



European Strategy
for Particle Physics

PARALLEL 7 / BSM

Higgs Sector & Electroweak Phase Transition

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On behalf of the PPG BSM WG

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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?

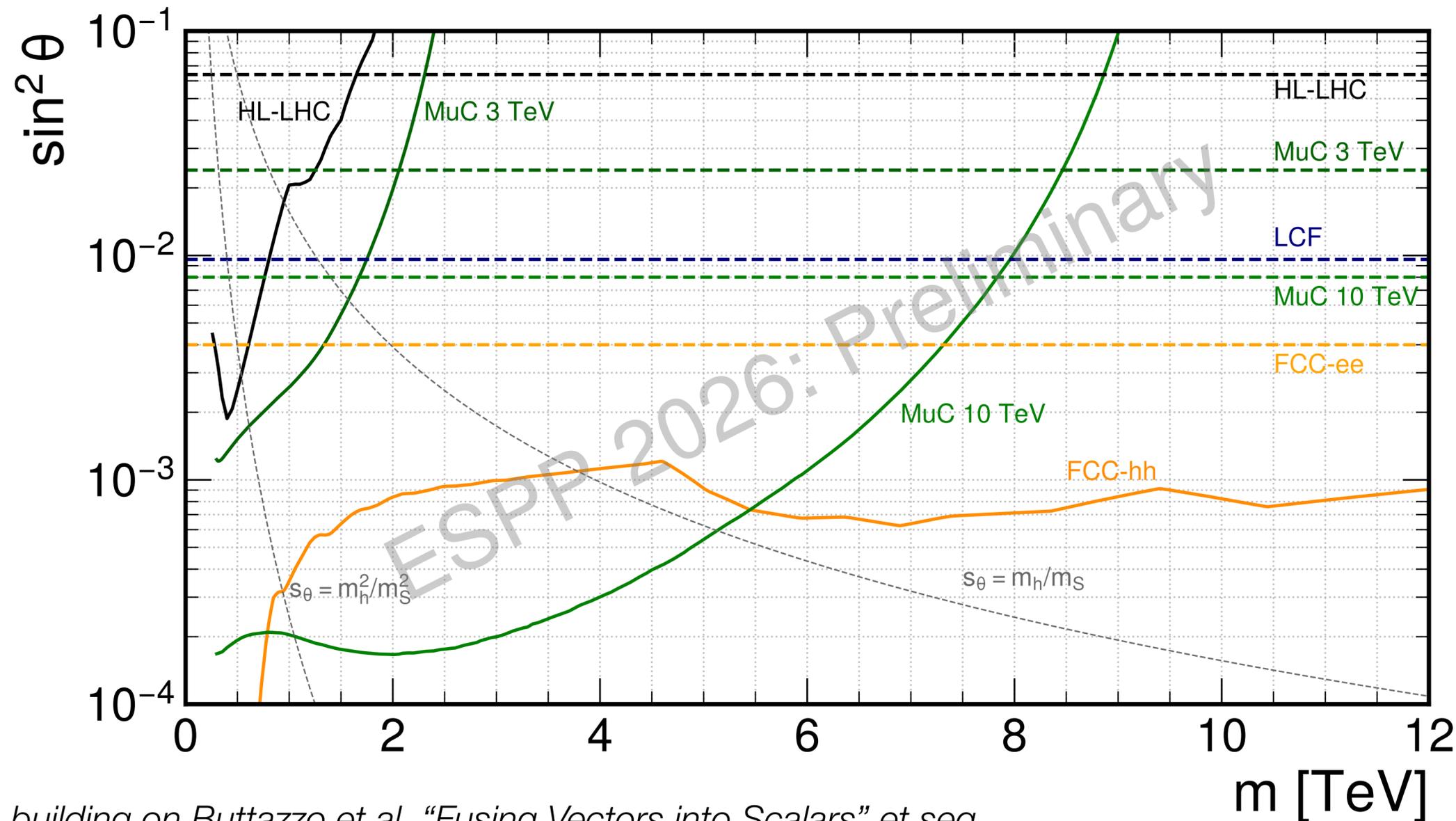
Ramifications for the Higgs potential, electroweak symmetry breaking, and the electroweak phase transition.

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



Singlet Higgses

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



$$\mu_S^2 \gg a_2 v^2, \mu_H^2 :$$

$$BR(hh) = BR(ZZ) = BR(WW)/2$$

HL-LHC [ID170]:

$S \rightarrow hh, S \rightarrow ZZ$

MuC 3, 10 [ID207]:

$S \rightarrow hh$

FCC-hh: extrap. HL-LHC

$S \rightarrow hh, S \rightarrow ZZ$

Dedicated study needed.

Indirect: 95% κ_Z from

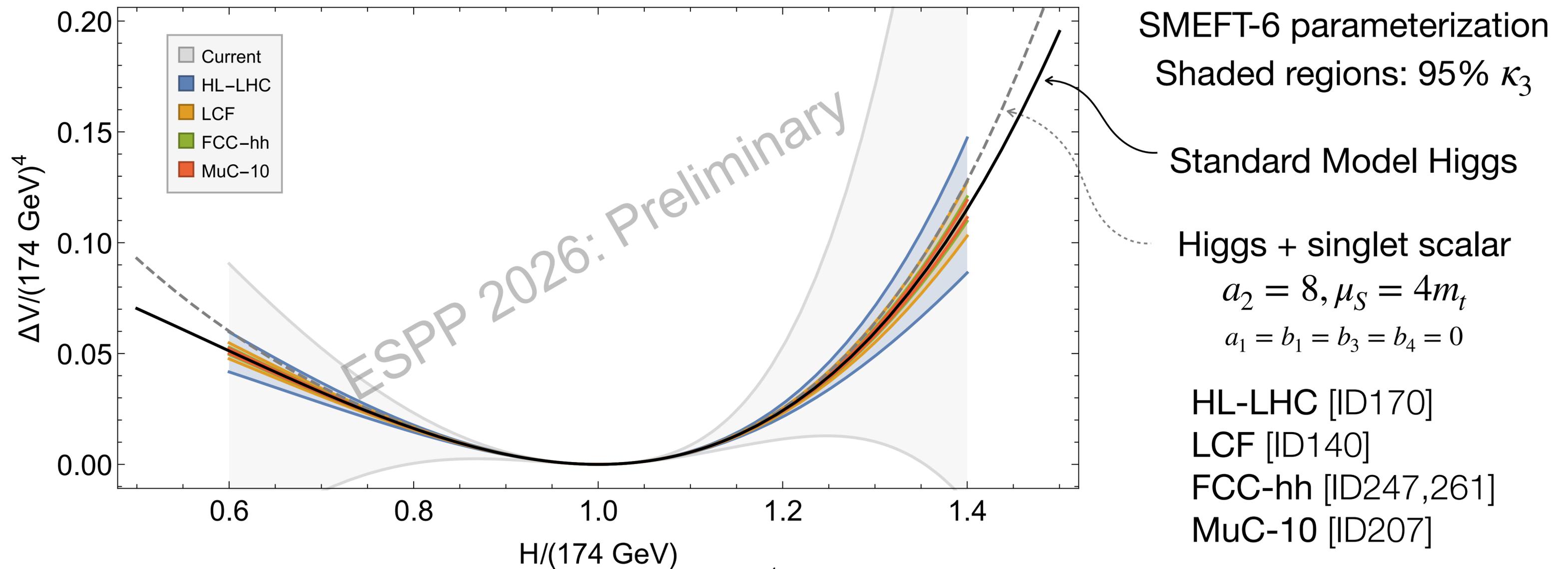
[ID140, ID170, ID207, ID203].

Use single-param c_H reach if/when uniformly available.

The Higgs Potential & New Physics

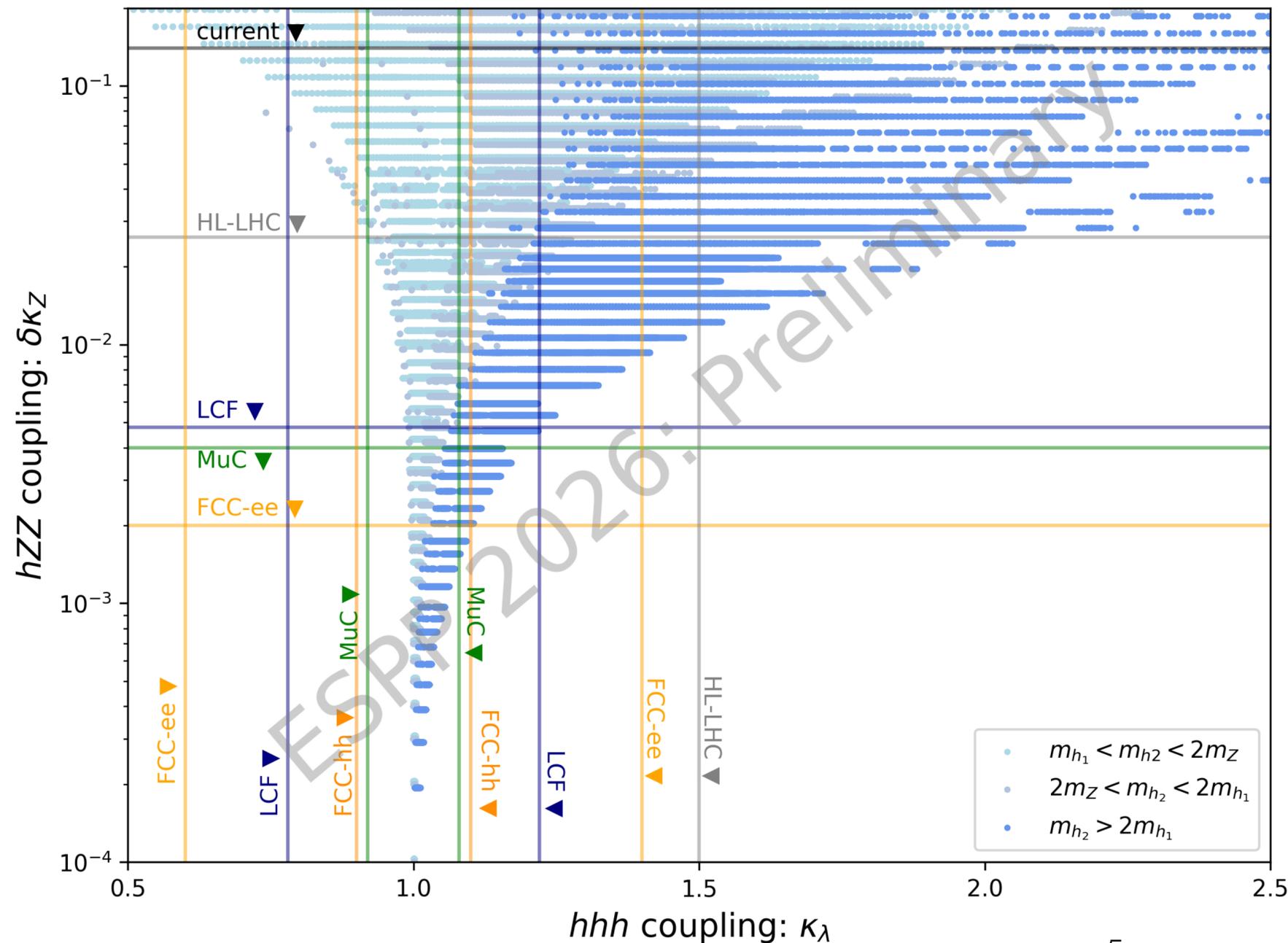
“Petrossian-Byrne plot”: self-coupling measurement as local potential

building on HL-LHC highlights [ID170]



First-Order Electroweak Phase Transition

building on “Constraining the Real Scalar Singlet” [ID267]



FOPT [ID267]: representative points from scanning

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

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

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

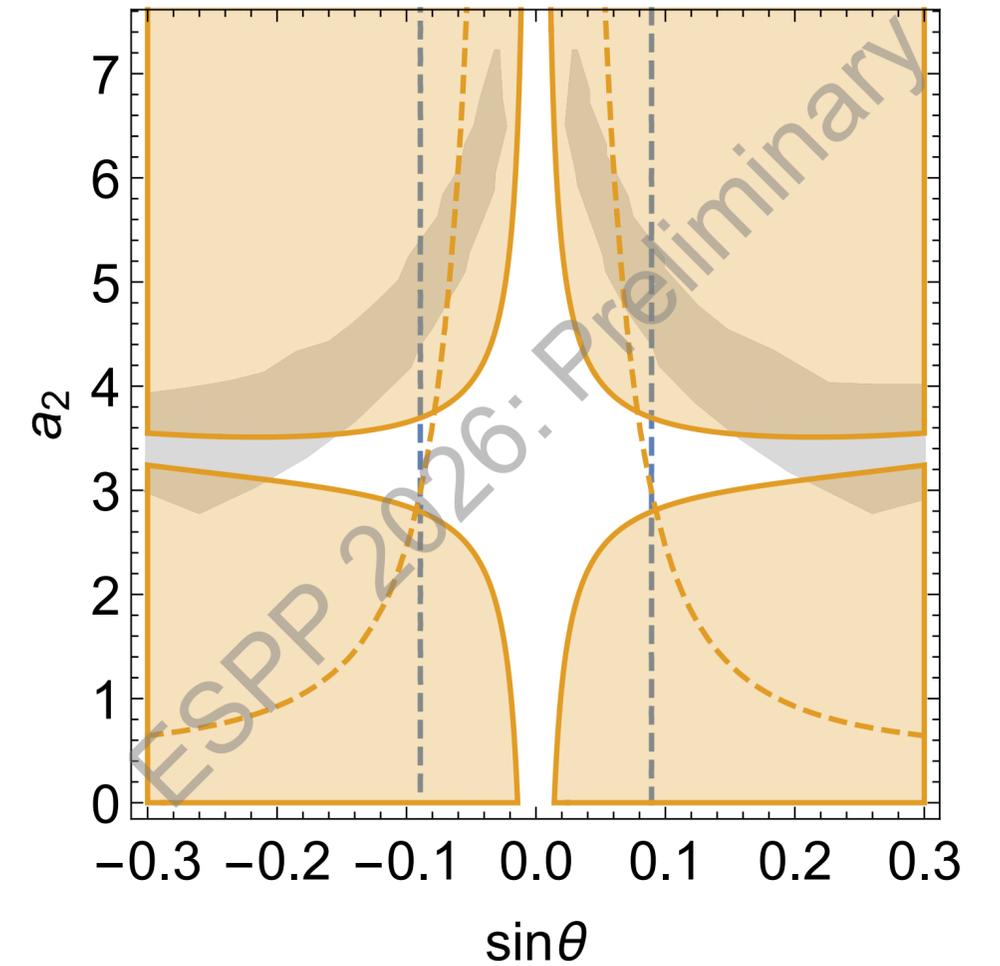
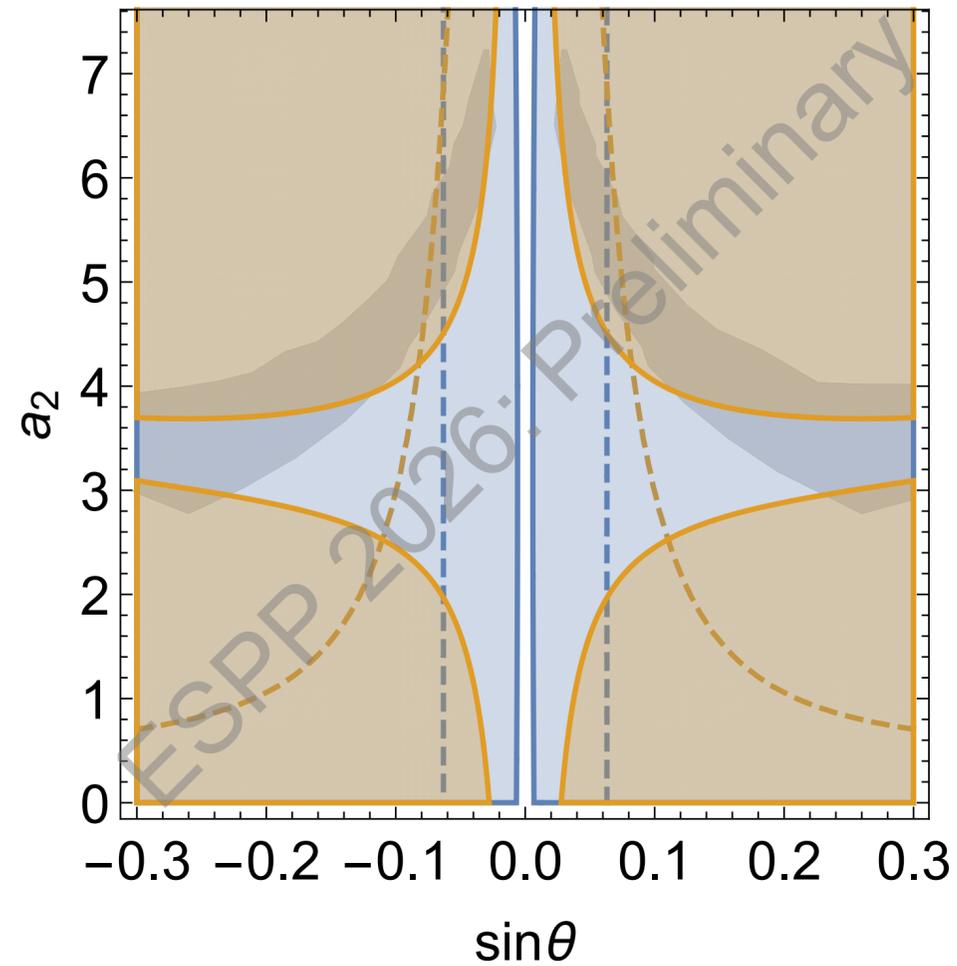
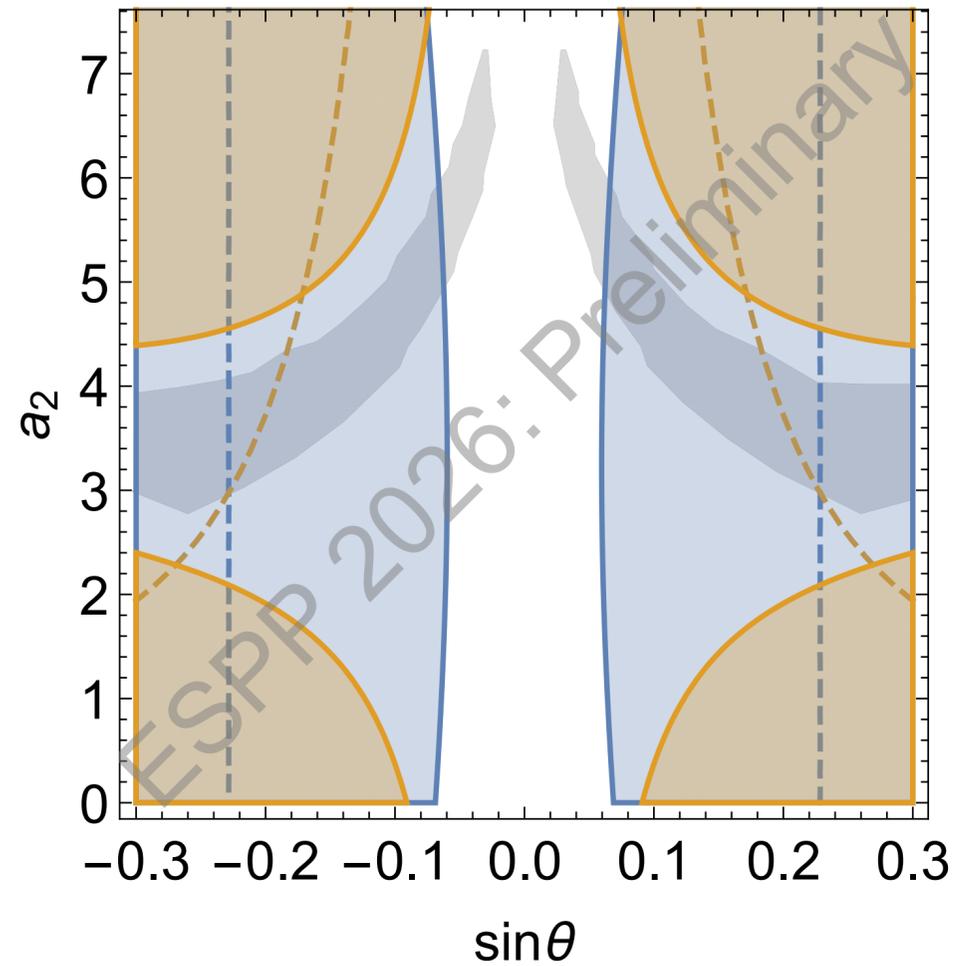
building on “Constraining the Real Scalar Singlet” [ID267]

$$b_1 = b_3 = b_4 = 0$$

HL-LHC ($m_{h_2}=600$ GeV)

FCC-ee/hh ($m_{h_2}=600$ GeV)

MuC-10 ($m_{h_2}=600$ GeV)



Strong FOPT

$S \rightarrow ZZ$

$S \rightarrow hh$

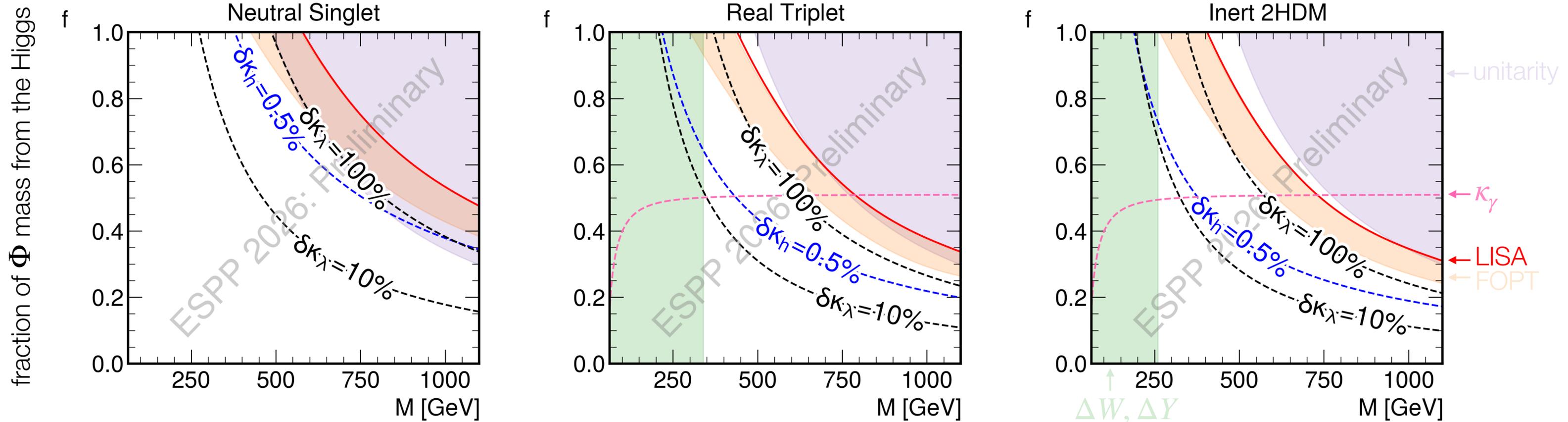
κ_Z 95%

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 $S \rightarrow hh$, $S \rightarrow ZZ$, MuC 10 $S \rightarrow ZZ$, refinement of illustrative benchmarks & additional examples, ...

Grazie mille!