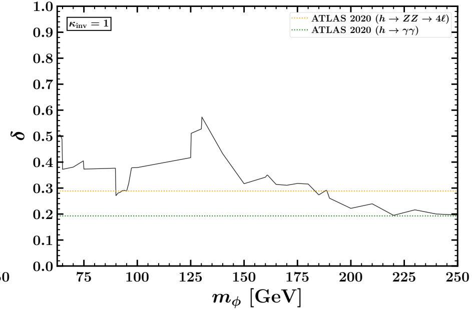

- Solid and dotted lines: current bounds

Some projections for (δ, m_ϕ)

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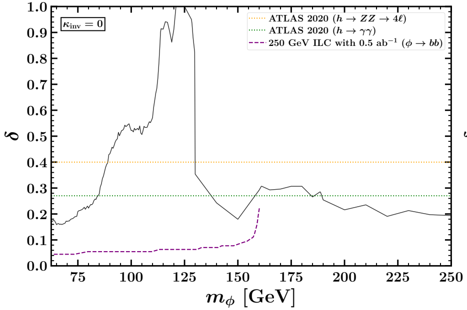

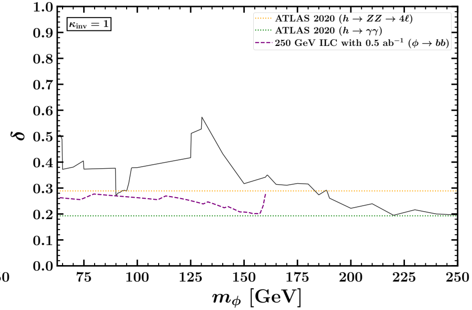

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- Dashed lines: future ILC projections for ϕ

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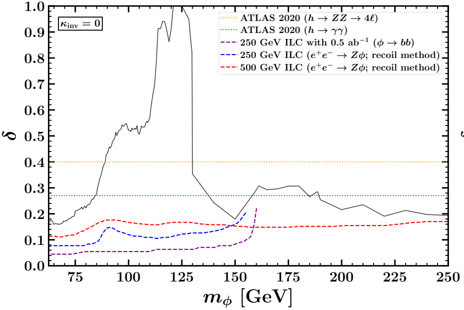

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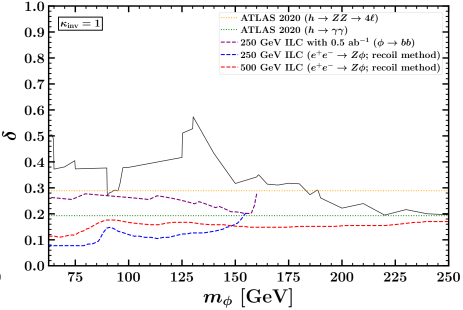

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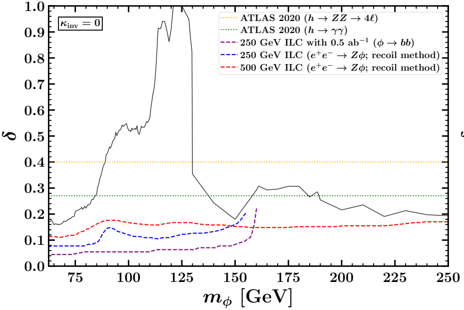

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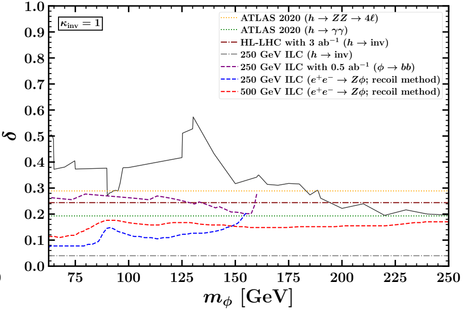

- Solid and dotted lines: current bounds
- Dashed lines: future ILC projections for ϕ
- Dash-dotted lines: future projections for $h \to$ invisible

High multiplicity of real singlet scalars

Consider N such gauge-singlets S_i each with an invisible width Γ_{inv}:

$$\begin{pmatrix} h_{\mathrm{SM}} \\ S_1 \\ S_2 \\ . \end{pmatrix} = \begin{pmatrix} \sqrt{1-\delta^2} & \eta & \eta & . \\ -\eta & 1+\epsilon & \epsilon & . \\ -\eta & \epsilon & 1+\epsilon & . \\ . & . & . & . \end{pmatrix} \begin{pmatrix} h \\ \phi_1 \\ \phi_2 \\ . \end{pmatrix}.$$

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The orthogonality of the above matrix implies that

$$\begin{aligned} \eta &= \frac{\delta}{\sqrt{N}}, \\ \epsilon &= \frac{1}{N}\left(\sqrt{1-\delta^2}-1\right) = -\frac{\delta^2}{2N} + \ldots . \end{aligned}$$

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If we assume $m_h/2 < m_{\phi_i} < 2m_h$, the bounds for ϕ (from previous slides) directly applicable but with $\delta \to \eta = \delta/\sqrt{N}$.

Reinterpreting bounds from $N = 1$ case

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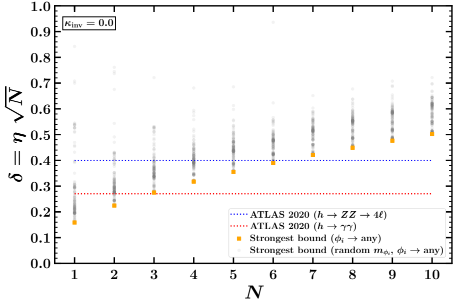

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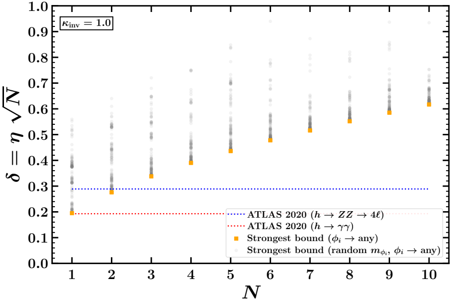

- Bounds get weaker for large N and/or large $\kappa_{\rm inv}$
- Precision probes for $h125$ might give the strongest bound!

Conclusion

The signals of the SM Higgs can be depleted, via two simple ways, if:

- Its couplings to SM states are universally suppressed
- Its branching fraction is partly drained into invisible states

The "depleted Higgs" is therefore an interesting possibility, and we

- Performed a comprehensive survey of its present status
- Considered extensions with singlet scalars where it naturally arises
- Found that in most cases the precision study of the 125 GeV Higgs is more powerful than searches for extra scalar states!

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Thank you!

BACKUP SLIDES

Strongest constraints on N scalars extension