European Strategy for Particle Physics

PARALLEL 7 / **BSM**

Higgs Sector & Electroweak Phase Transition

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The Higgs Sector & Phase Transition

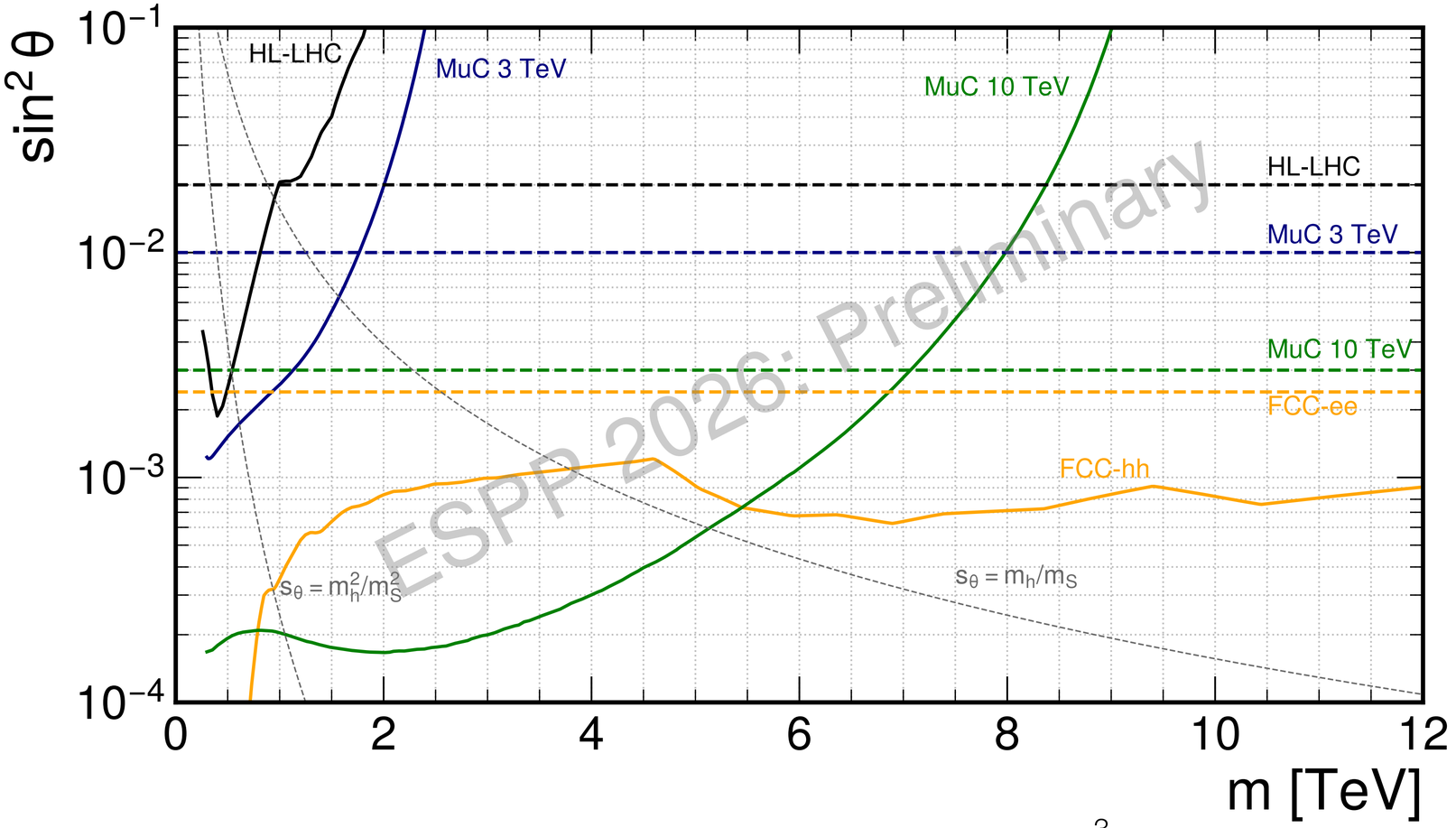
The J=1/2 and J=1 sectors of our universe are rich in multiplicity; why not the J=0 sector as well?

Ramifications for the Higgs potential, electroweak symmetry breaking, and the electroweak phase transition.

Weakly constrained at present, with enormous potential at future collider facilities & strong complementarity with other experiments.

Singlet Higgses

$$V(H,S) = -\mu_H^2|H|^2 + \lambda_H|H|^4 + b_1 S - \frac{\mu_S}{2}S^2 + \frac{b_4}{4}S^4 + \frac{b_3}{3}S^3 + \frac{a_1}{2}|H|^2 S + \frac{a_2}{2}|H|^2 S^2$$



$$\mu_S^2 \gg a_2 v^2, \mu_H^2 :$$
$$BR(hh) = BR(ZZ) = BR(WW)/2$$

HL-LHC [ID170]:
$S \to hh, S \to ZZ$

MuC 3, 10 [ID207]:
$S \to hh$

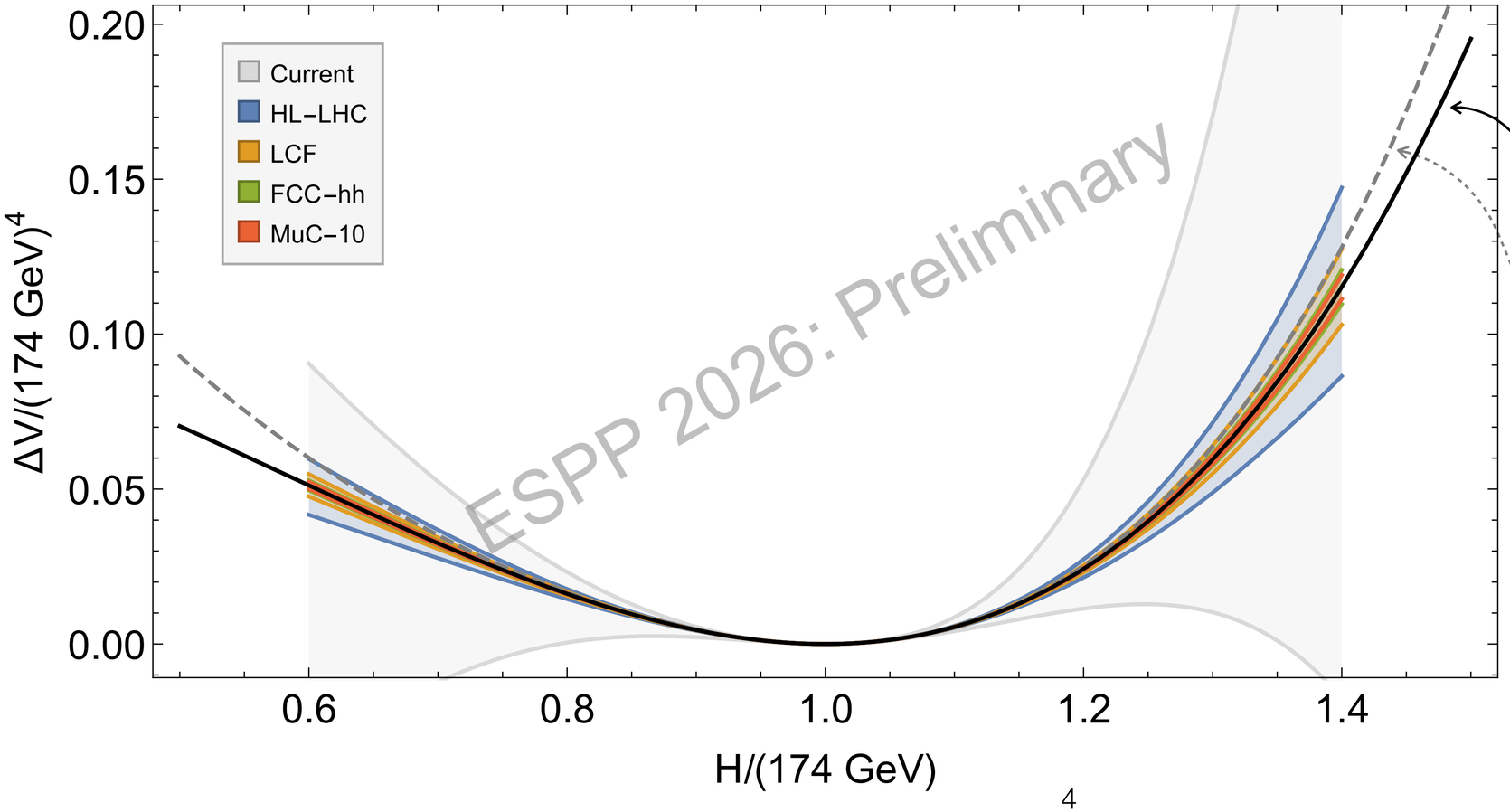
FCC-hh: extrap. HL-LHC
$S \to hh, S \to ZZ$
Dedicated study needed.

Indirect: 95% single-param c_H from [ID170, ID207, ID203].
Add LCF when available.

The Higgs Potential & New Physics

"Petrossian-Byrne plot": self-coupling measurement as local potential

building on HL-LHC highlights [ID170]



SMEFT-6 parameterization

Shaded regions: 95% κ_3

Standard Model Higgs

Higgs + singlet scalar

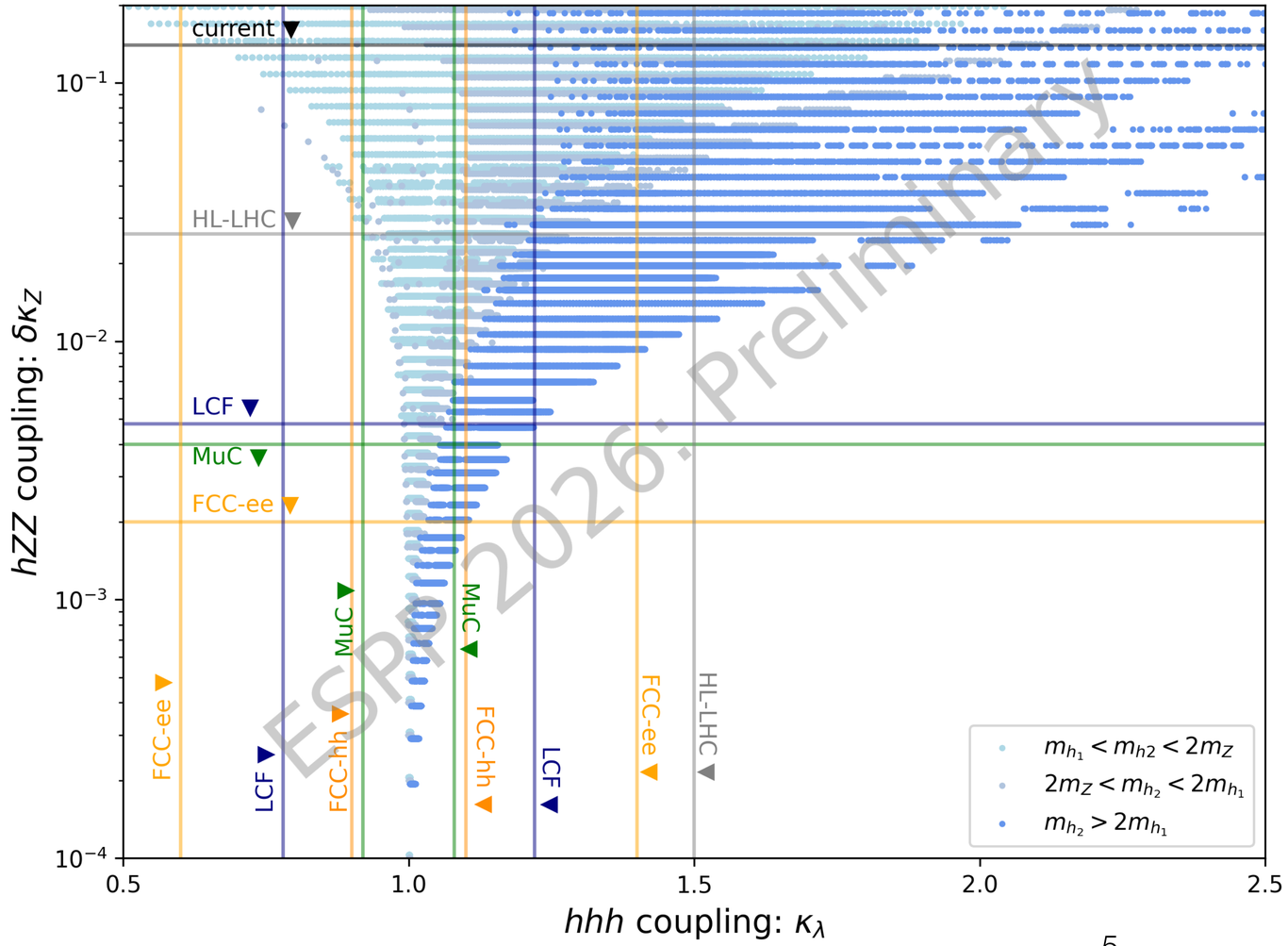
$a_2 = 8, \mu_S = 4m_t$

$a_1 = b_1 = b_3 = b_4 = 0$

HL-LHC [ID170]
LCF [ID140]
FCC-hh [ID247,261]
MuC-10 [ID207]

First-Order Electroweak Phase Transition

building on "Constraining the Real Scalar Singlet" [ID267]



FOPT [ID267]: representative points from scanning

$m_{h_2} \in [130,800]\,\mathrm{GeV}, s_\theta \in [-0.3,0.3]$

$a_2 \in [0,12], b_3 \in [-200,200]\,\mathrm{GeV}, b_4 \in [0,2]$

Strongly first-order $\Delta v/T_c > 1$

Limits: 95% κ_Z and κ_3

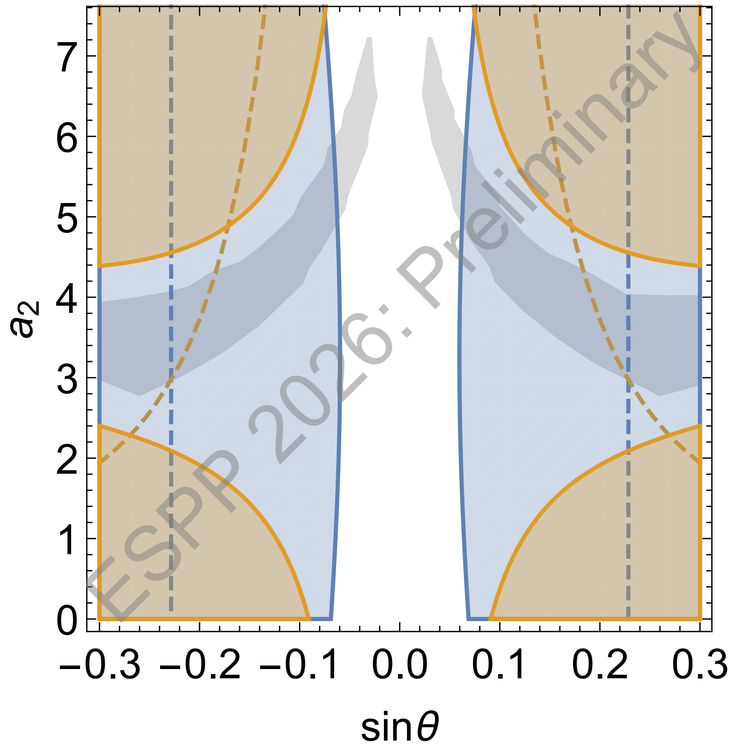
HL-LHC [ID170]
LCF [ID140]
FCC-ee [ID233]
FCC-hh [ID247,261]
MuC-10 [ID207]

First-Order Electroweak Phase Transition

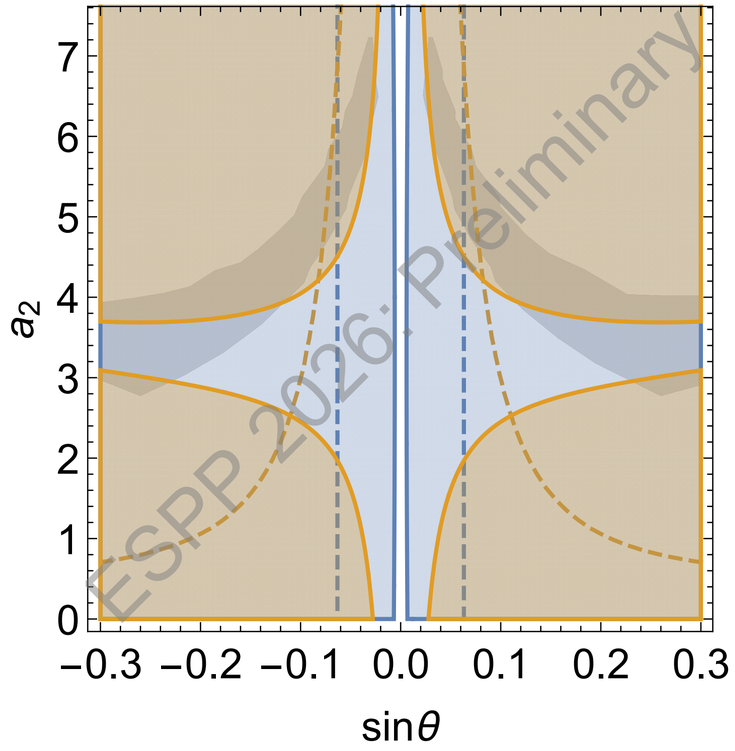
building on "Constraining the Real Scalar Singlet" [ID267]

$$b_1 = b_3 = b_4 = 0$$

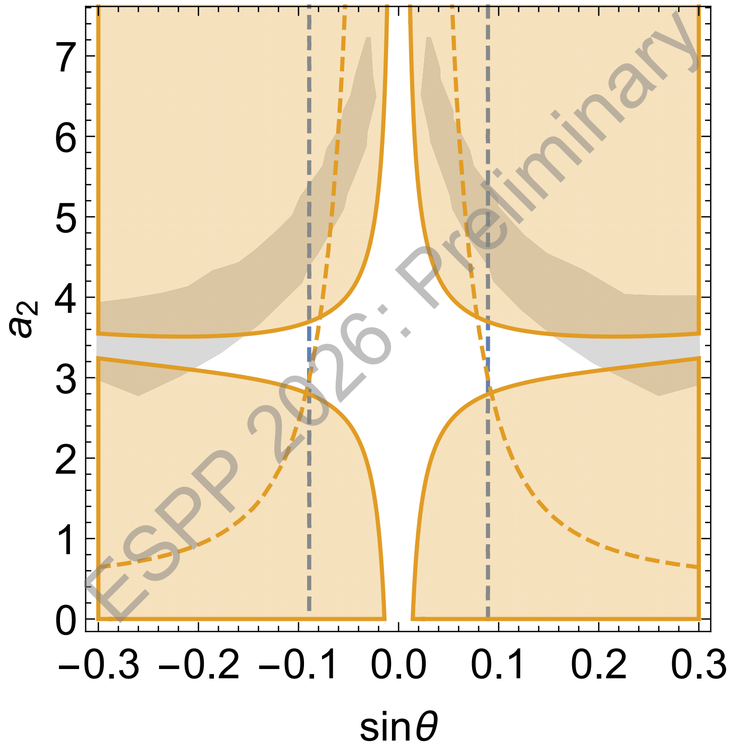
HL–LHC (m_{h2}=600 GeV)



FCC–ee/hh (m_{h2}=600 GeV)



MuC–10 (m_{h2}=600 GeV)

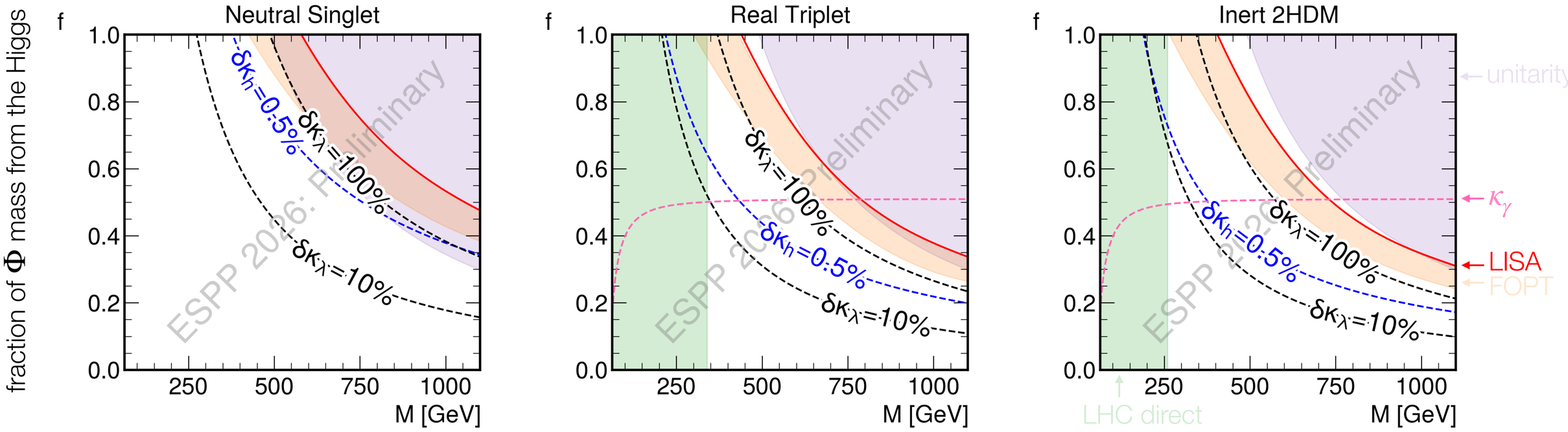


Strong FOPT $S \to ZZ$ $S \to hh$ κ_Z 95% κ_h 95%

$\mathbb{Z}_2$ Symmetric Scalars

building on Crawford & Sutherland, "Scalars with non-decoupling phenomenology at future colliders"

$$V(H,\Phi) \supset \lambda\,|H|^2\,|\Phi|^2$$



Yesterday's "nightmare scenario" is tomorrow's target.

Takeaways & Next Steps

- Discovery of the Higgs at the LHC opens the door to the exploration of a Higgs sector. HL-LHC, Higgs factories, and energy frontier colliders enable us to walk through.
- Improvements in overall Higgs precision & self-coupling will qualitatively advance our knowledge of the Higgs sector; direct searches dramatically increase reach.
- Space of theories enabling strongly first-order electroweak PT is bounded and coverable by the combination of direct searches, Higgs precision, and self-coupling.
- Next steps: dedicated study of FCC-hh sensitivity to $S \to hh, S \to ZZ$, MuC 10 $S \to ZZ$, refinement of illustrative benchmarks & additional examples, …

Grazie mille!