BPCS 2025 (Beijing)

Ref: JHEP 12 (2023) 018,

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Phys.Lett.B 833 (2022) 137301

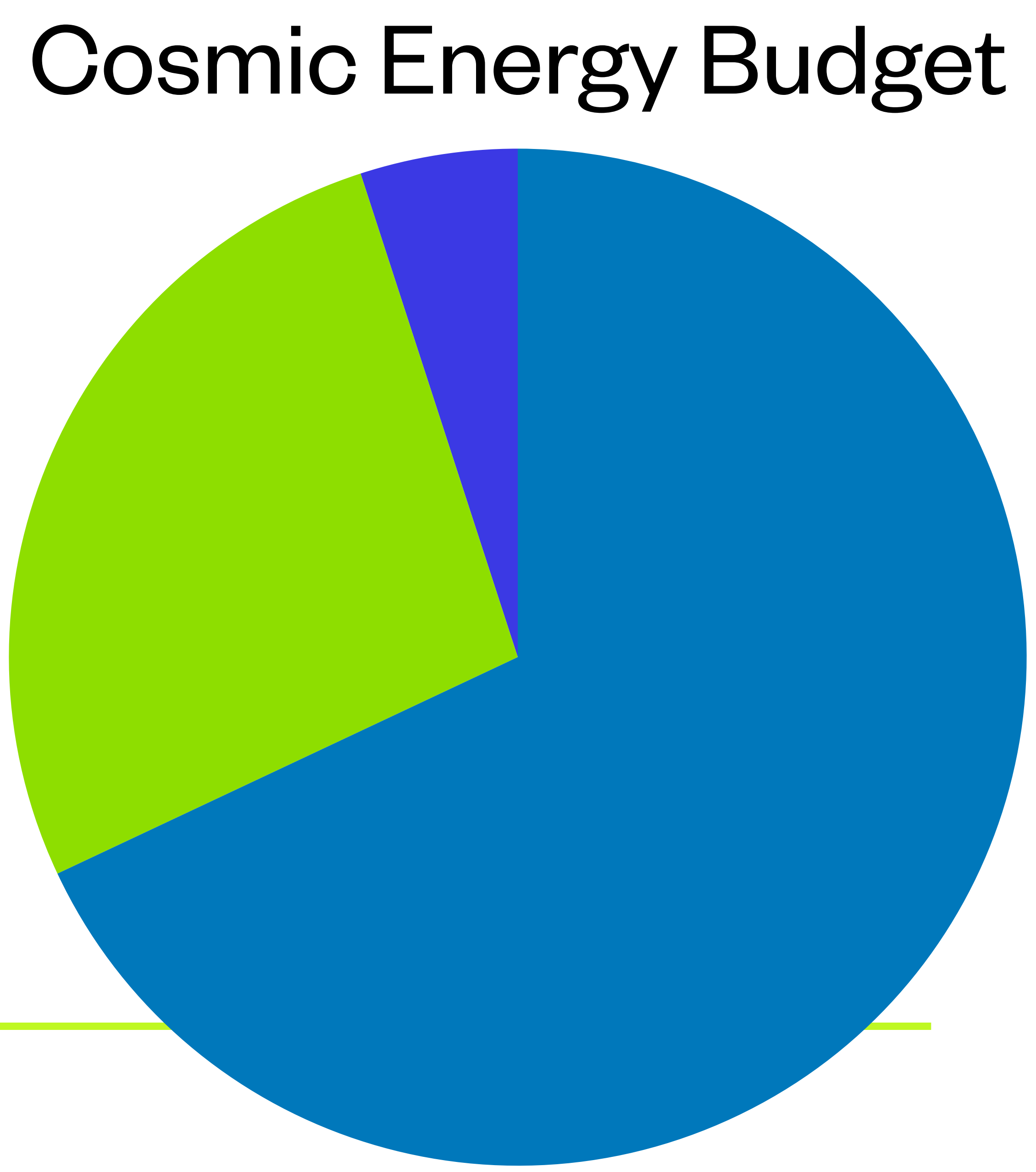
arXiv: 2307.02187

Wenxing Zhang(Hebei U.)

Testing Phase Transition and cosmological history at colliders

Collaborators: Yizhou Cai, Hao-Lin Li, Kun Liu, Michael Ramsey-Musolf, Lei Zhang

Bayon asymmetry of the Universe



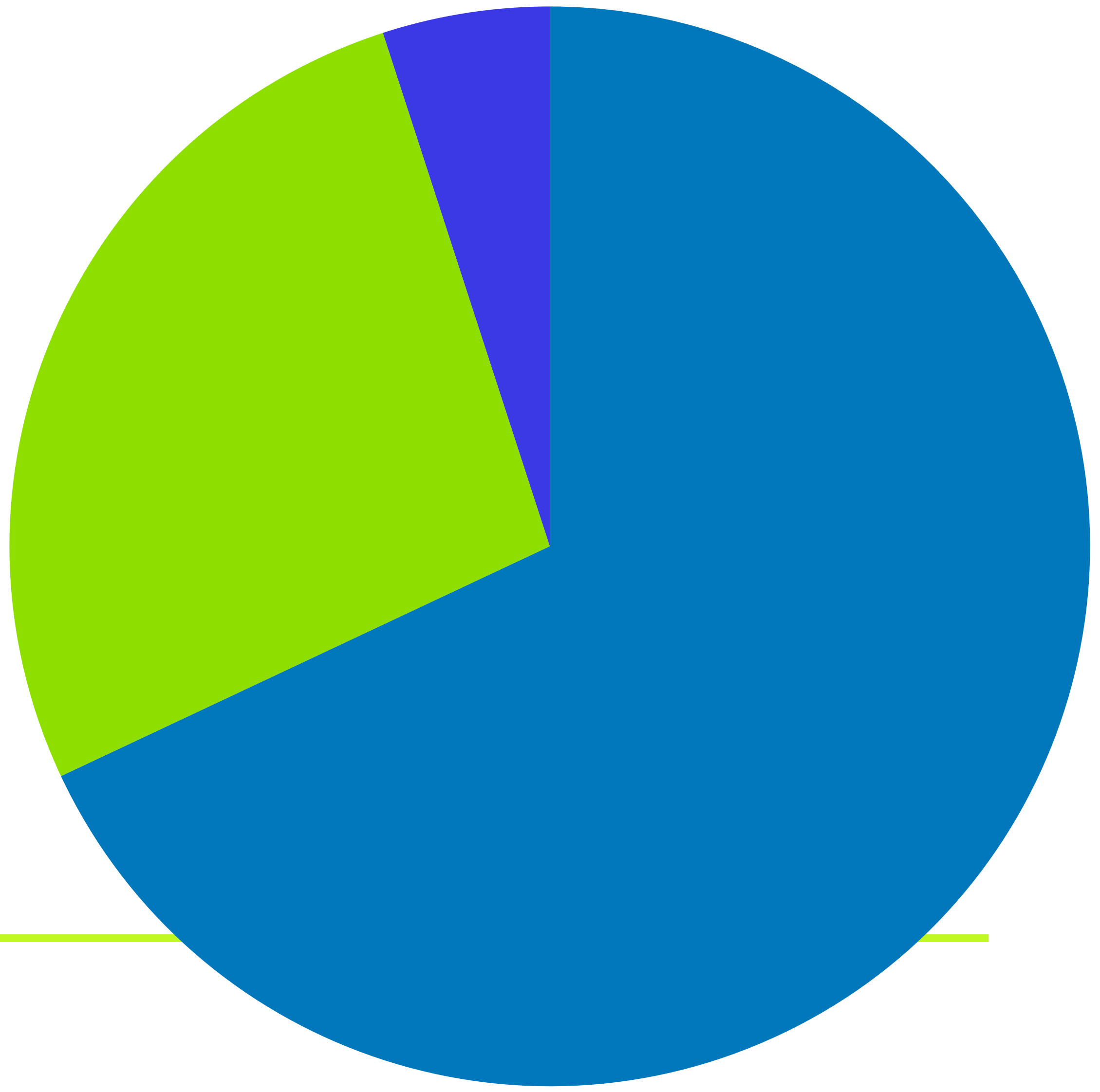
Bayon asymmetry of the Universe

44 different ways to creat baryons in the Universe

1. GUT baryogenesis
2. GUT baryogenesis after preheating
3. Baryogenesis from primordial black holes
4. String scale baryogenesis
5. Affleck-Dine (AD) baryogenesis
6. Hybridized AD baryogenesis
7. No-scale AD baryogenesis
8. Single field baryogenesis
9. Electroweak (EW) baryogenesis
10. Local EW baryogenesis
11. Non-local EW baryogenesis
12. EW baryogenesis at preheating
13. SUSY EW baryogenesis
14. String mediated EW baryogenesis
15. Baryogenesis via leptogenesis
16. Inflationary baryogenesis
17. Resonant leptogenesis
18. Spontaneous baryogenesis
19. Coherent baryogenesis
20. Gravitational baryogenesis
21. Defect mediated baryogenesis
22. Baryogenesis from long cosmic strings
23. Baryogenesis from short cosmic strings
24. Baryogenesis from collapsing loops

Shaposhnikov, DISCRETE 08, 11, Dec

Cosmic Energy Budget



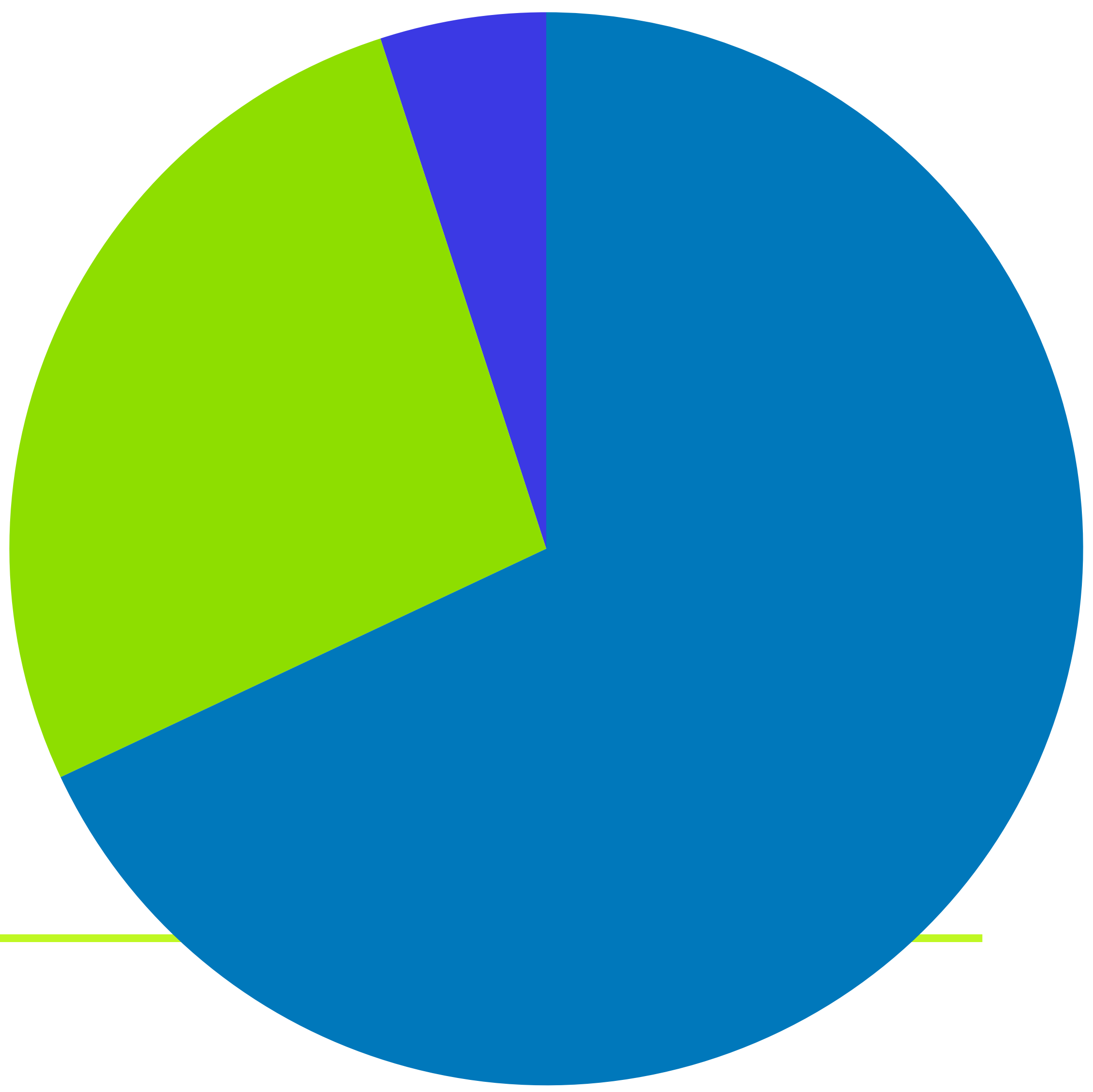
Bayon asymmetry of the Universe

44 different ways to creat baryons in the Universe

25. Baryogenesis through collapse of vortons
26. Baryogenesis through axion domain walls
27. Baryogenesis through QCD domain walls
28. Baryogenesis through unstable domain walls
29. Baryogenesis from classical force
30. Baryogenesis from electrogenesis
31. B-ball baryogenesis
32. Baryogenesis from CPT breaking
33. Baryogenesis through quantum gravity
34. Baryogenesis via neutrino oscillations
35. Monopole baryogenesis
36. Axino induced baryogenesis
37. Gravitino induced baryogenesis
38. Radion induced baryogenesis
39. Baryogenesis in large extra dimensions
40. Baryogenesis by brane collision
41. Baryogenesis via density fluctuations
42. Baryogenesis from hadronic jets
43. Thermal leptogenesis
44. Nonthermal leptogenesis

Shaposhnikov, DISCRETE 08, 11, Dec

Cosmic Energy Budget



Electroweak Baryogenesis

Sakharov conditions:

- Baryon number violating interactions. ☑
- C and CP violation. ☒
- Departure from thermal equilibrium. ☒

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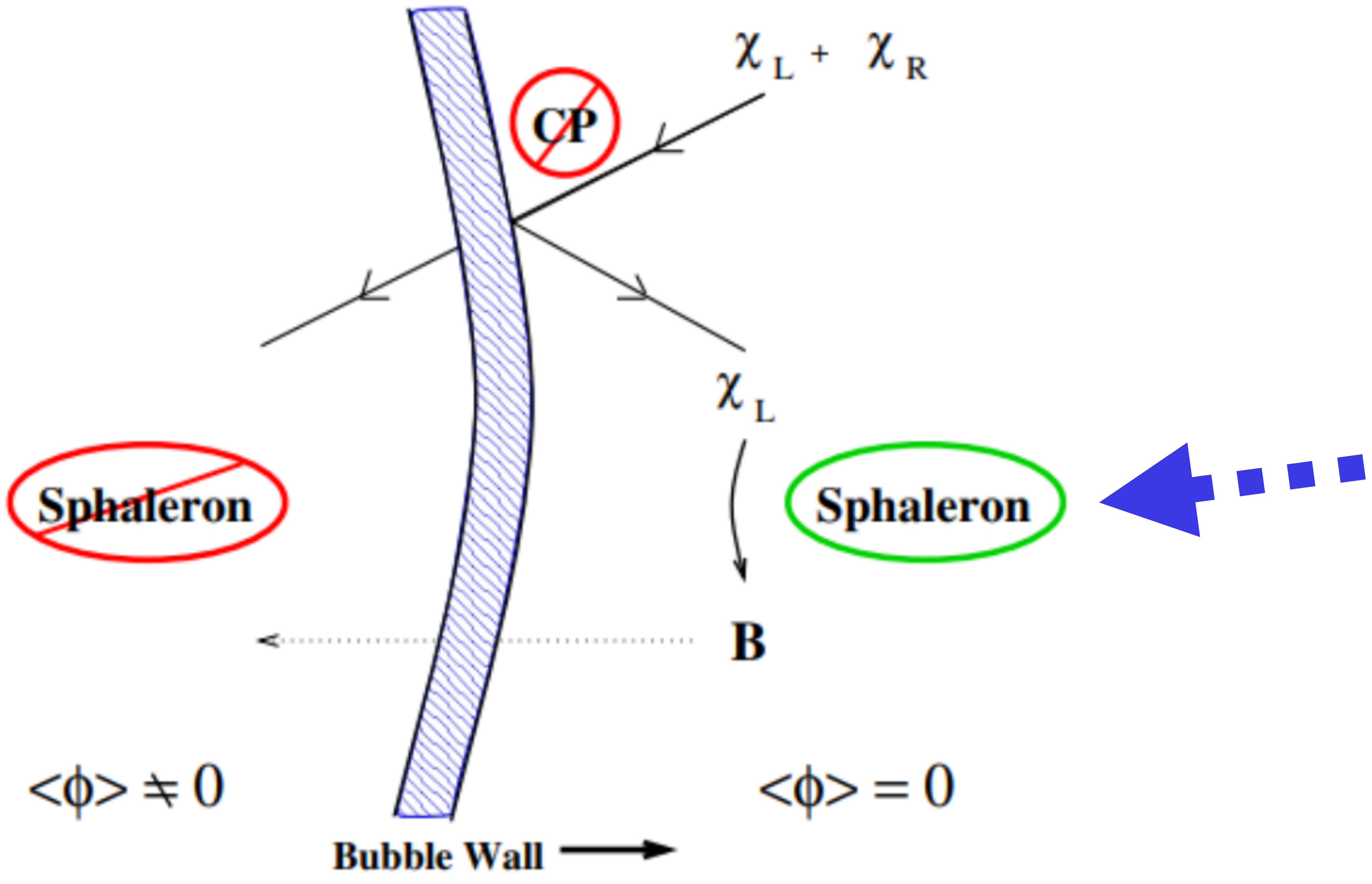

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NEW J.PHYS. 14 (2012) 125003,
DAVID E.MORRISSEY, MICHAEL J. RAMSEY-MUSOLF

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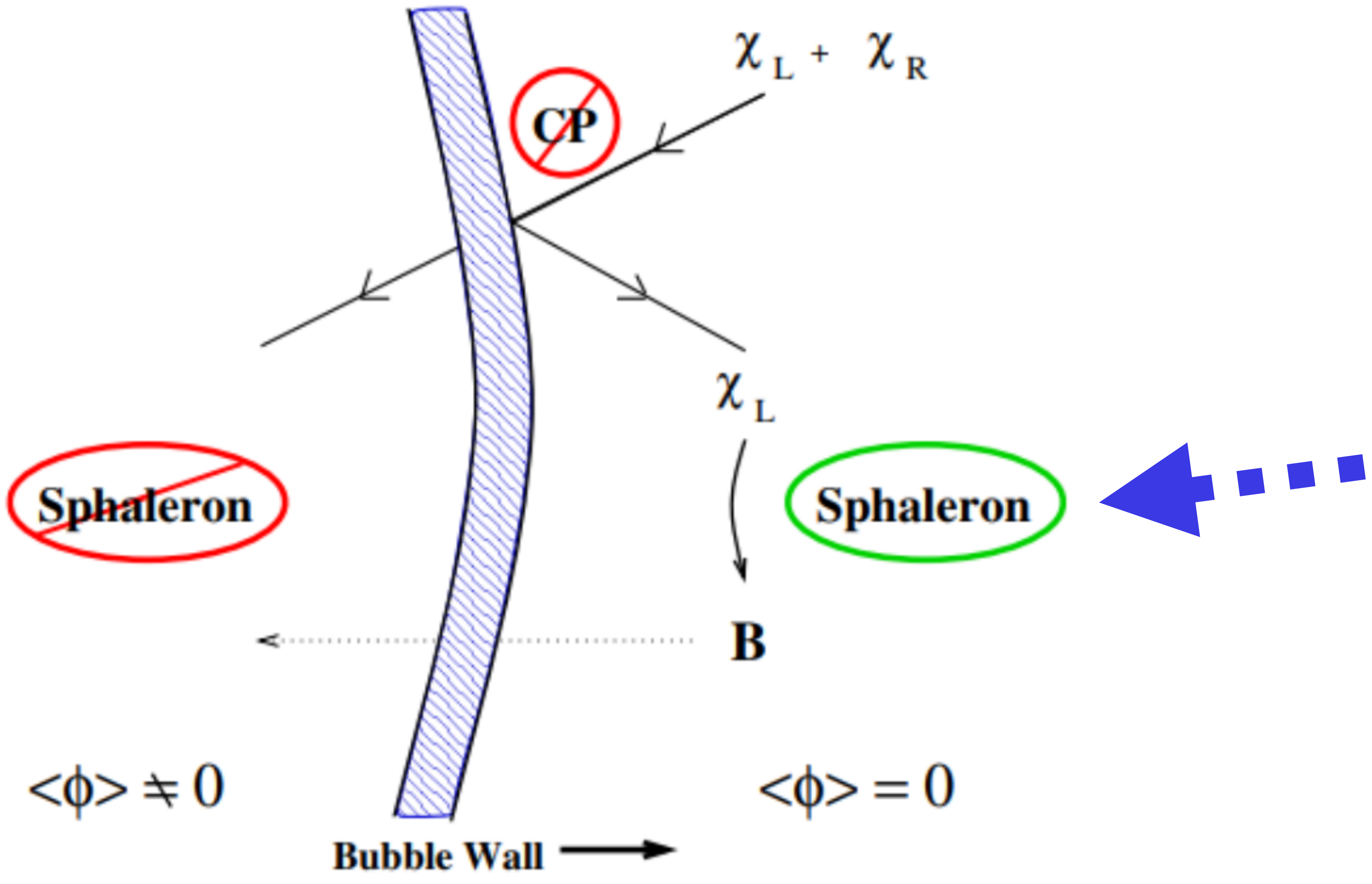

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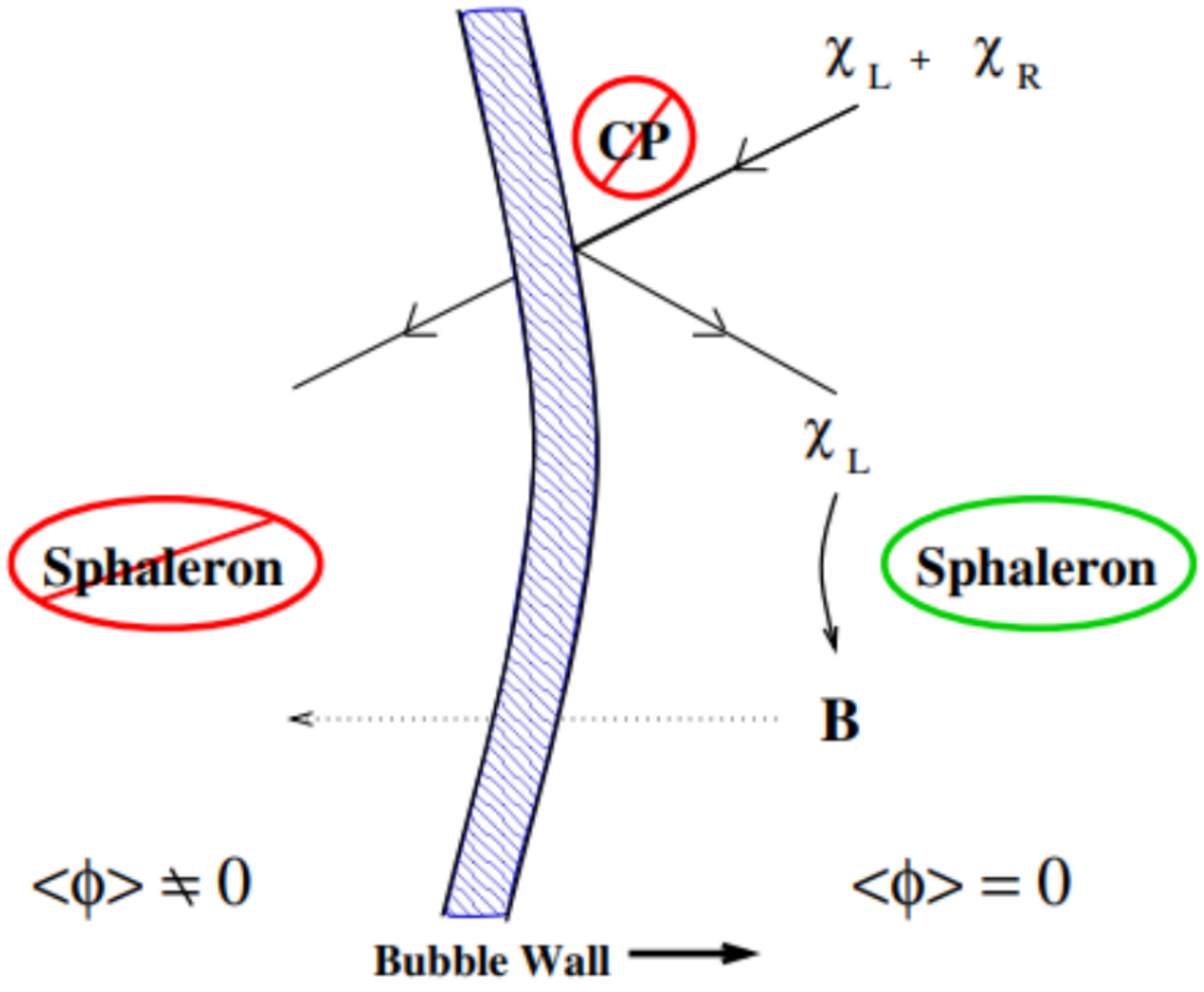

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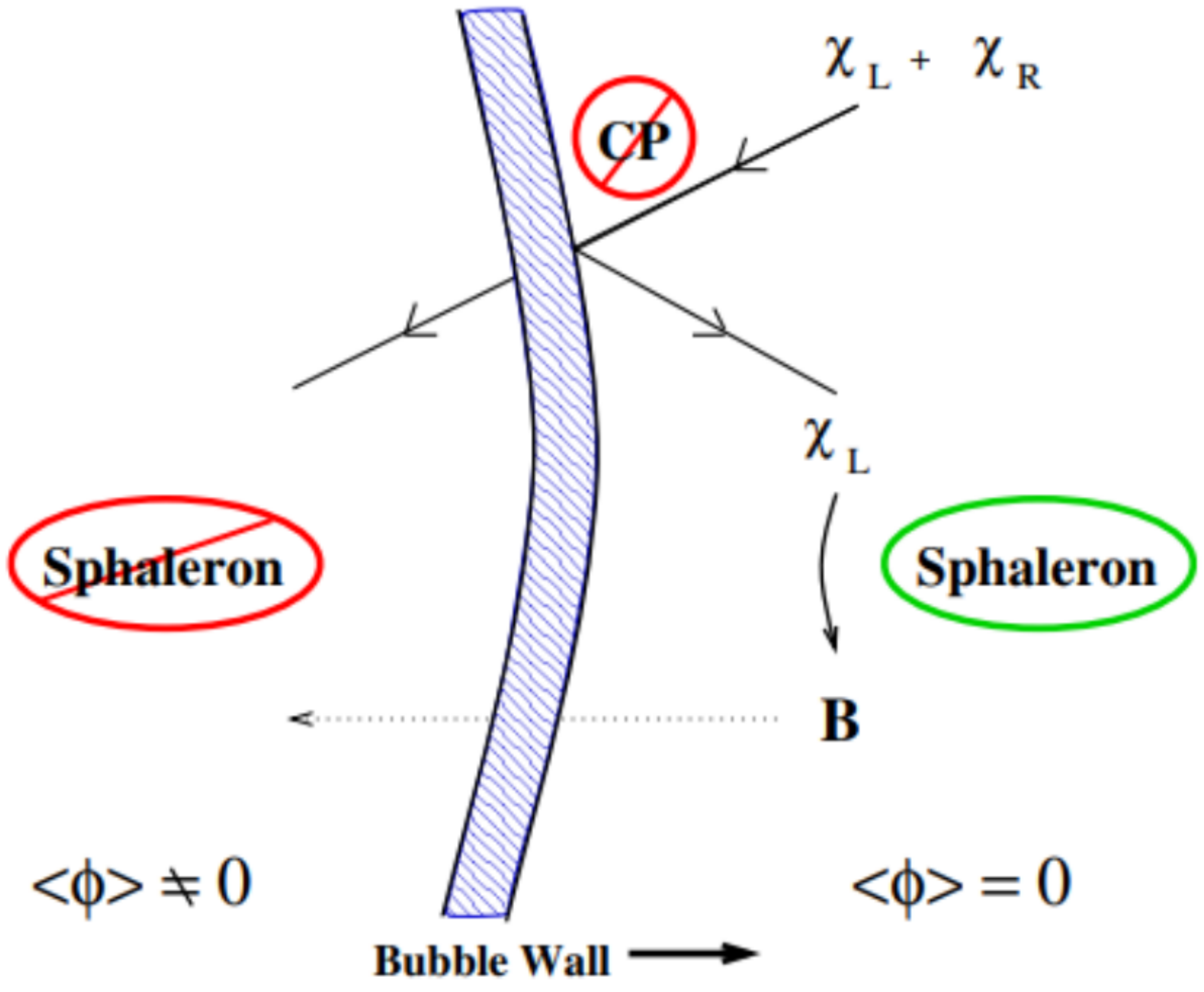

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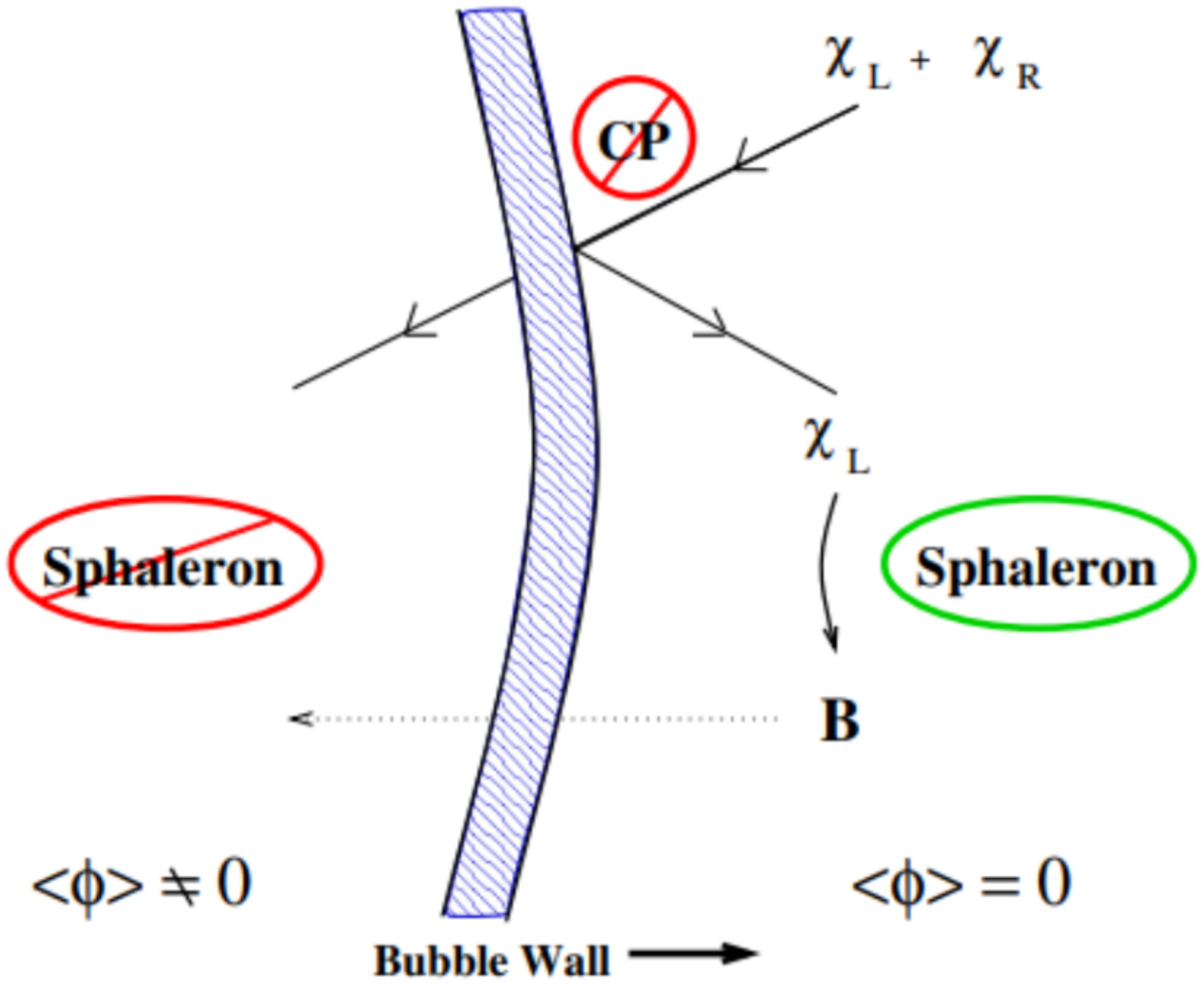

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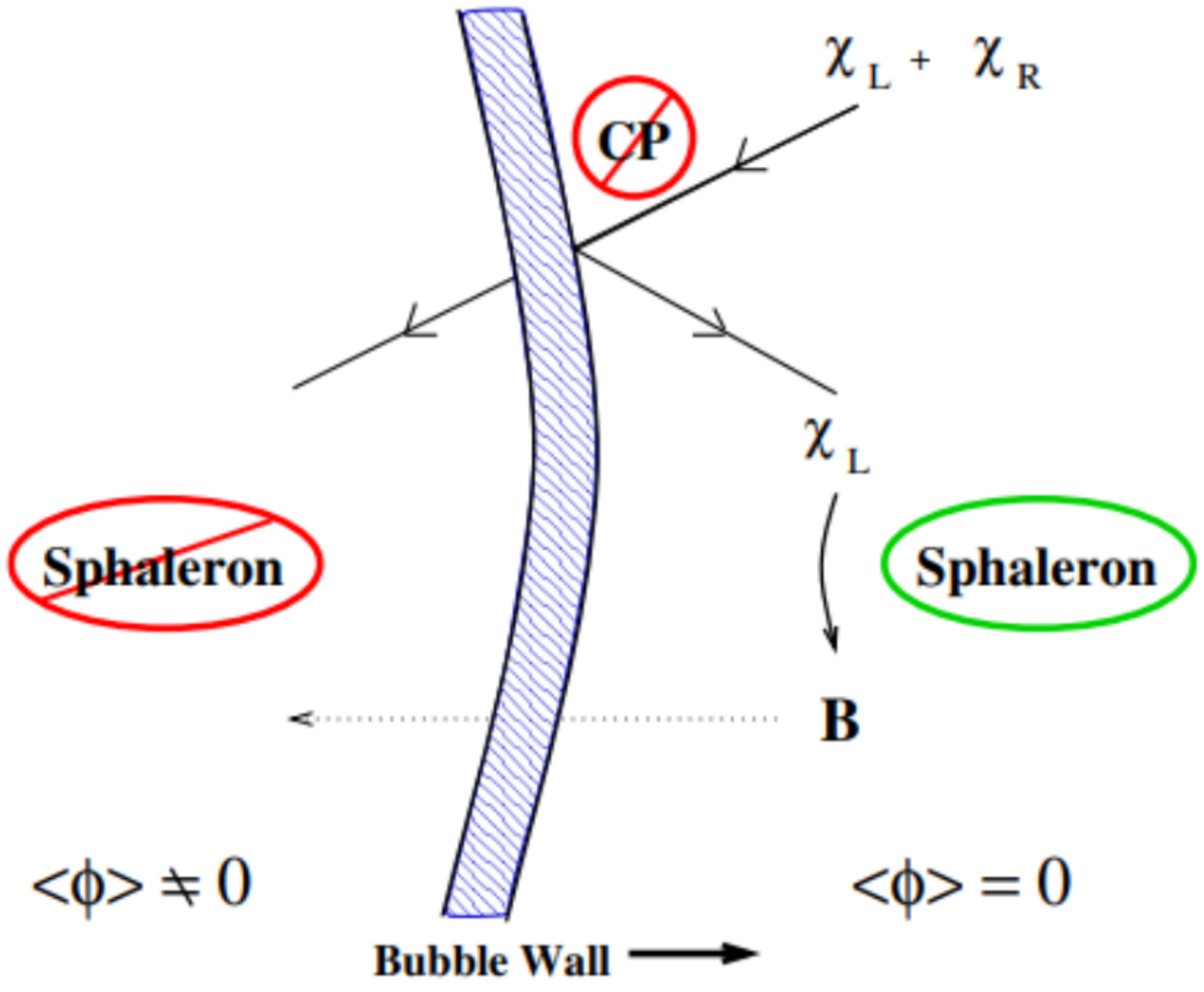

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$$\frac{\bar{v}_c(T)}{T} > \zeta_{sph} \sim 1$$

SFOEWPT in BSM: Multi-step EWPT

$$V_0(H,S) = -\mu^2(H^\dagger H) + \lambda(H^\dagger H)^2 + \frac{a_1}{2}(H^\dagger H)S + \frac{a_2}{2}(H^\dagger H)S^2 + \frac{b_2}{2}S^2 + \frac{b_3}{3}S^3 + \frac{b_4}{4}S^4,$$

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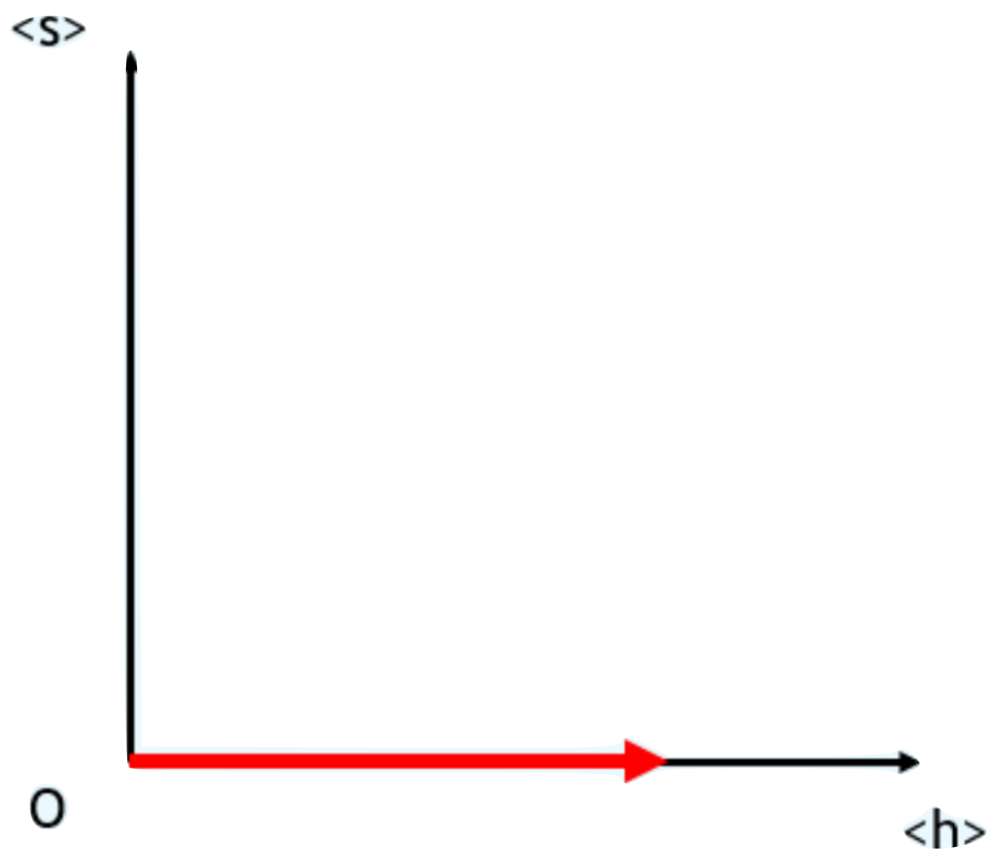

EWPT in SM

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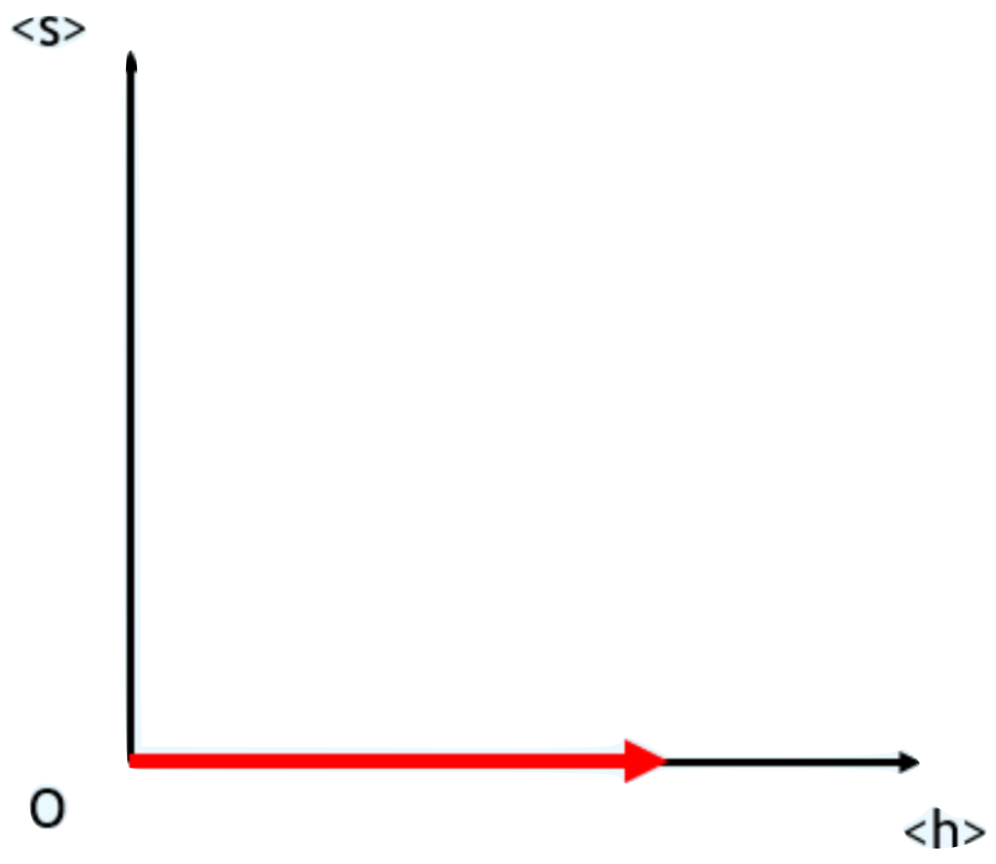

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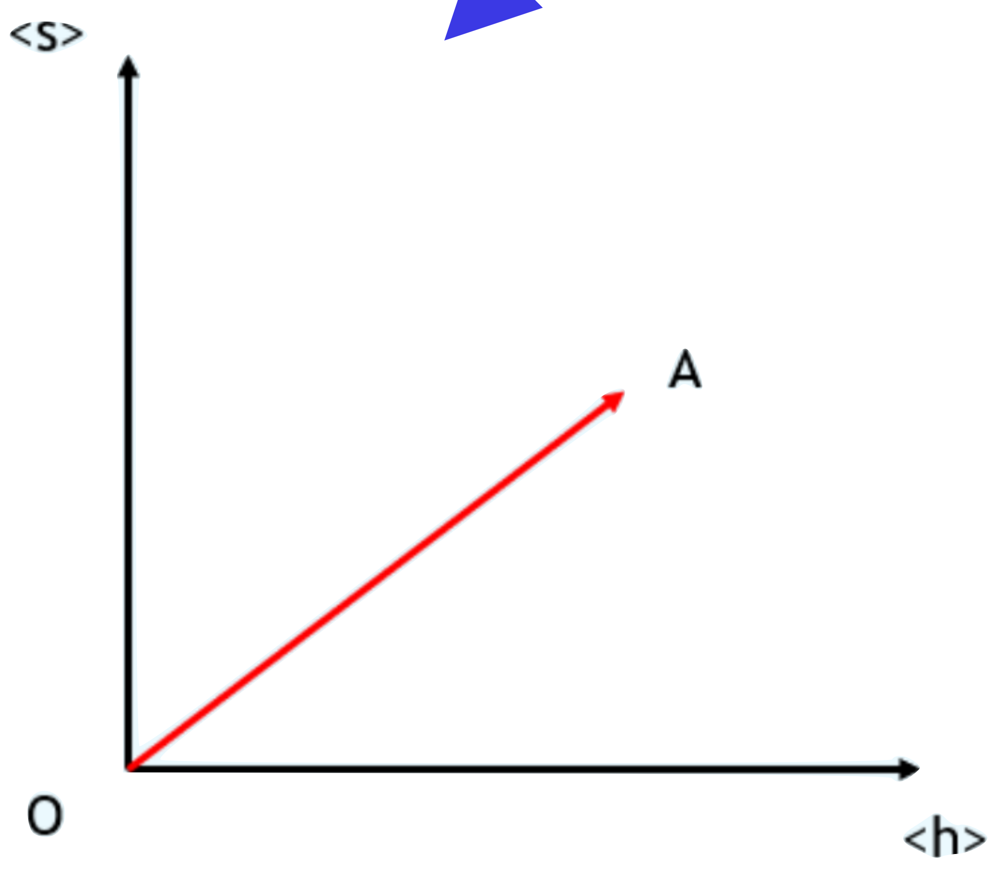

1-step EWPT in BSM

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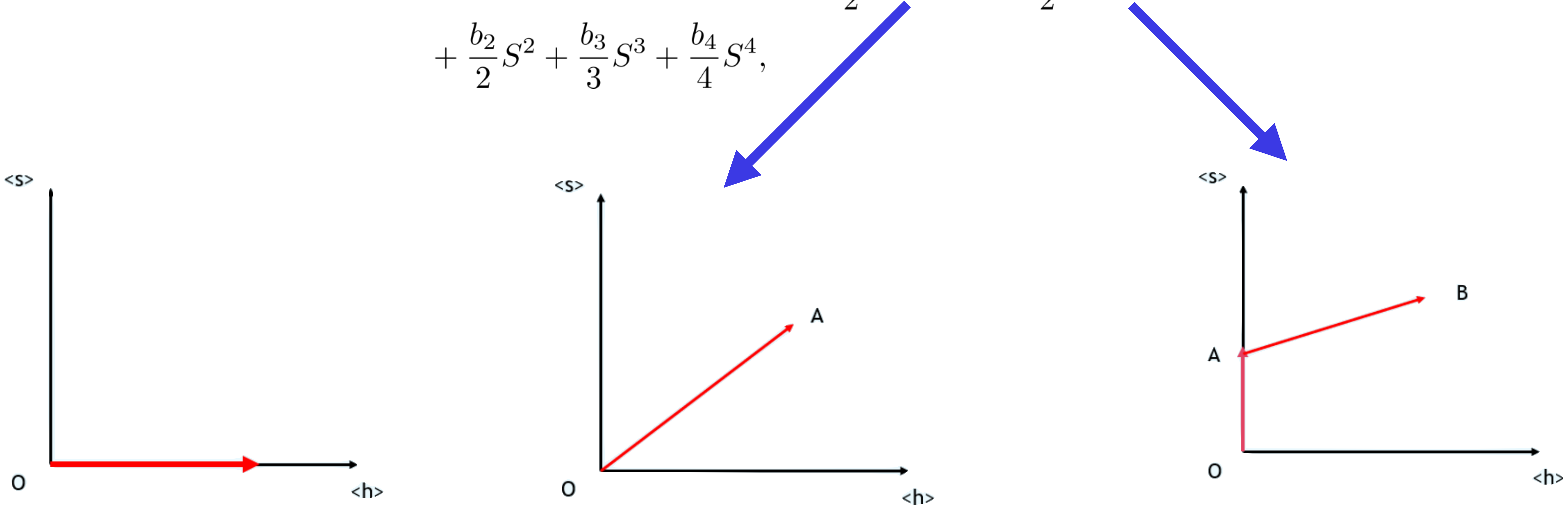

EWPT in SM

1-step EWPT in BSM

2-step EWPT in BSM

EWPT with a DM candidate: the cxSM

$$V_0(H,S) = \frac{\mu^2}{2}(H^\dagger H) + \frac{\lambda}{4}(H^\dagger H)^2 + \frac{\delta_2}{2}H^\dagger H|S|^2 + \frac{b_2}{2}|S|^2 + \frac{d_2}{4}|S|^4 + a_1 S + \frac{b_1}{4}S^2 + h.c..$$

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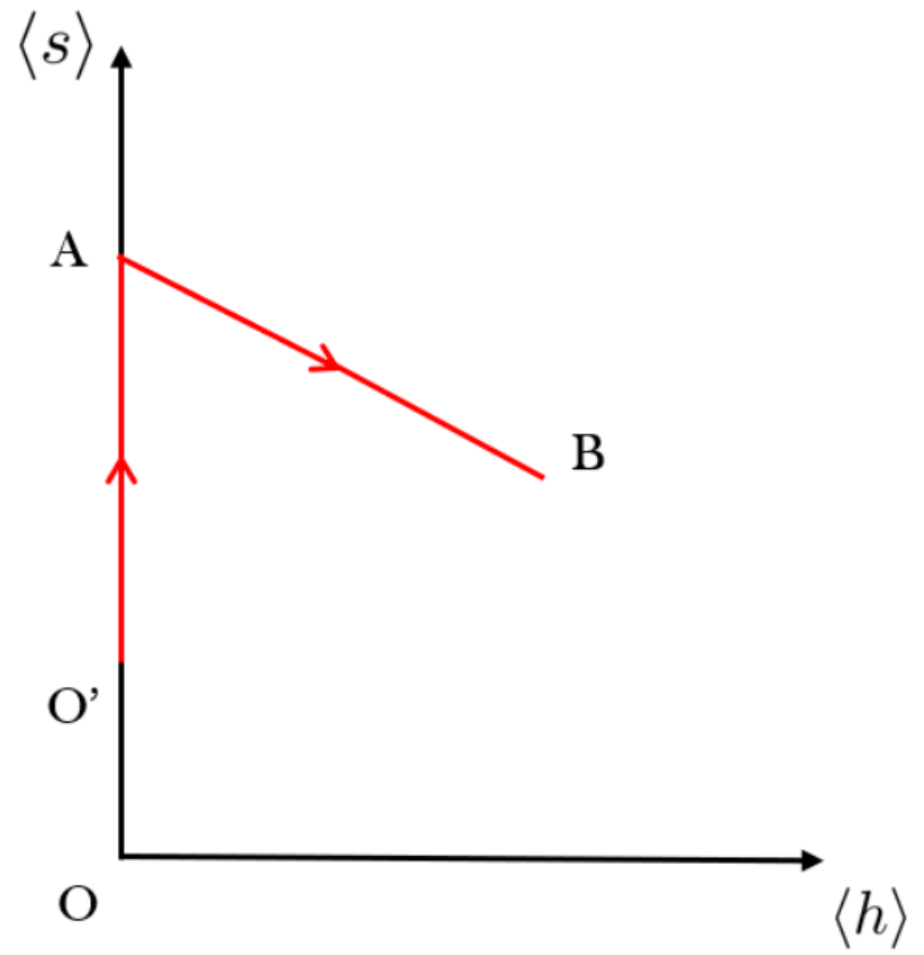

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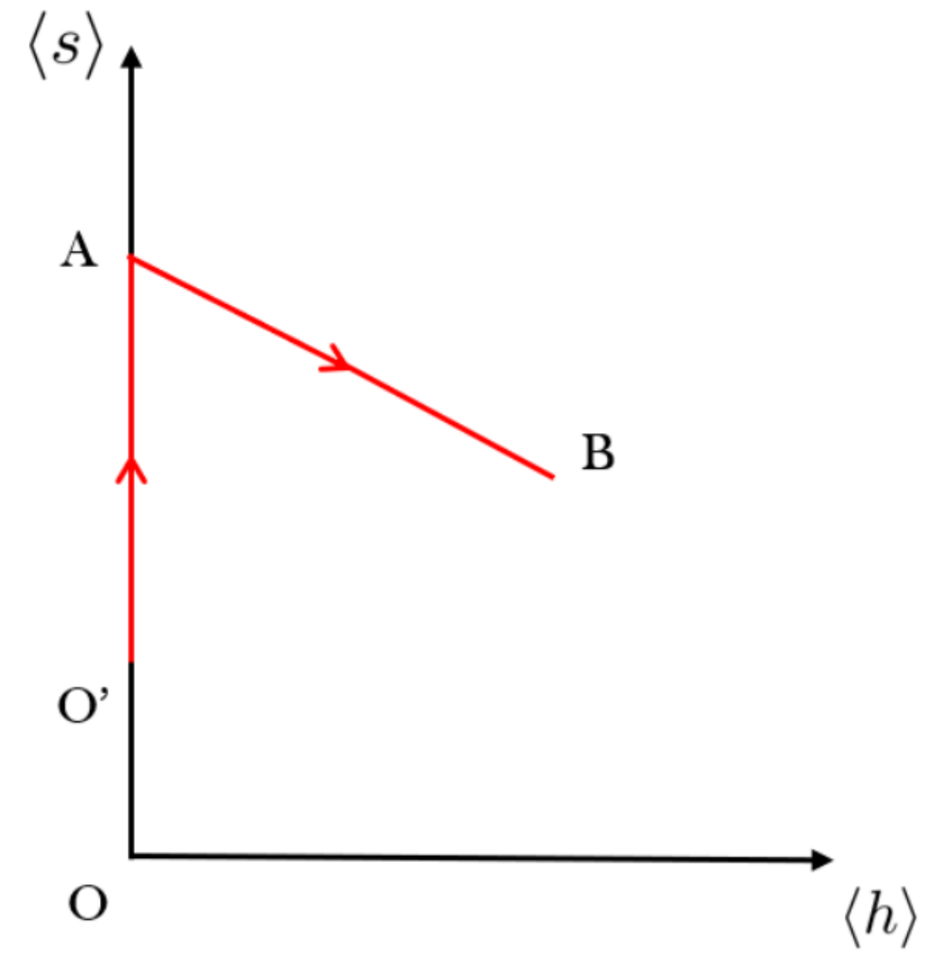

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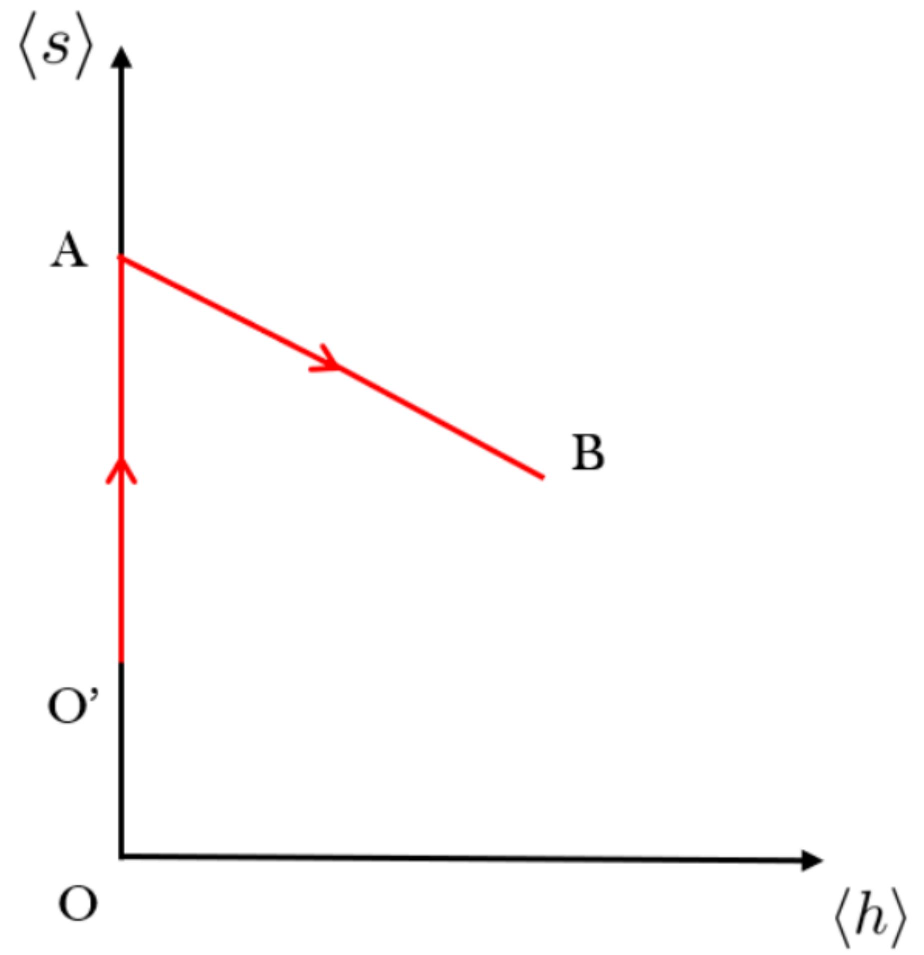
$S = x_0 + s + iA$



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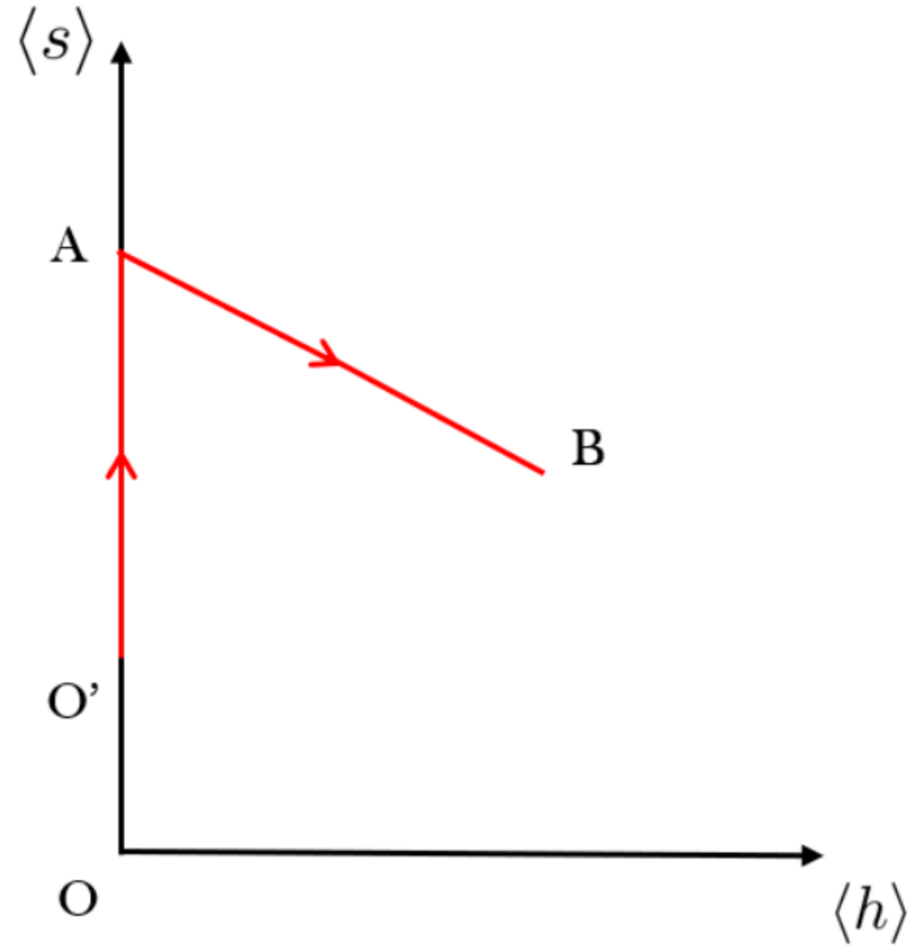

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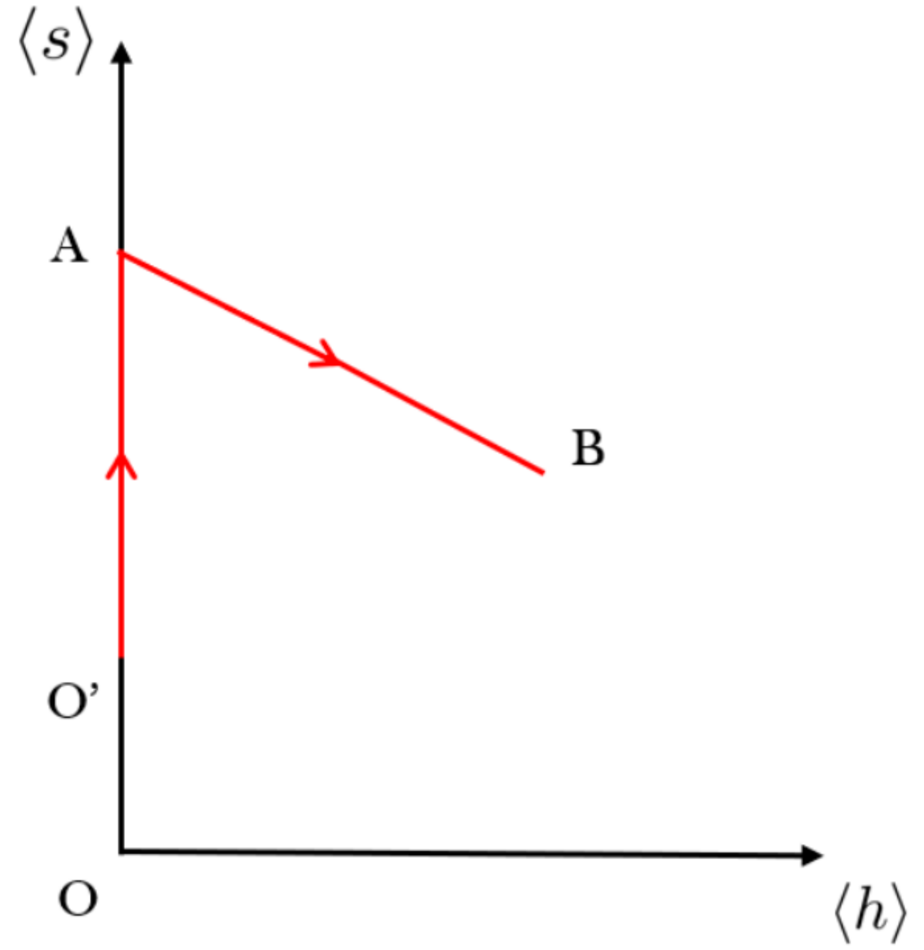
AVOID DOMAIN WALL PROBLEM
EWPT STRENGTH



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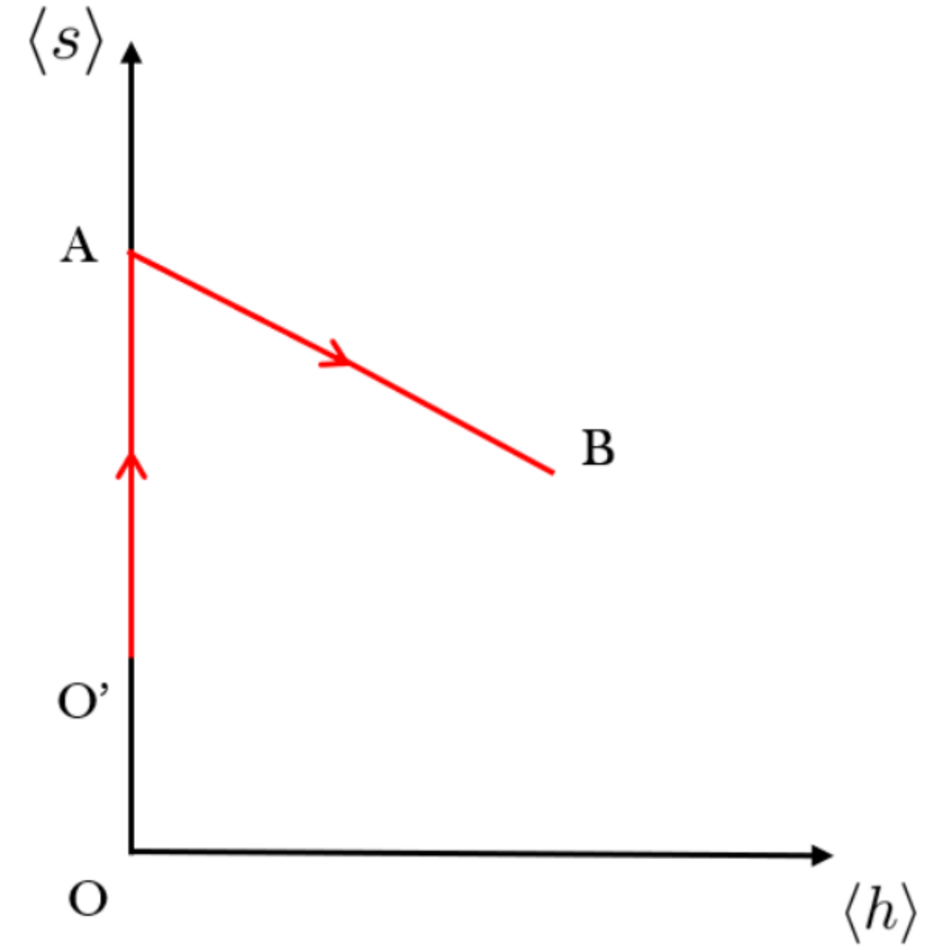
U(1) SSB: MASSIVE PSEUDO-GOLDSTONE BOSON

AVOID DOMAIN WALL PROBLEM
EWPT STRENGTH



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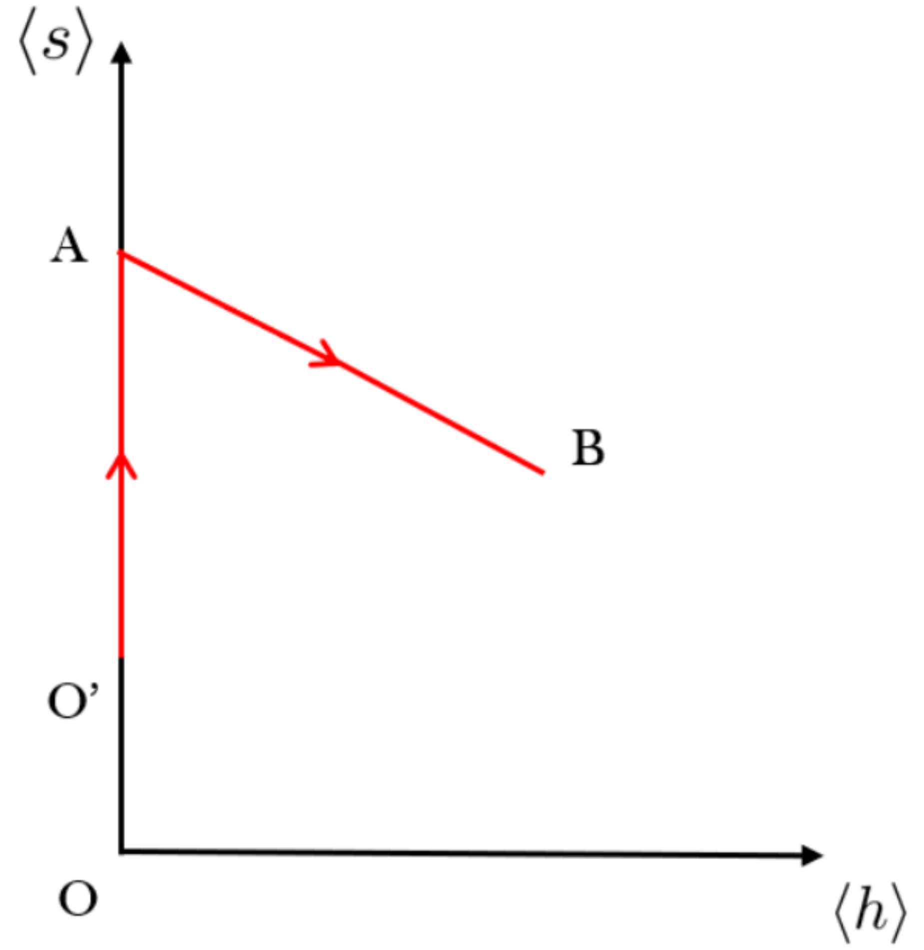

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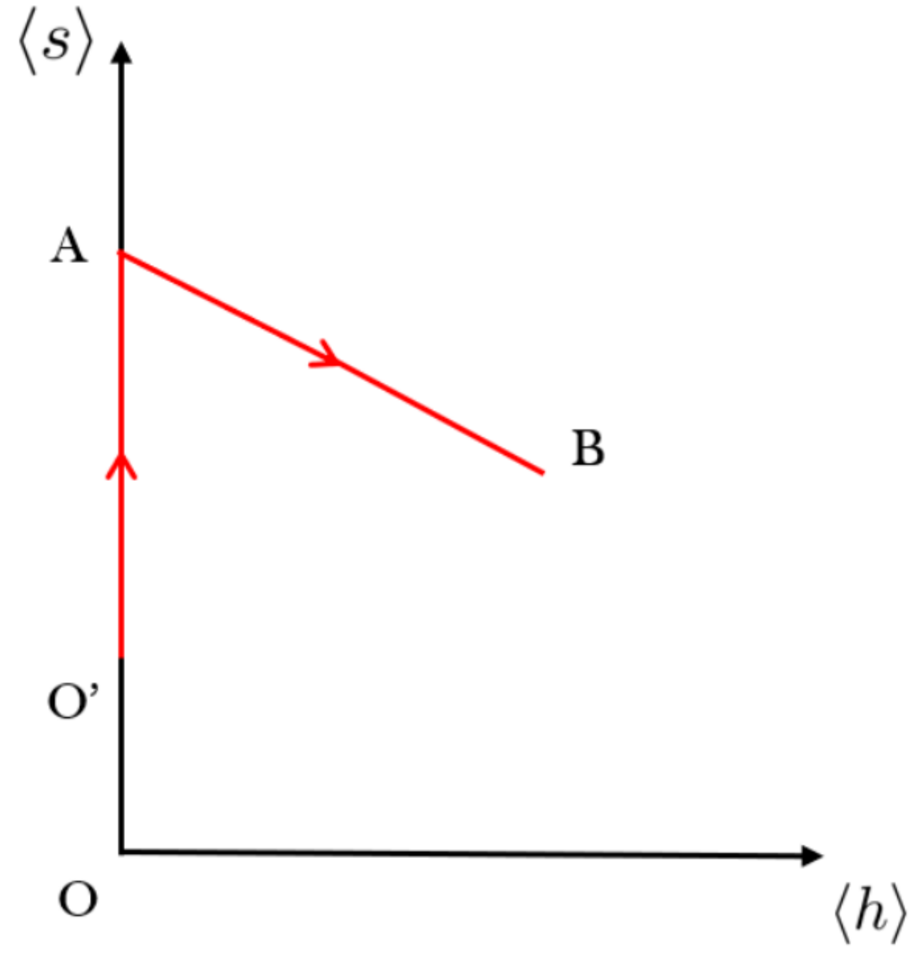

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AVOID DOMAIN WALL PROBLEM
EWPT STRENGTH

MIXING & EWPT

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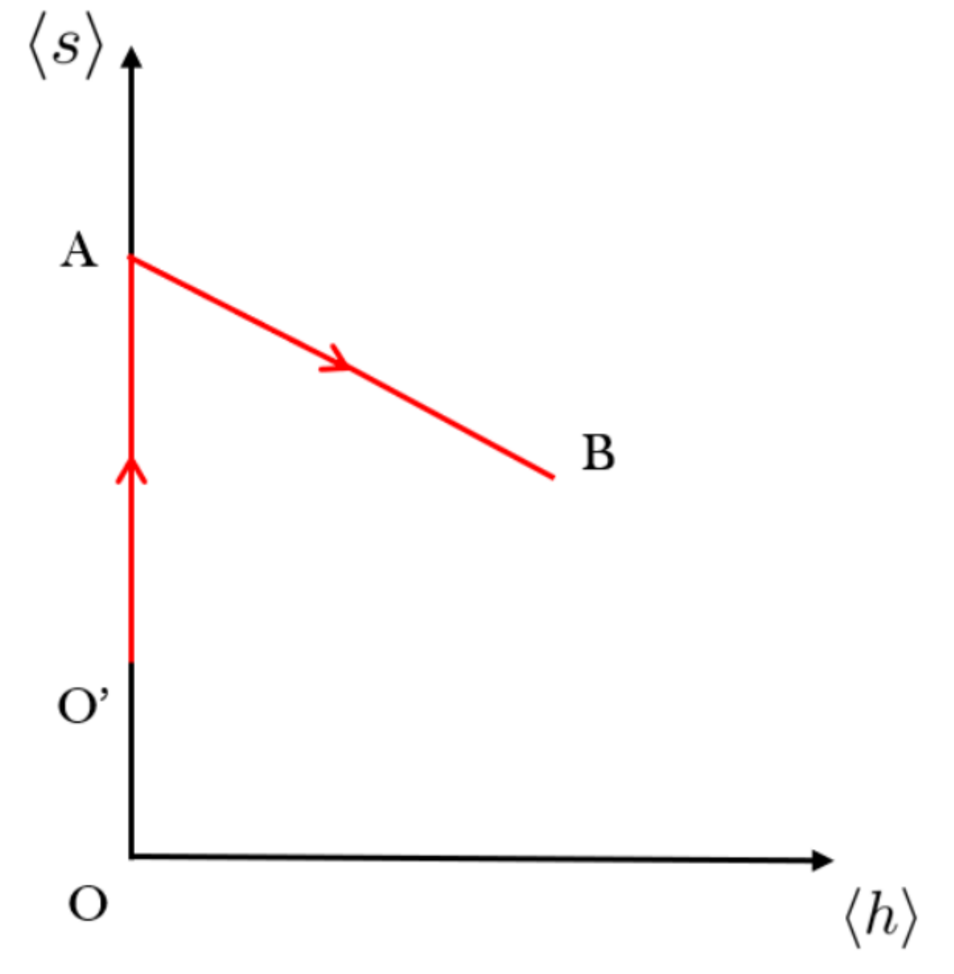

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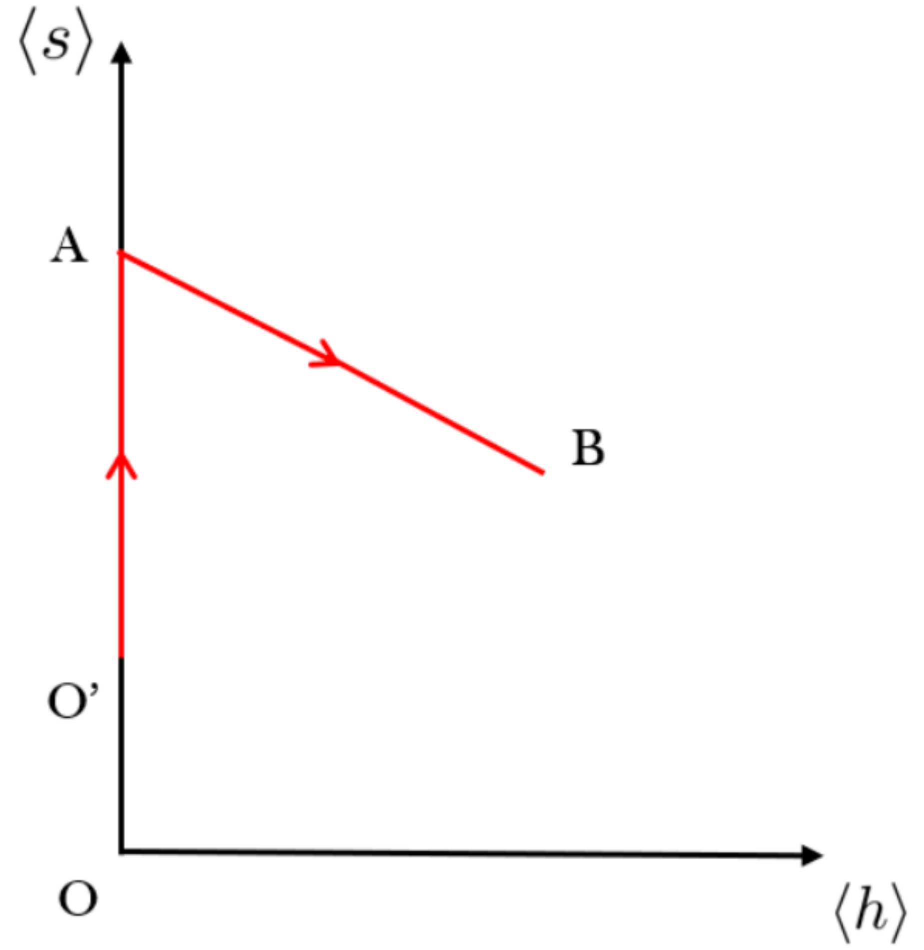
AVOID DOMAIN WALL PROBLEM
EWPT STRENGTH



Theoretical Constraints : Vacuum Stability & Perturbation

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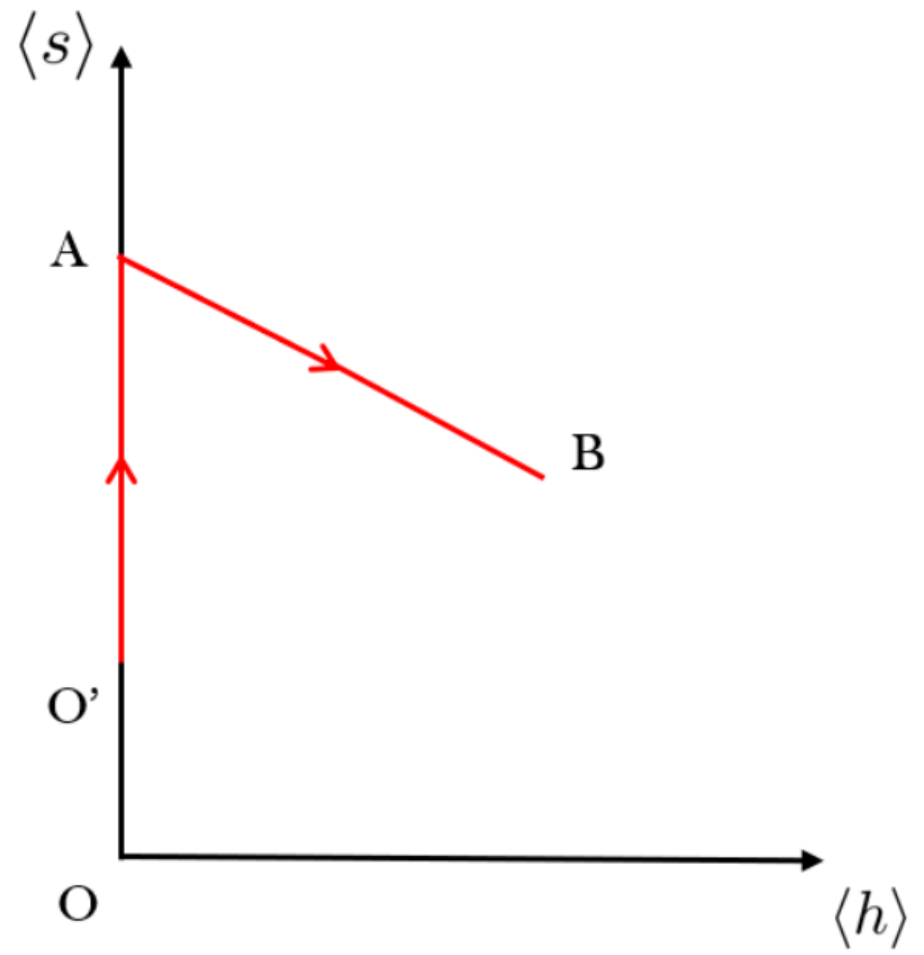
EWPT STRENGTH



QUARTIC COUPLINGS & STRENGTH OF EWPT

Theoretical Constraints : Vacuum Stability & Perturbation

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$U(1)$

Z_2

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AVOID DOMAIN WALL PROBLEM
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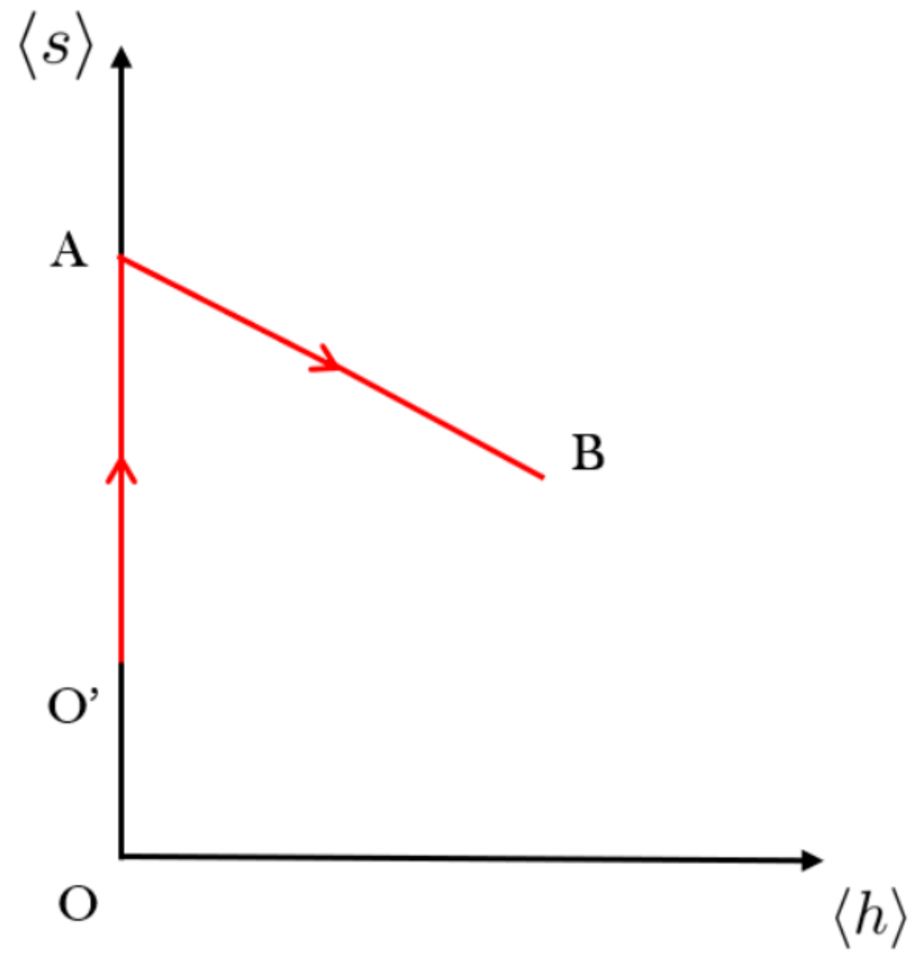

QUARTIC COUPLINGS & STRENGTH OF EWPT

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Experimental Constraints : EW Precision Observables & Higgs Measurement

EWPT with a DM candidate: the cxSM

$$V_0(H,S) = \frac{\mu^2}{2}(H^\dagger H) + \frac{\lambda}{4}(H^\dagger H)^2 + \frac{\delta_2}{2} H^\dagger H |S|^2 + \frac{b_2}{2}|S|^2 + \frac{d_2}{4}|S|^4 + a_1 S + \frac{b_1}{4} S^2 + h.c..$$

$U(1)$

Z_2

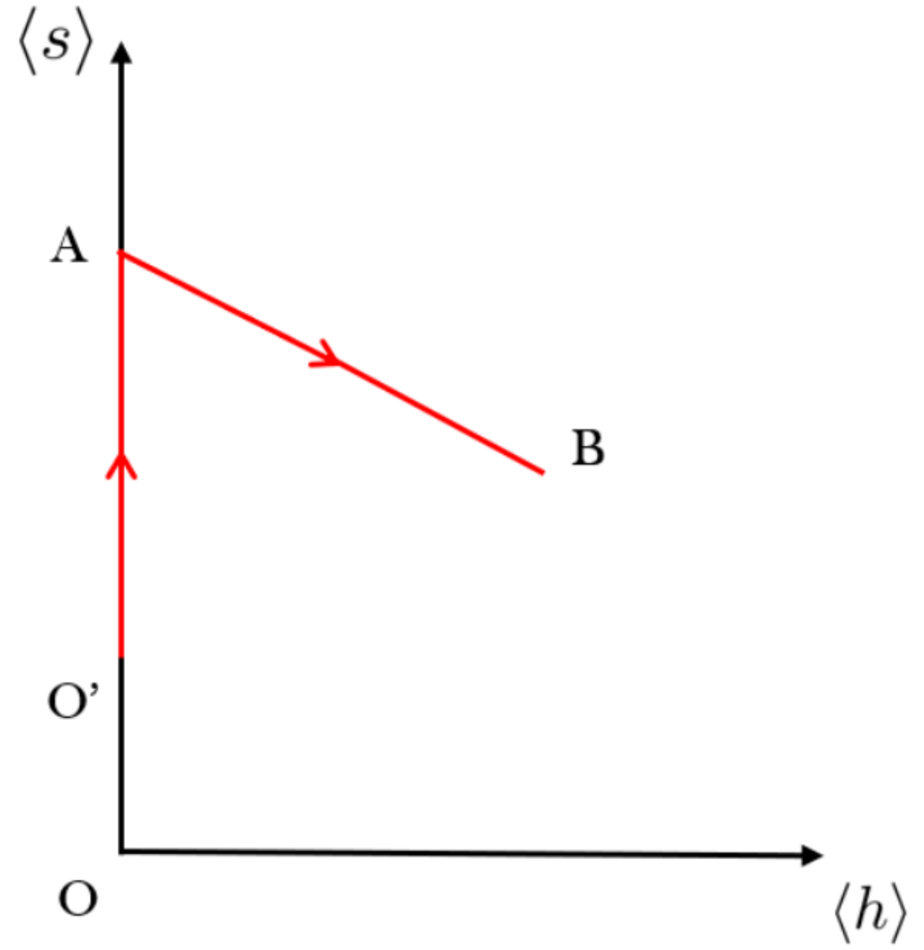
MIXING & EWPT

$$\mathcal{M}_h^2 \equiv \begin{pmatrix} M_{hh} & M_{hs} & M_{hA} \\ M_{sh} & M_{ss} & M_{sA} \\ M_{Ah} & M_{As} & M_{AA} \end{pmatrix} = \begin{pmatrix} \frac{1}{2}\lambda v_0^2 & \frac{\delta_2}{2} v_0 v_s & 0 \\ \frac{\delta_2}{2} v_0 v_s & \frac{1}{2} d_2 v_s^2 - \frac{\sqrt{2} a_1}{v_s} & 0 \\ 0 & 0 & -\frac{\sqrt{2} a_1}{v_s} - b_1 \end{pmatrix}$$

$S = x_0 + s + iA$

U(1) SSB: MASSIVE PSEUDO-GOLDSTONE BOSON

AVOID DOMAIN WALL PROBLEM
EWPT STRENGTH



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MIXING ANGLE & DM & HEAVY HIGGS MASS & EWPT & COLLIDER

Constraints: W mass measurement

$$\Delta\mathcal{O} = (\cos^2\theta - 1)\mathcal{O}^{\rm SM}(m_{h_1}) + \sin^2\theta\mathcal{O}^{\rm SM}(m_{h_2}) = \sin^2\theta\left[\mathcal{O}^{\rm SM}(m_{h_2}) - \mathcal{O}^{\rm SM}(m_{h_1})\right]$$

$$\Delta S = 0.086 \pm 0.077,$$
$$\Delta T = 0.177 \pm 0.070$$

$$\rho_{ij} = \begin{pmatrix} 1 & 0.89 \\ 0.89 & 1 \end{pmatrix}.$$

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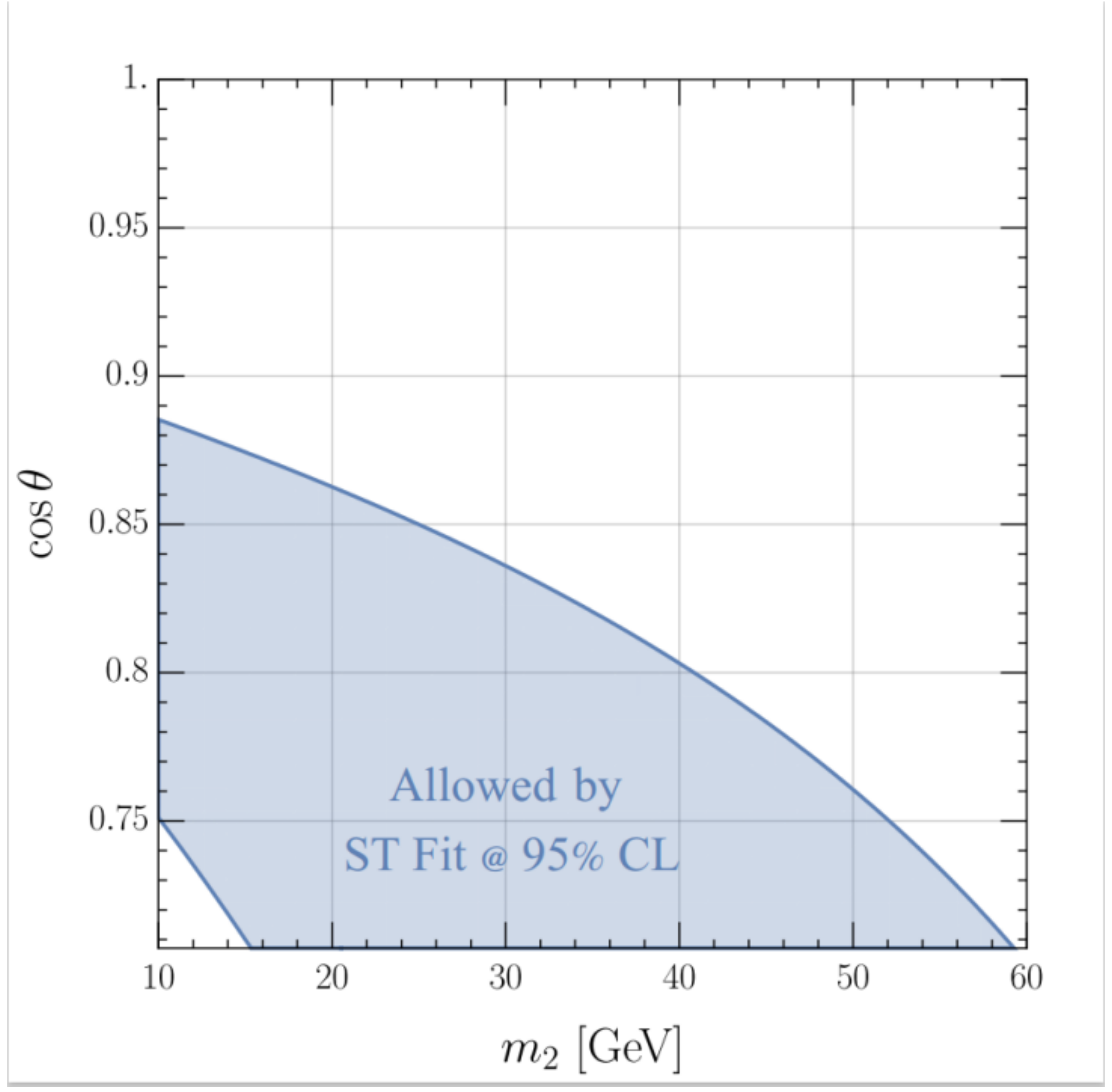

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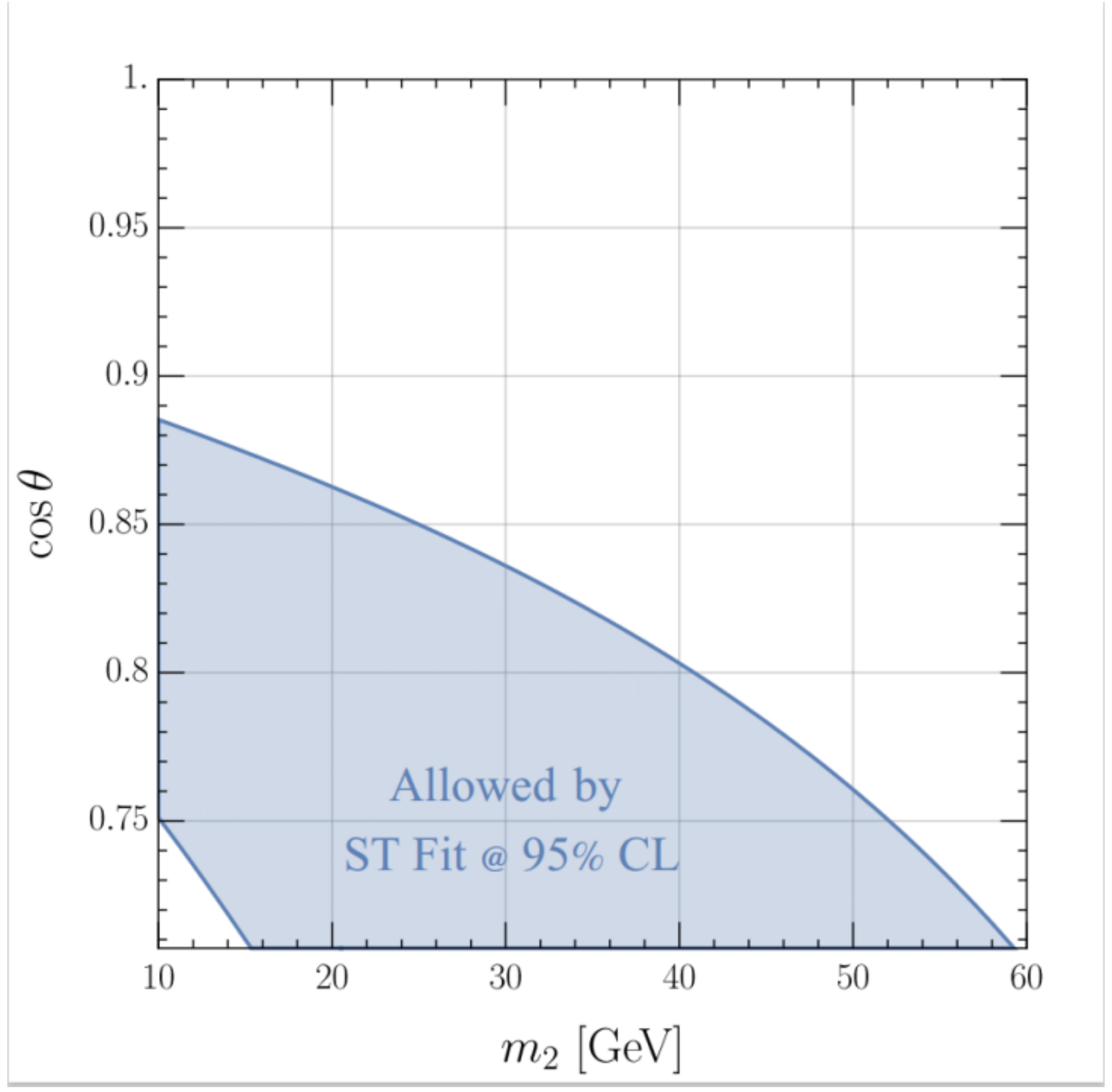

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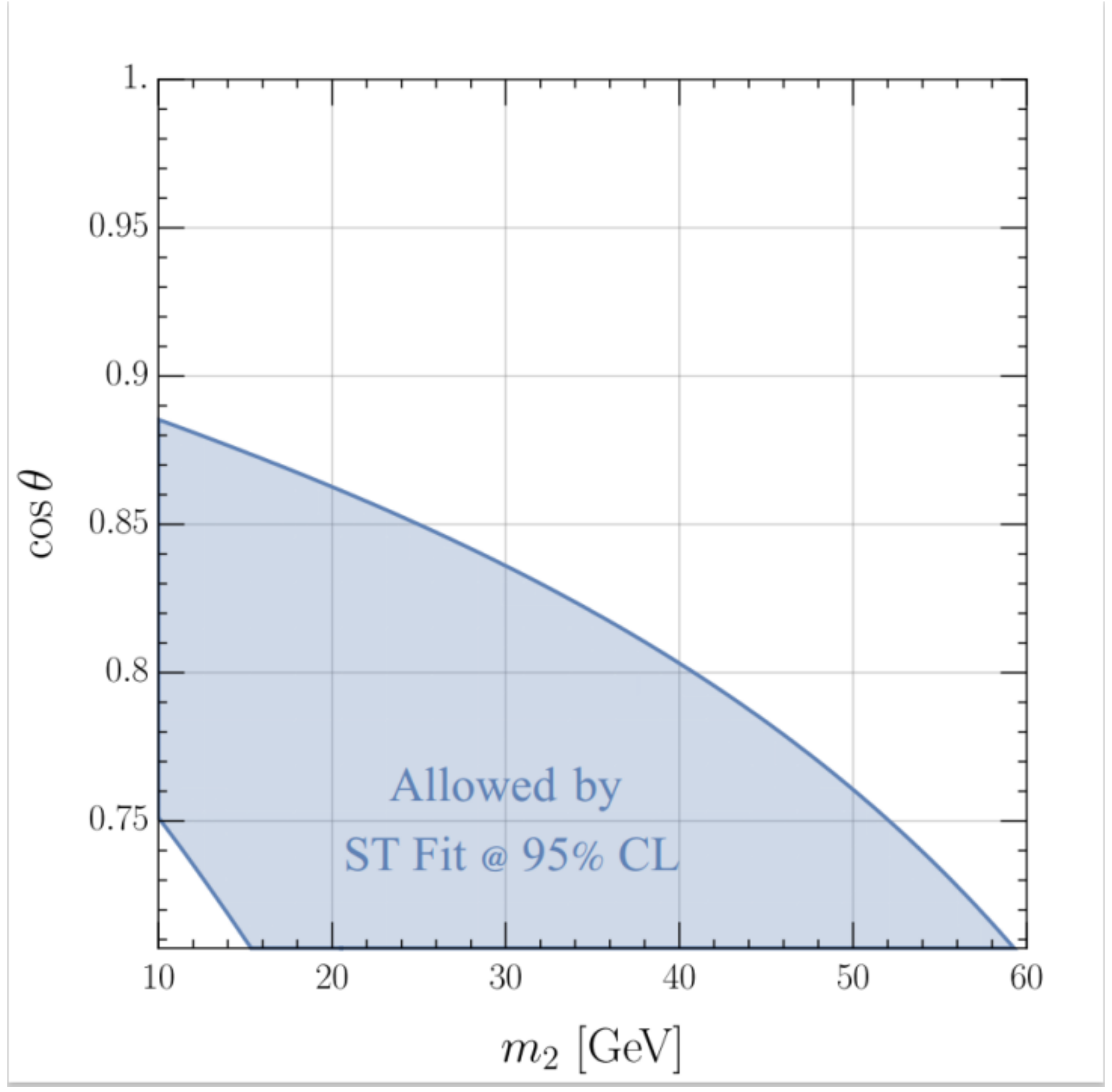

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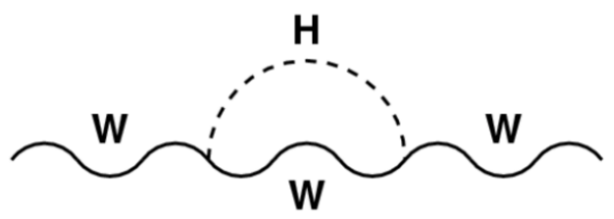

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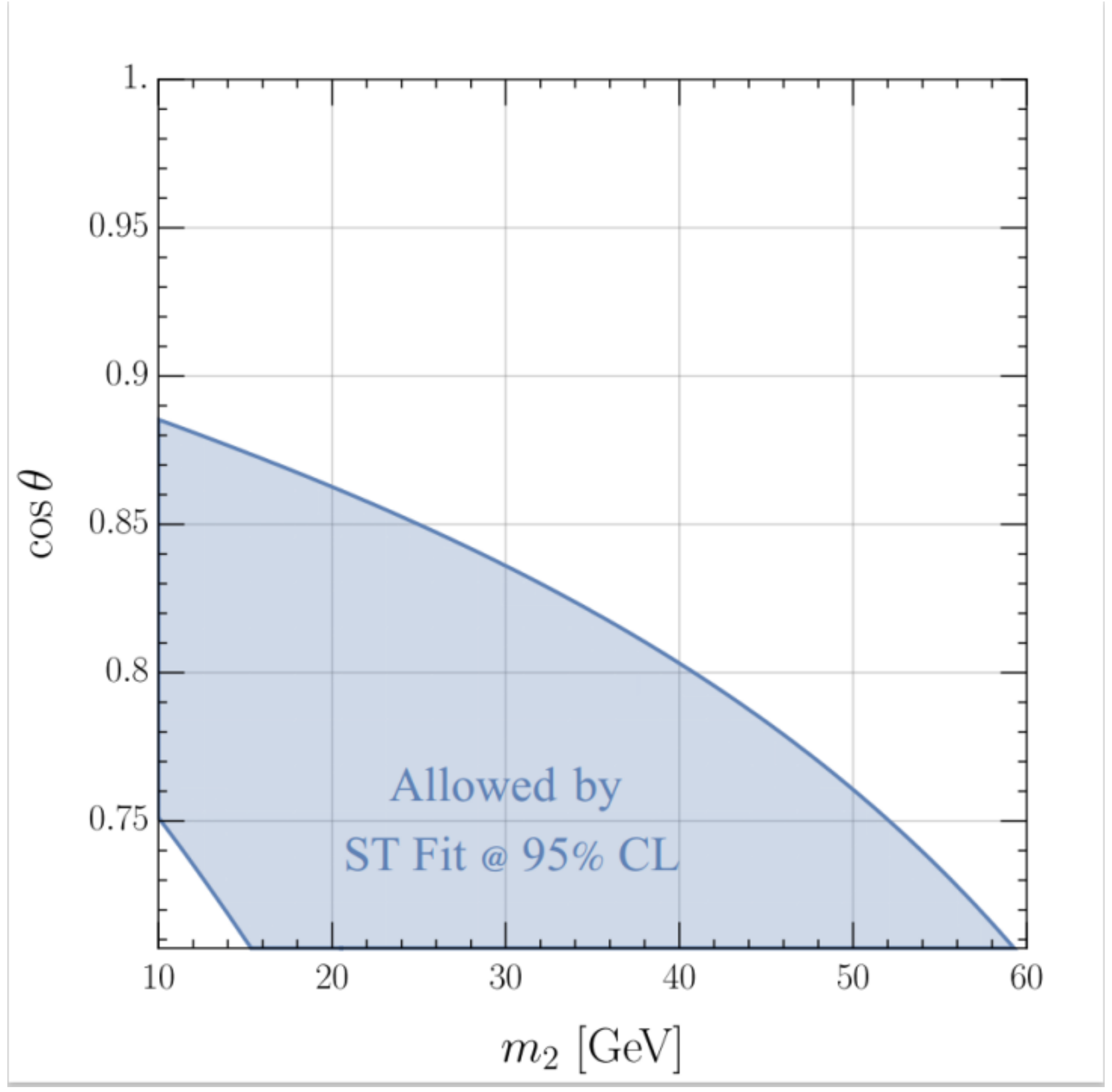

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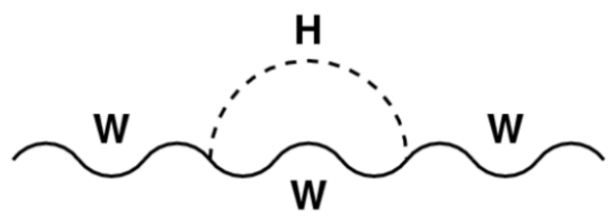

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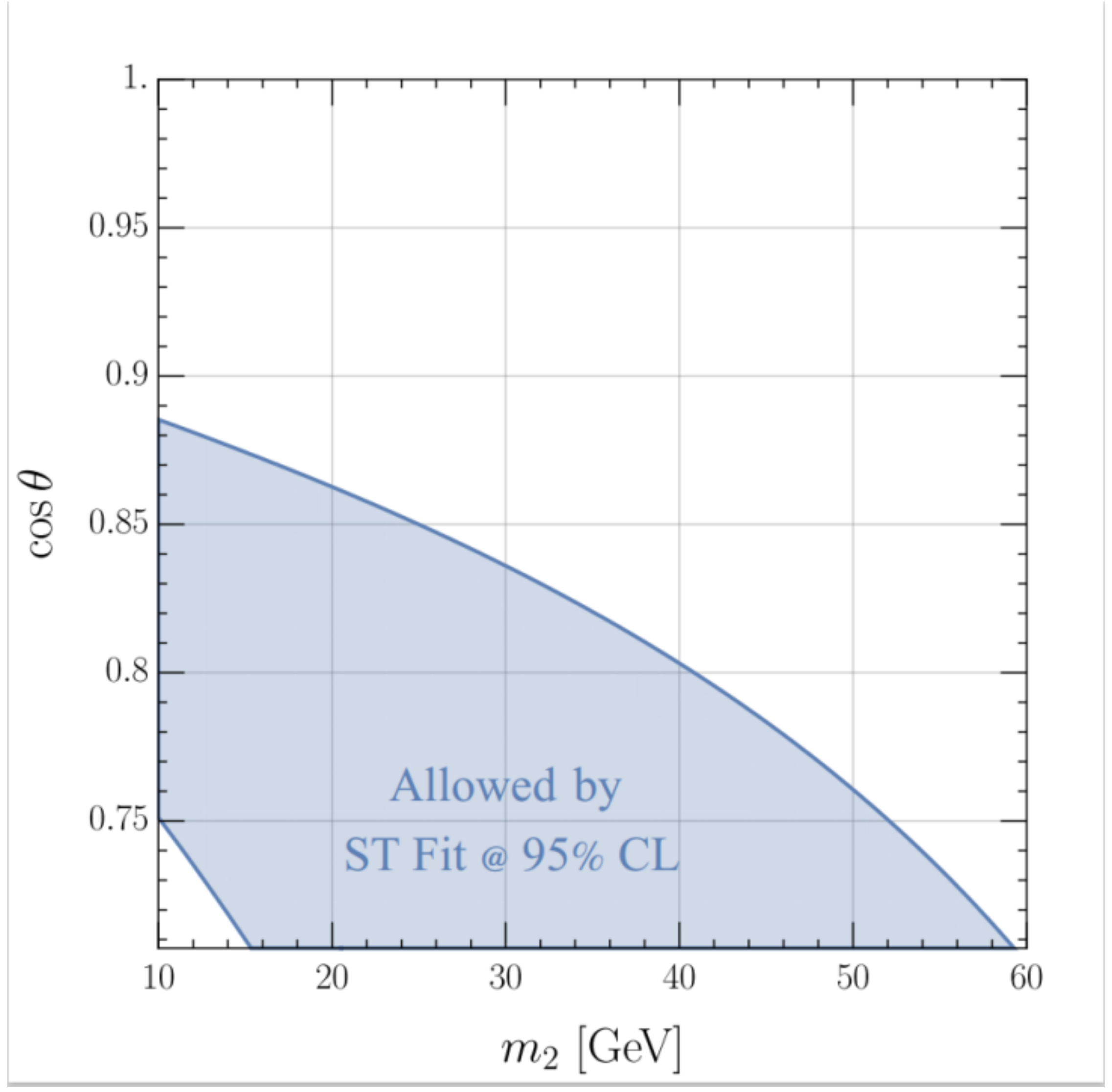

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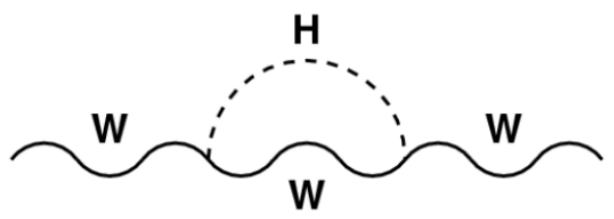

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The answer is NO!!

This is not a UV complete model

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Eur.Phys.J.C 78 (2018) 8

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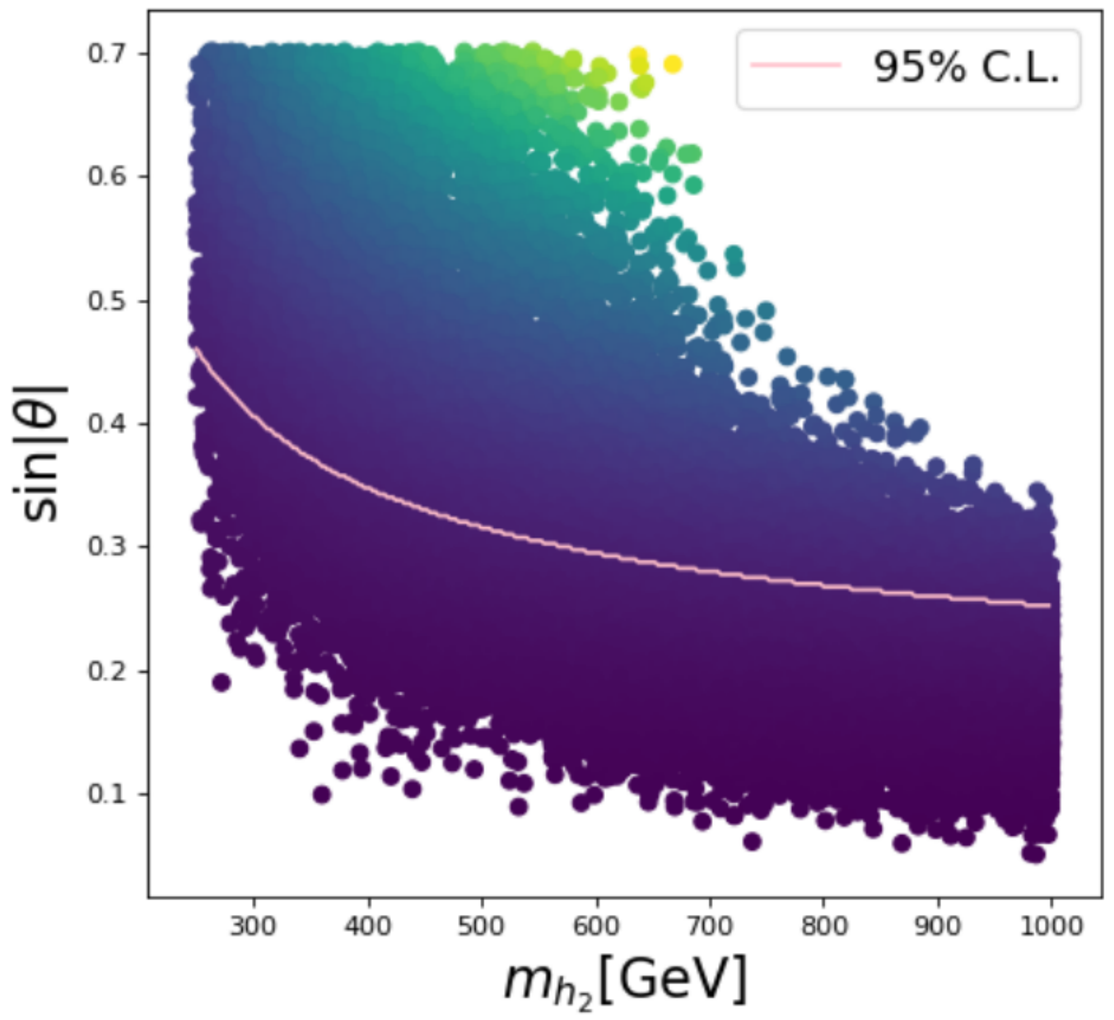

JHEP 01 (2024) 051,
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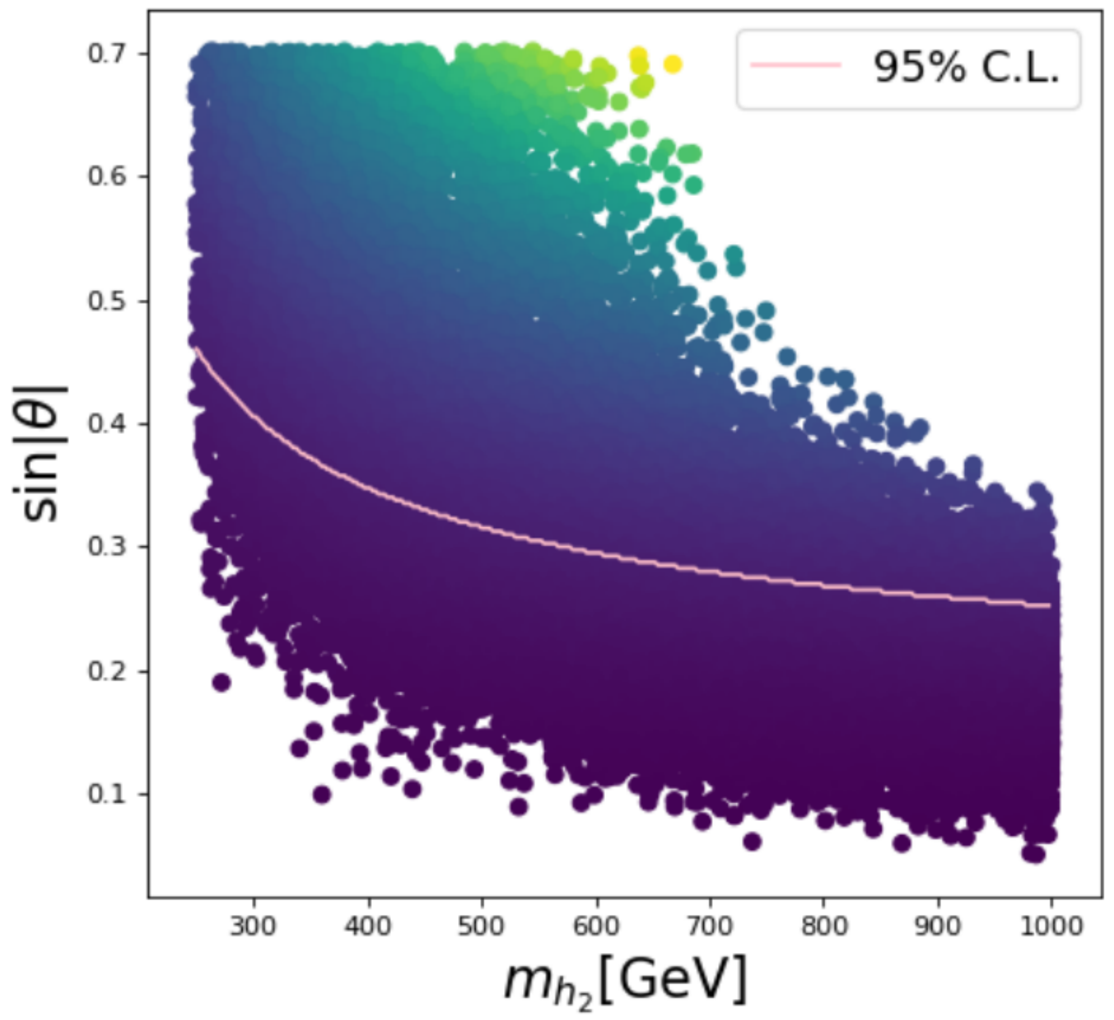

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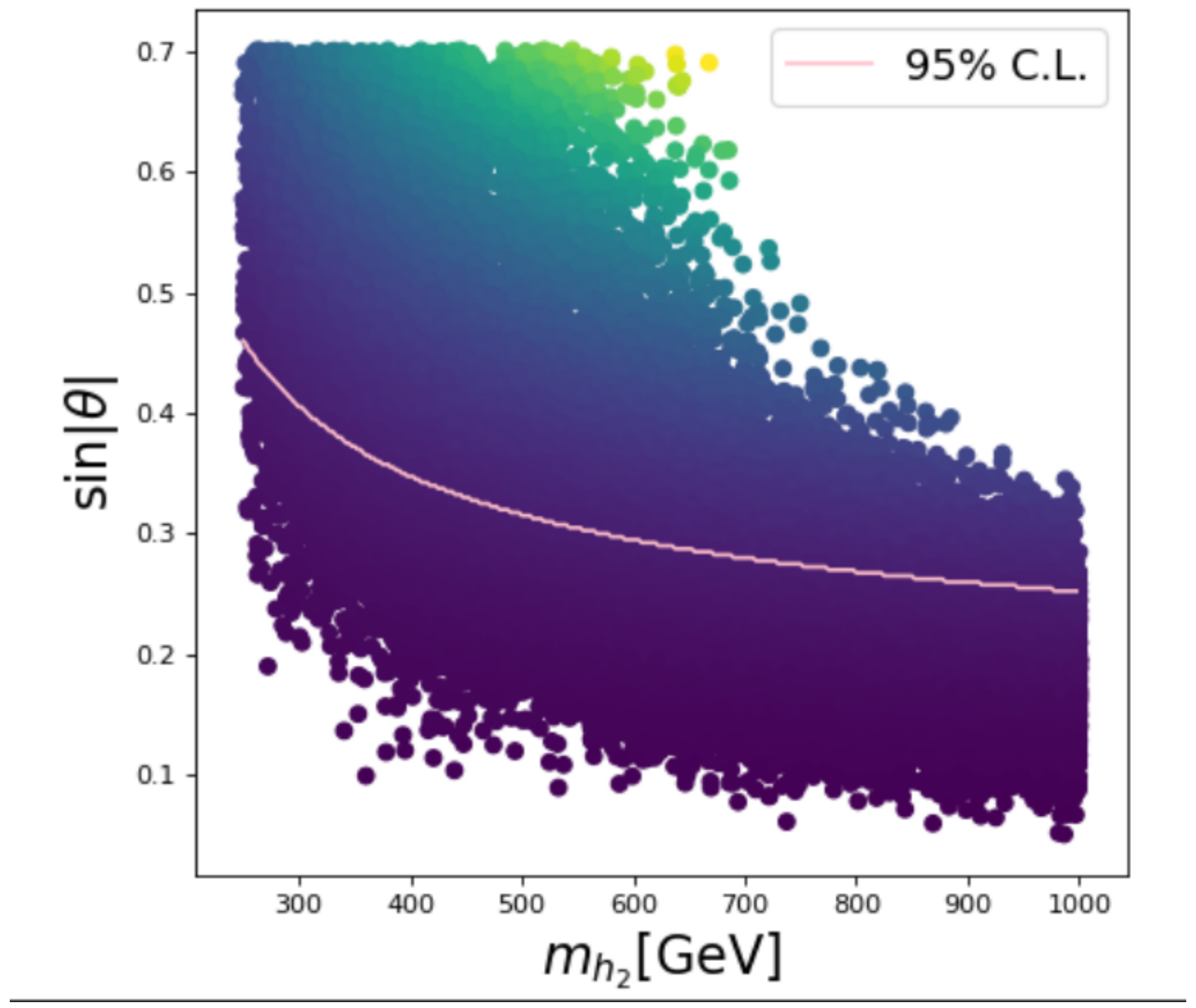

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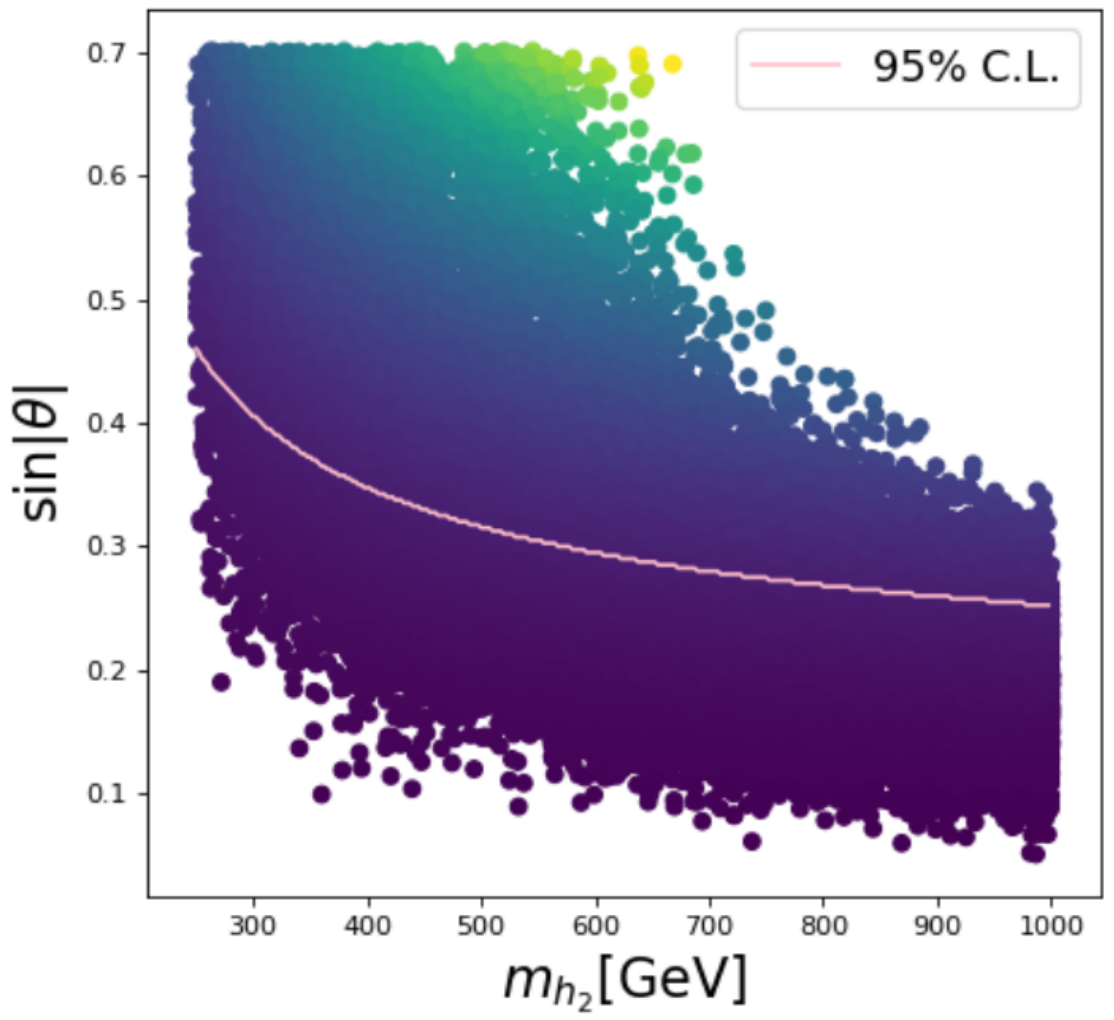

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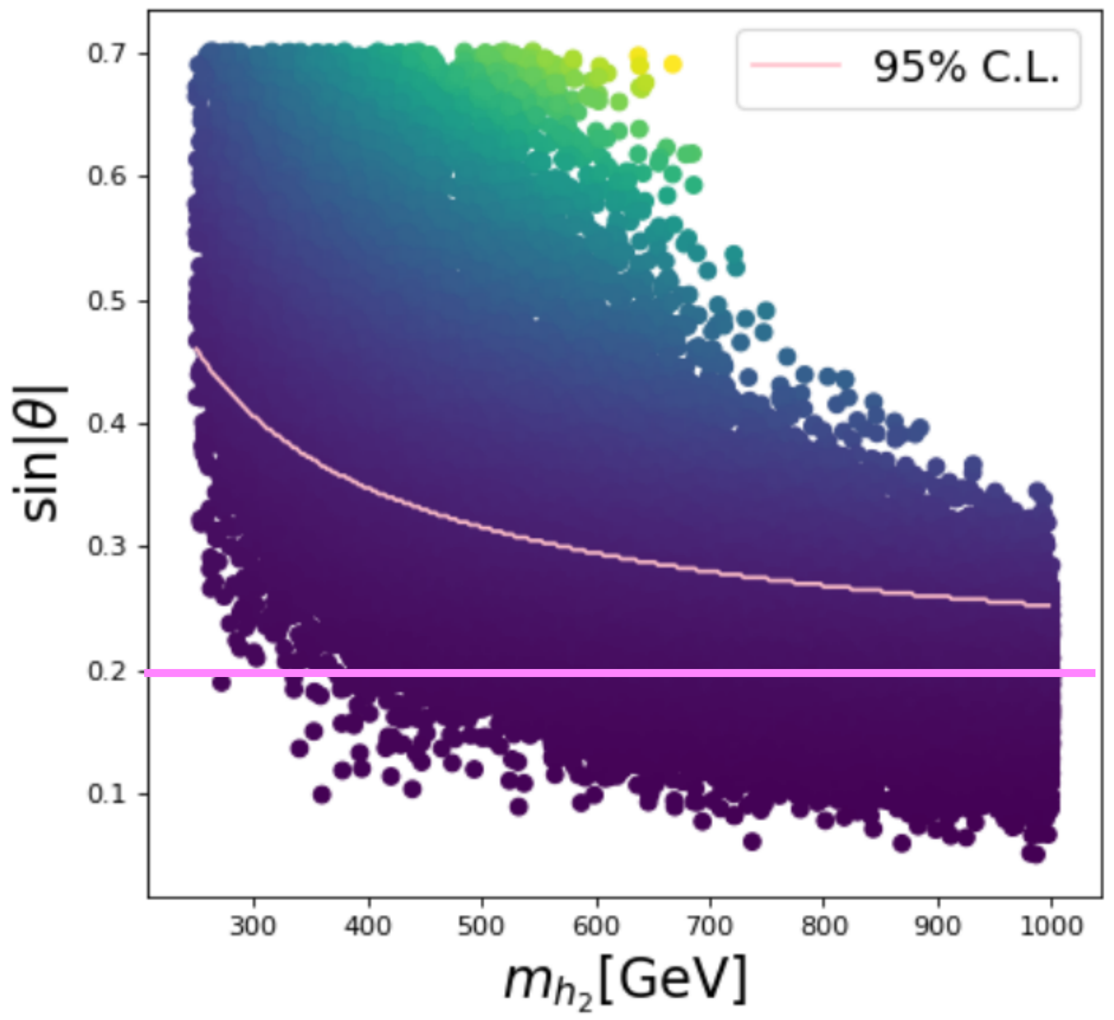

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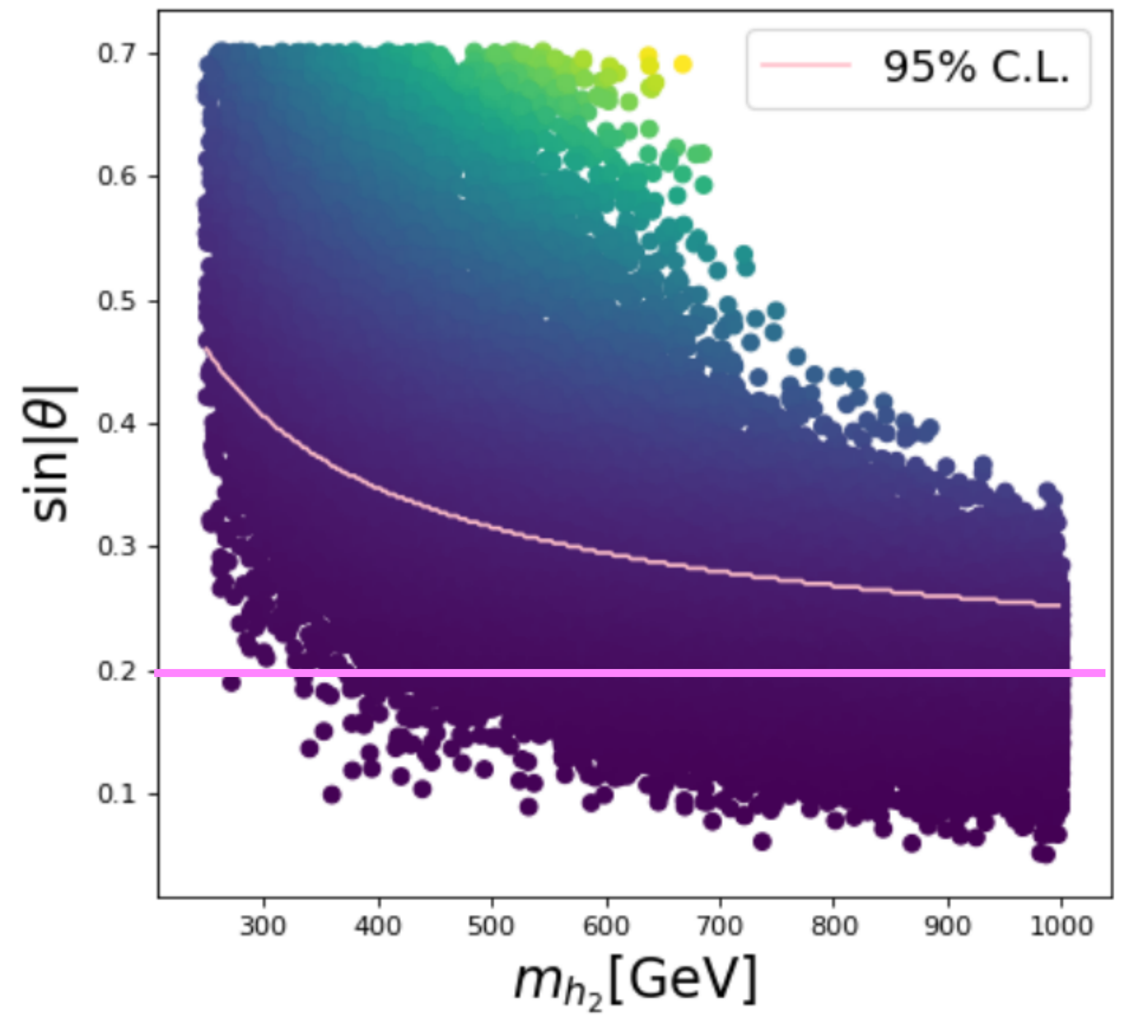

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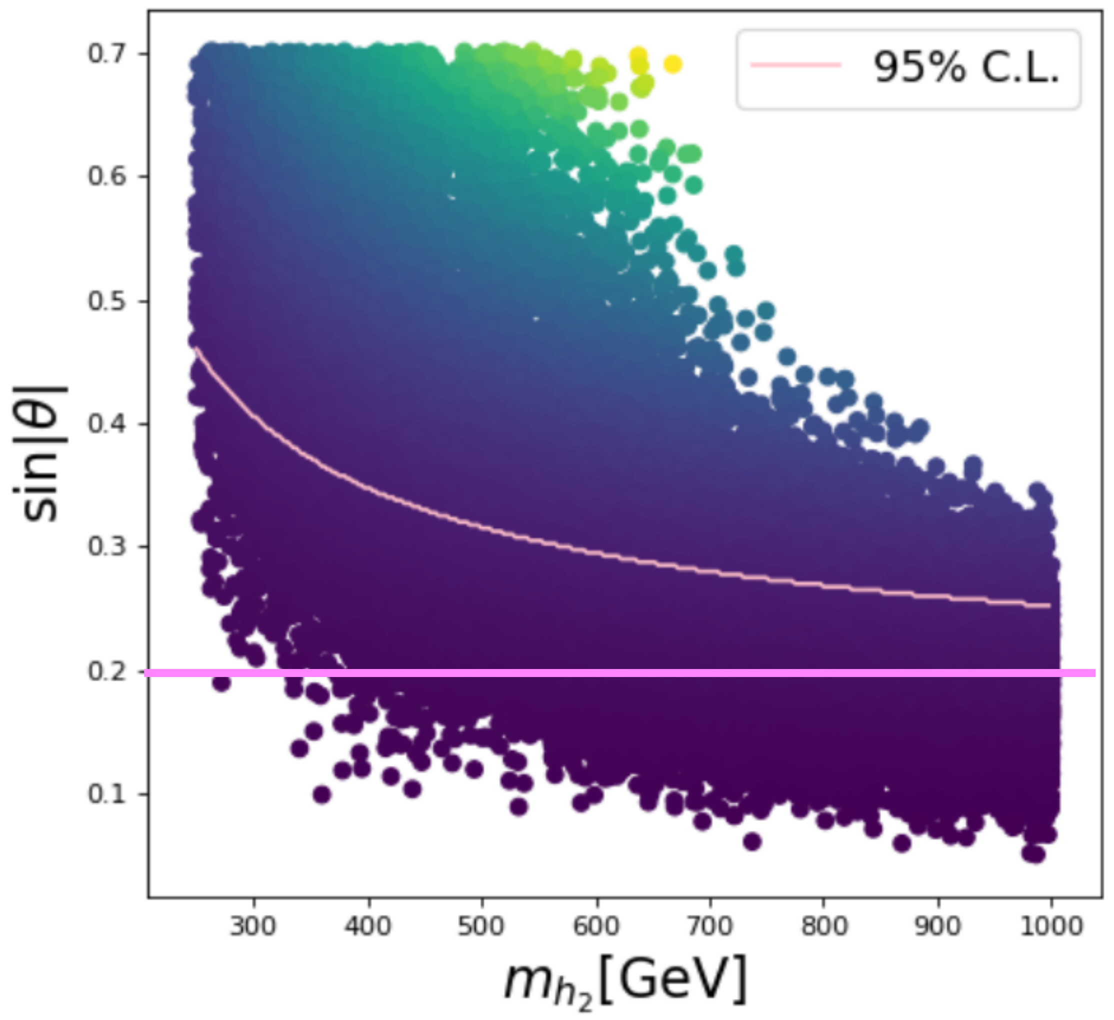

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OPPORTUNITIES AT FUTURE COLLIDERS!!!

Detect the SFOEWPT at colliders

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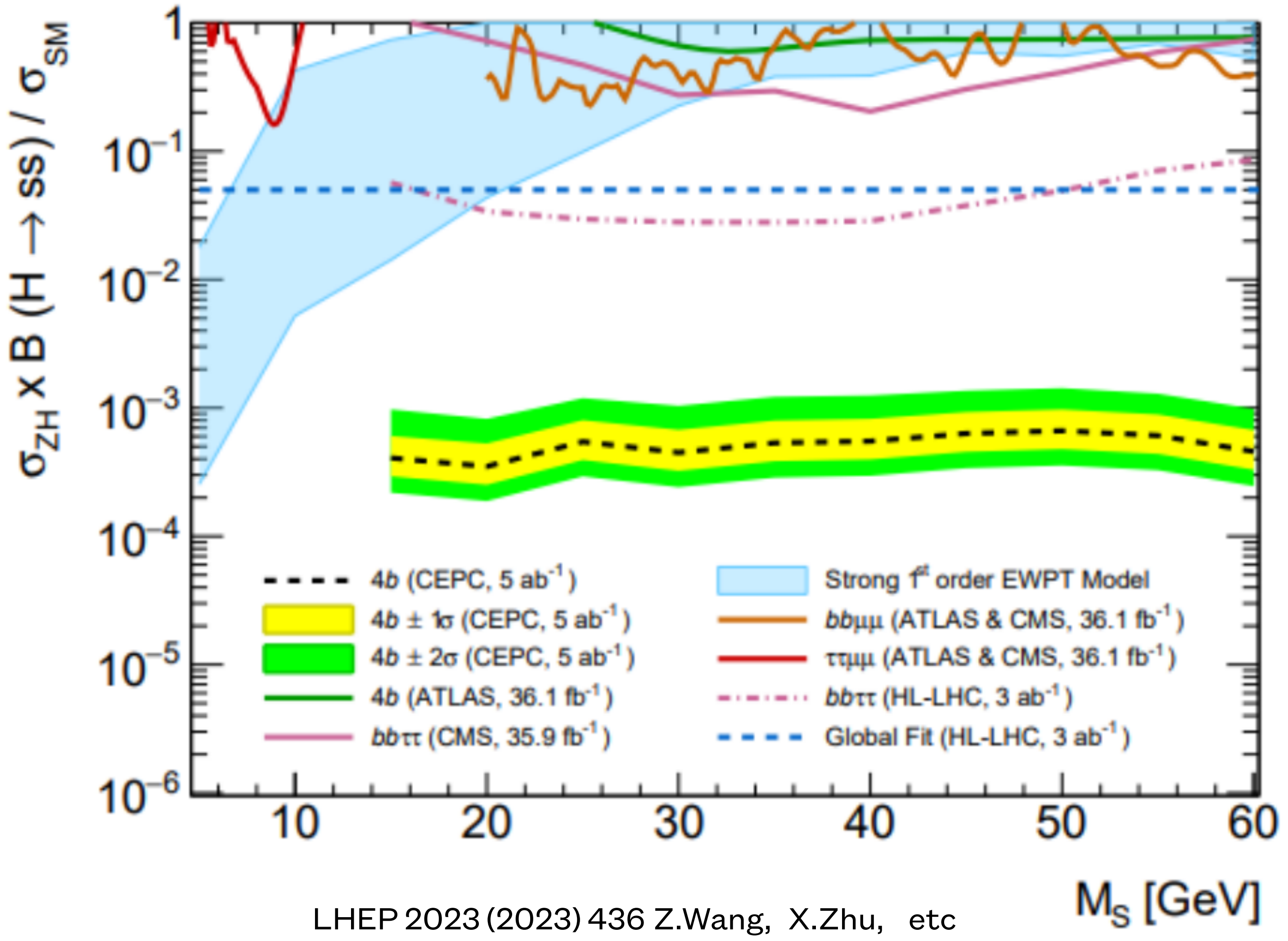

LHEP 2023 (2023) 436 Z.Wang, X.Zhu, etc

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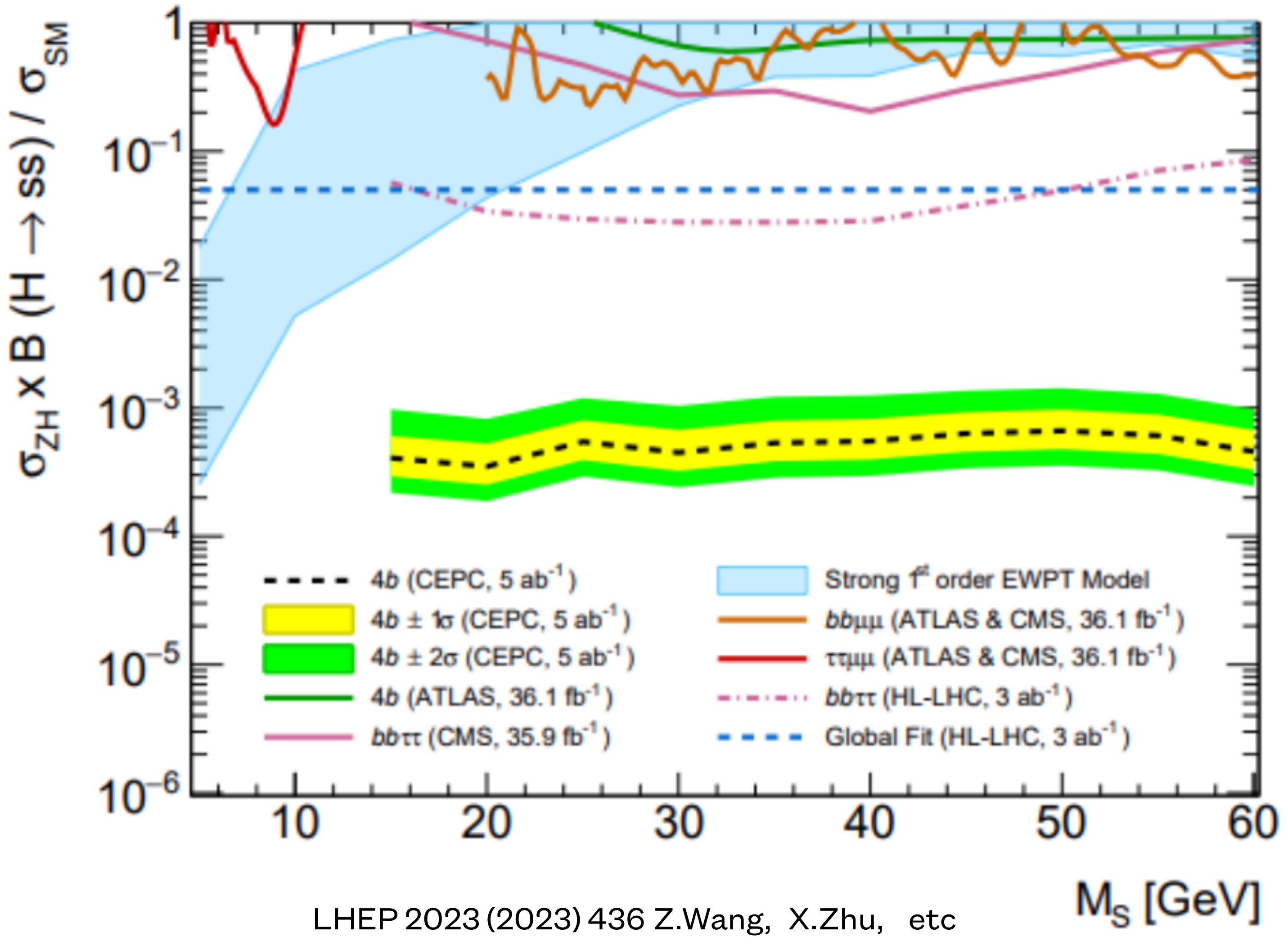

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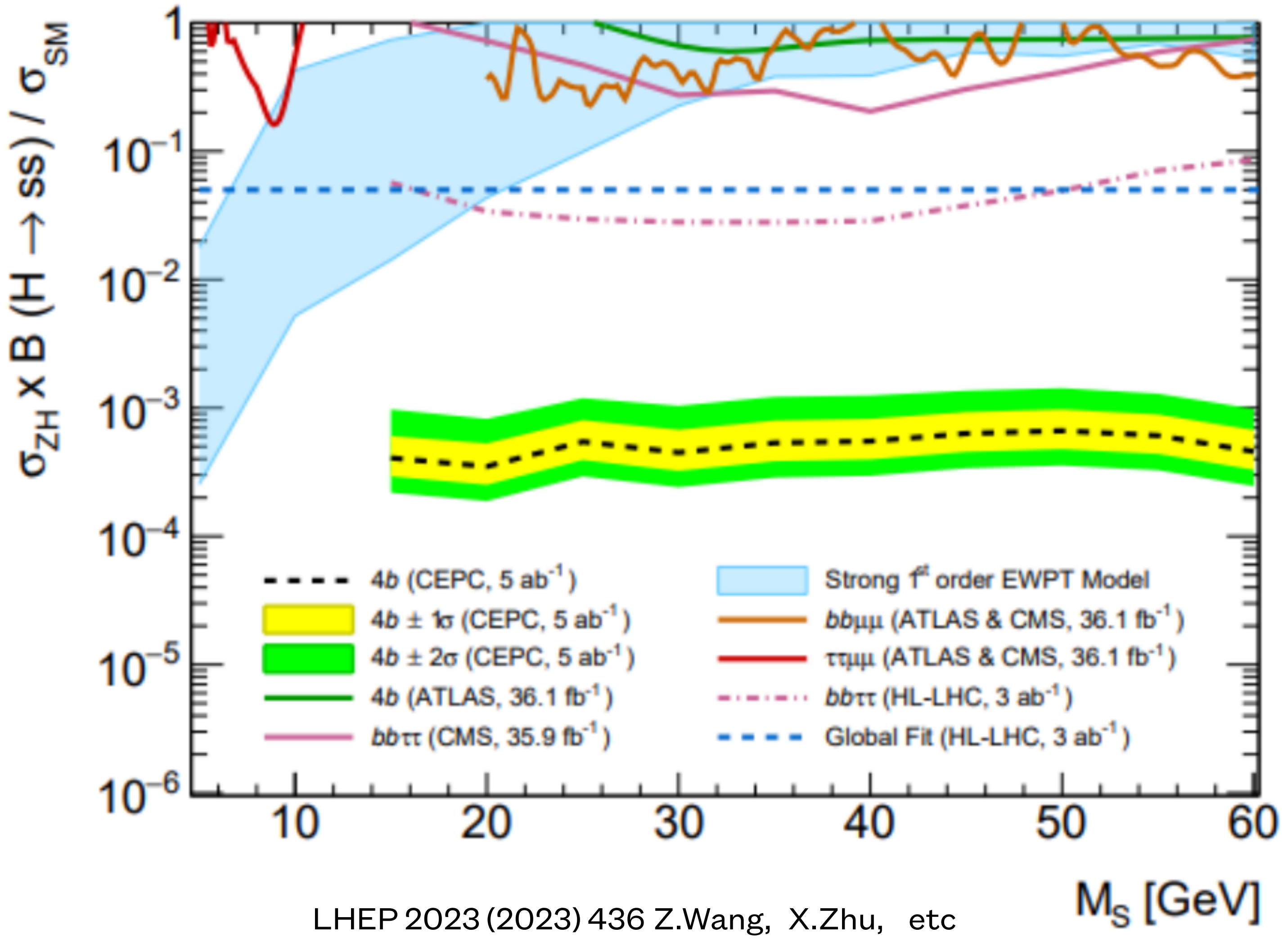

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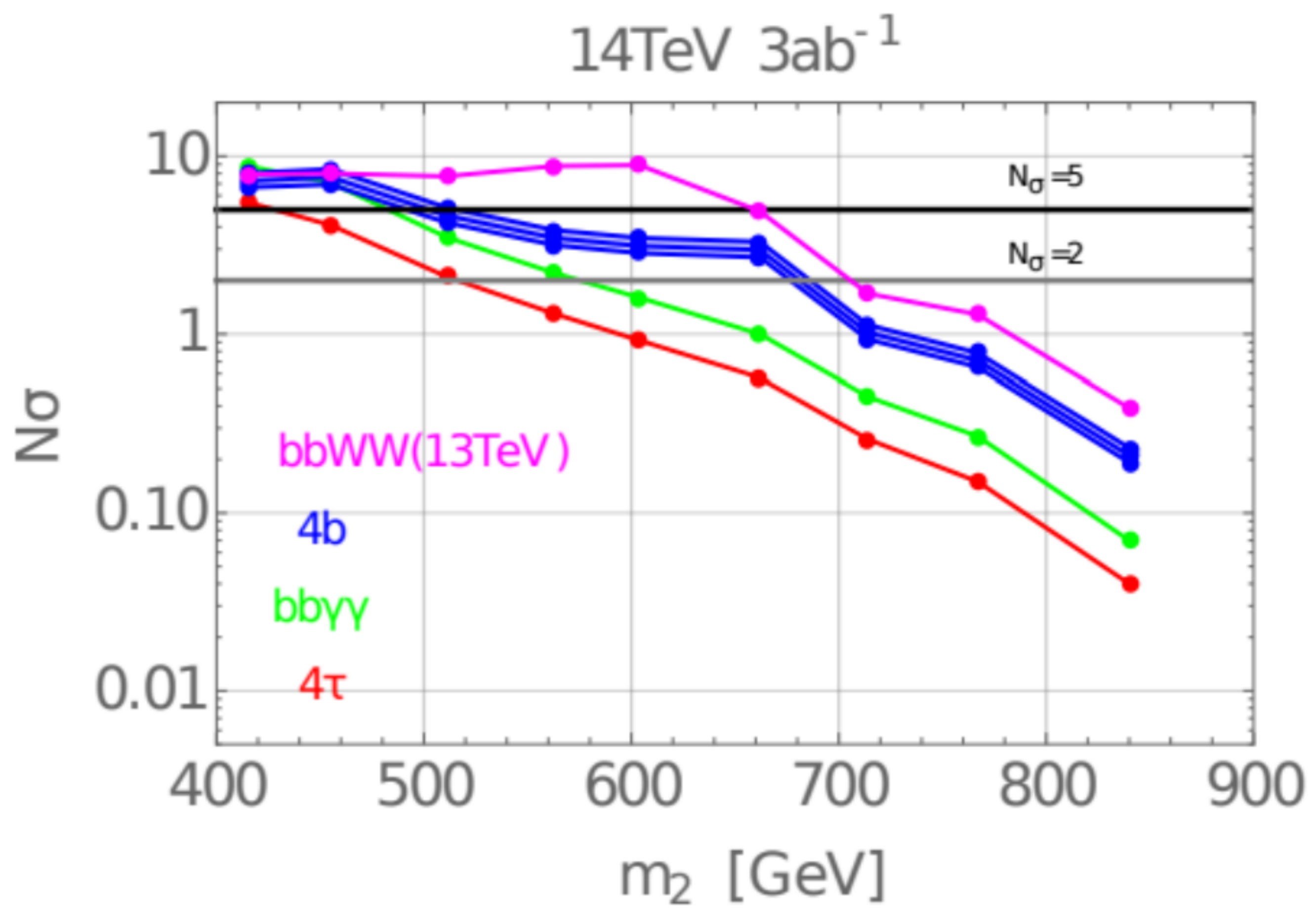

Phys.Rev.D 100 (2019) 7, 075035, H-L Li, MJRM, S. Wilocq

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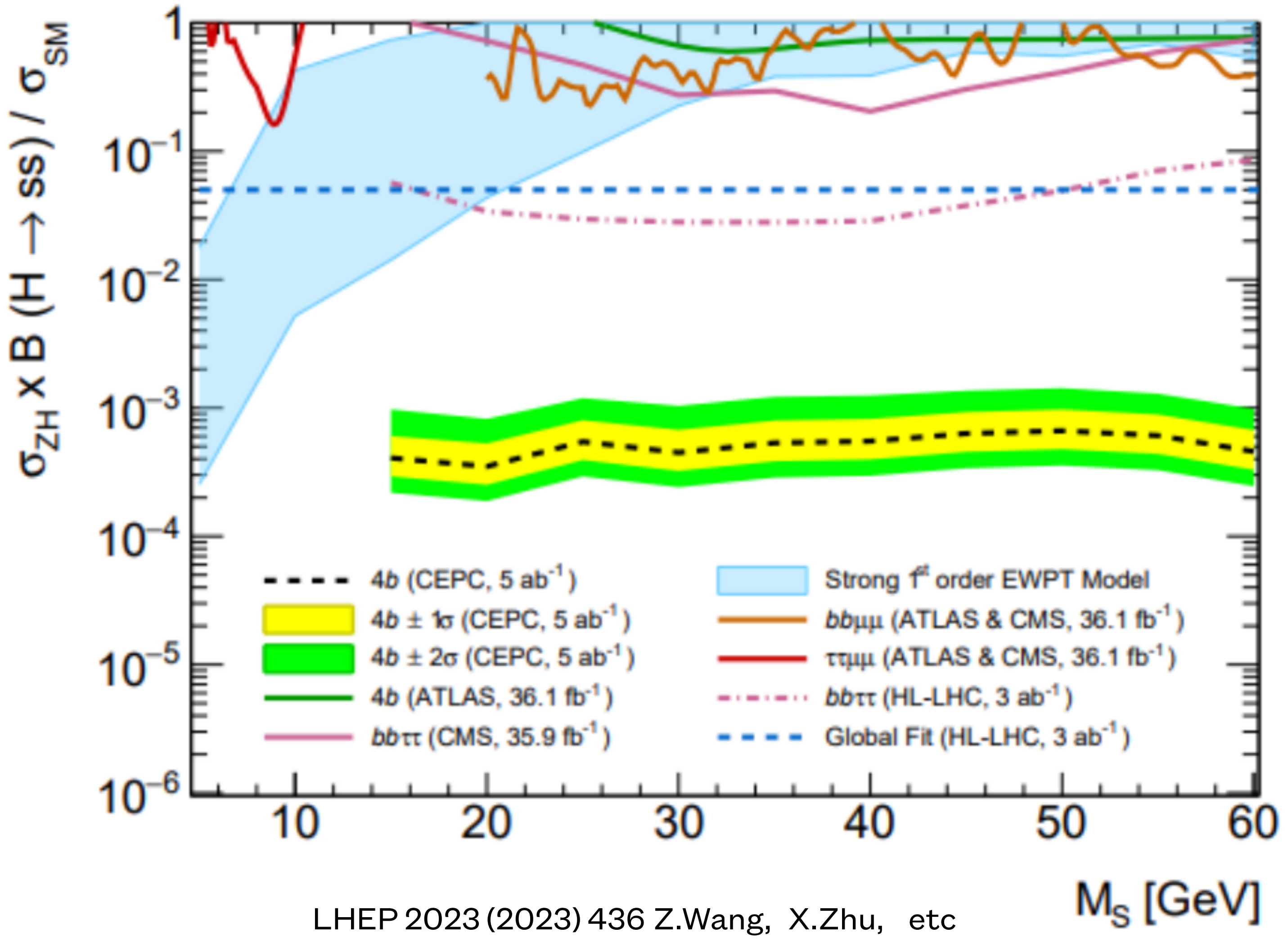

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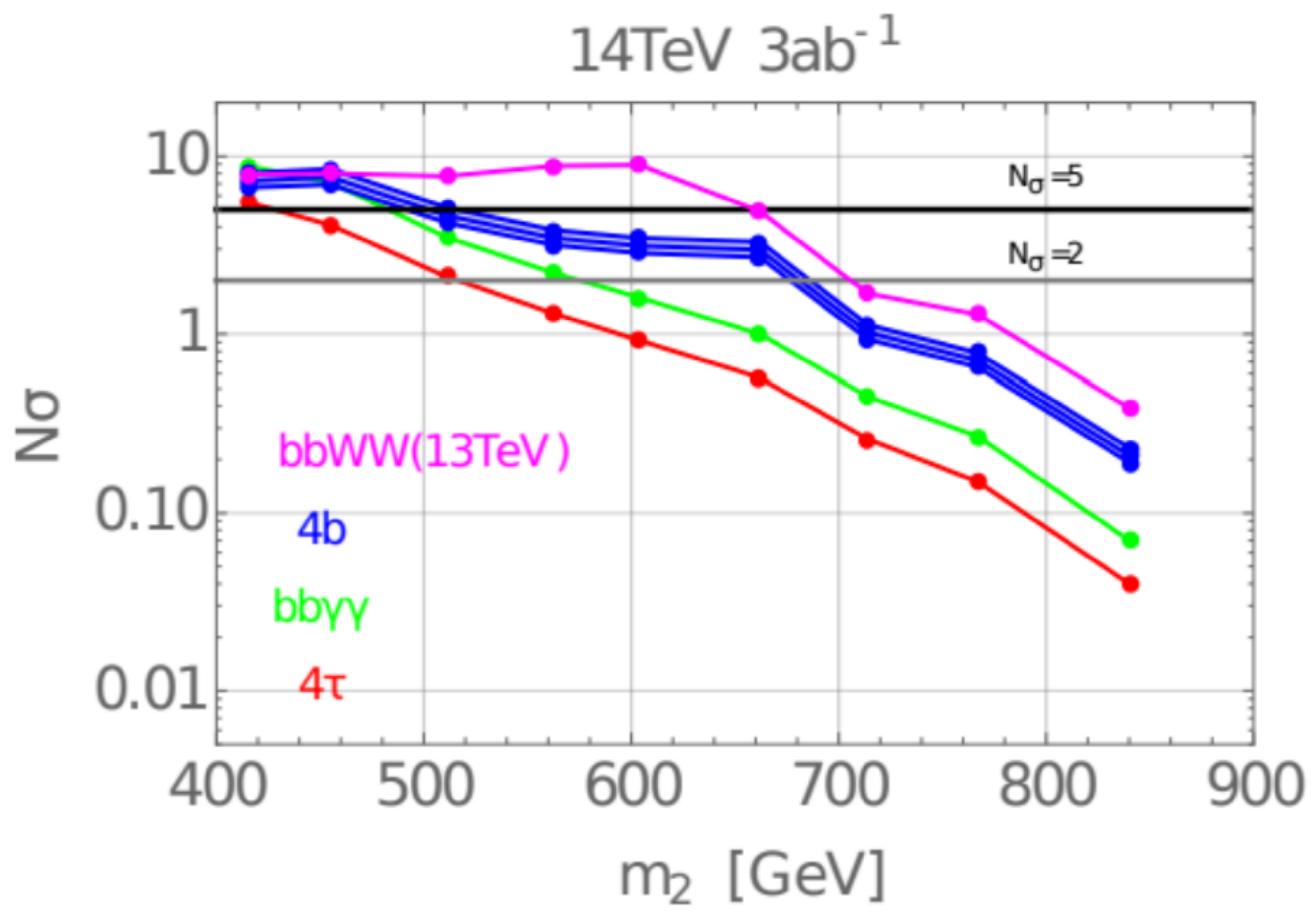

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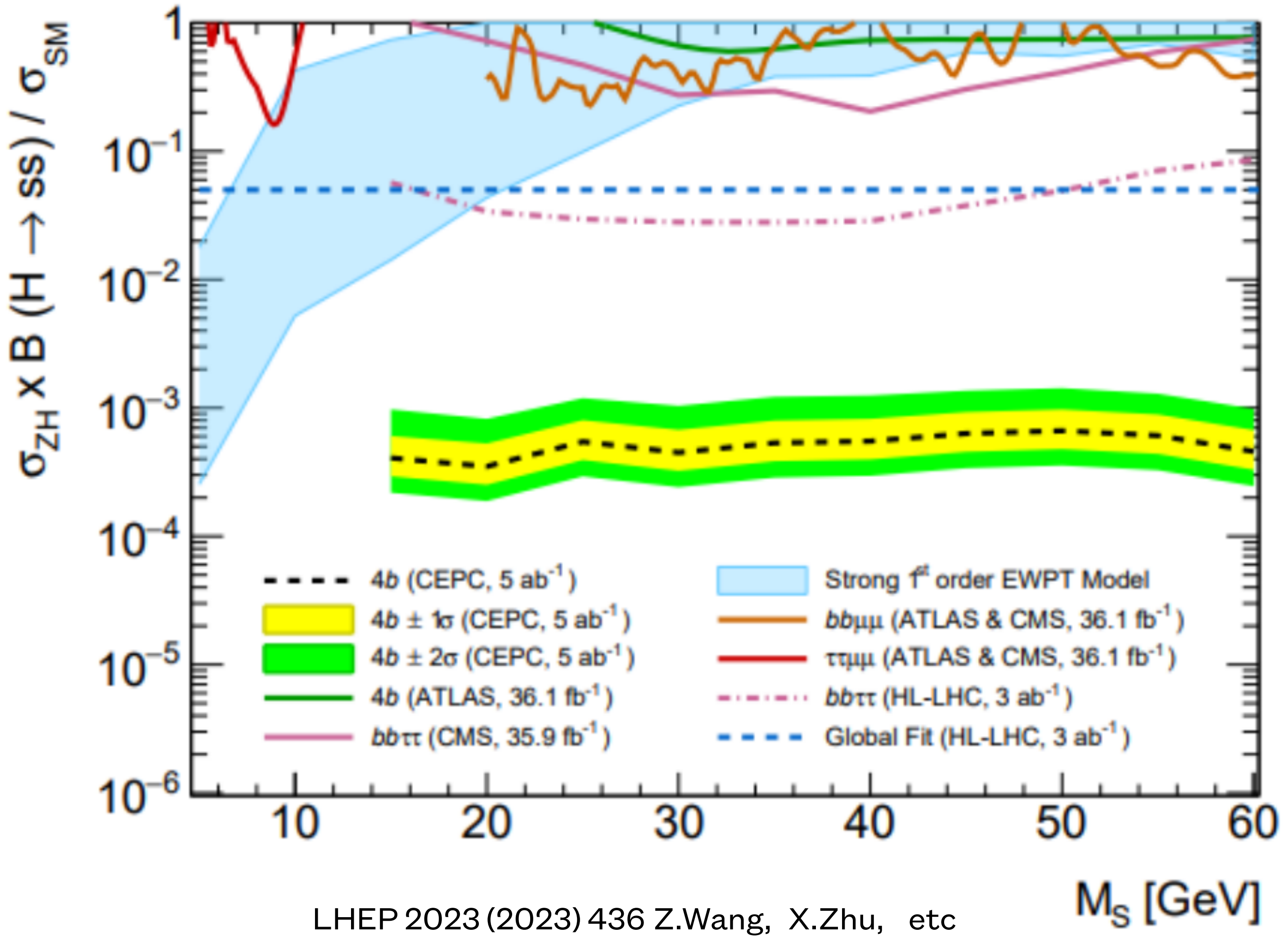

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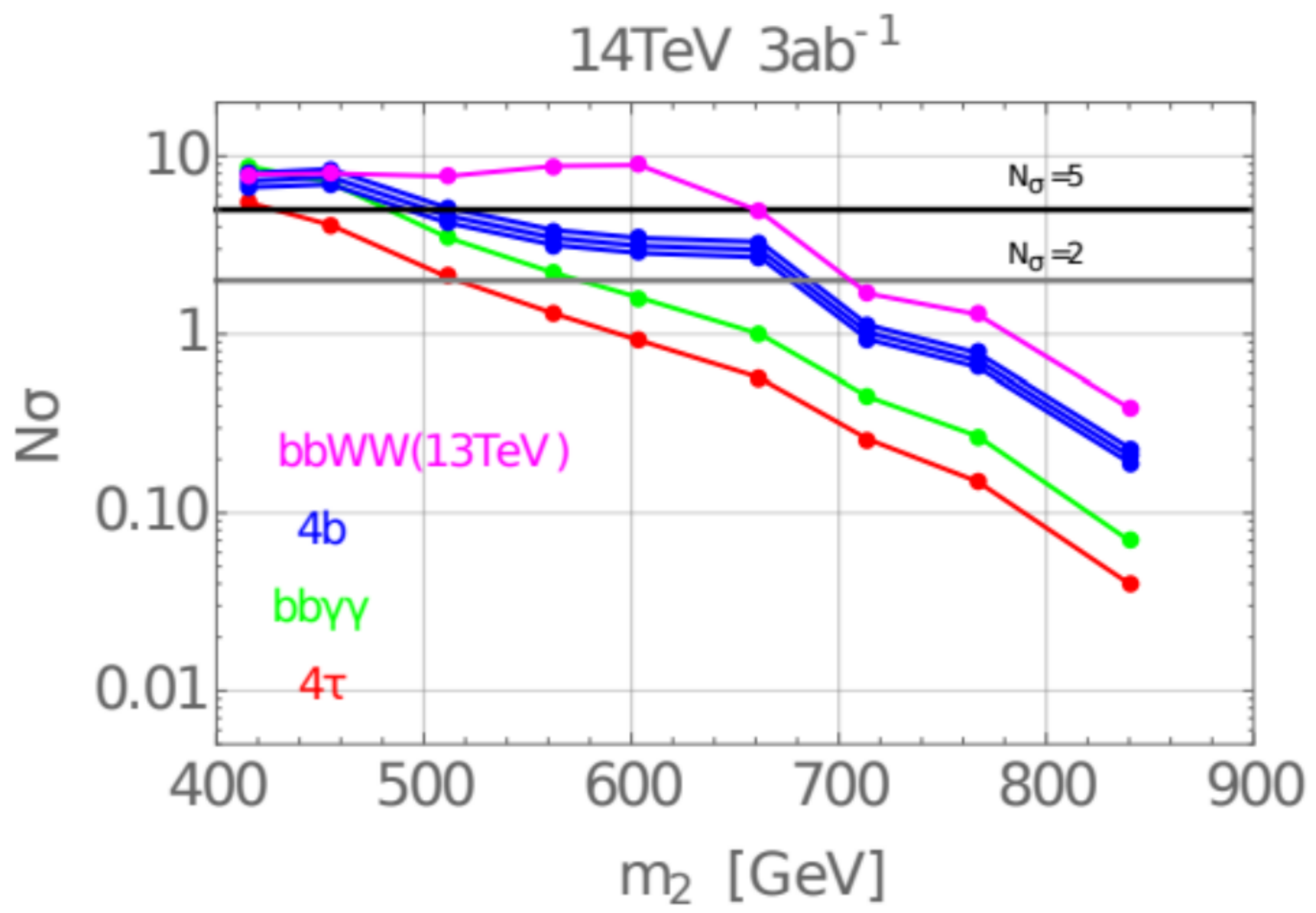

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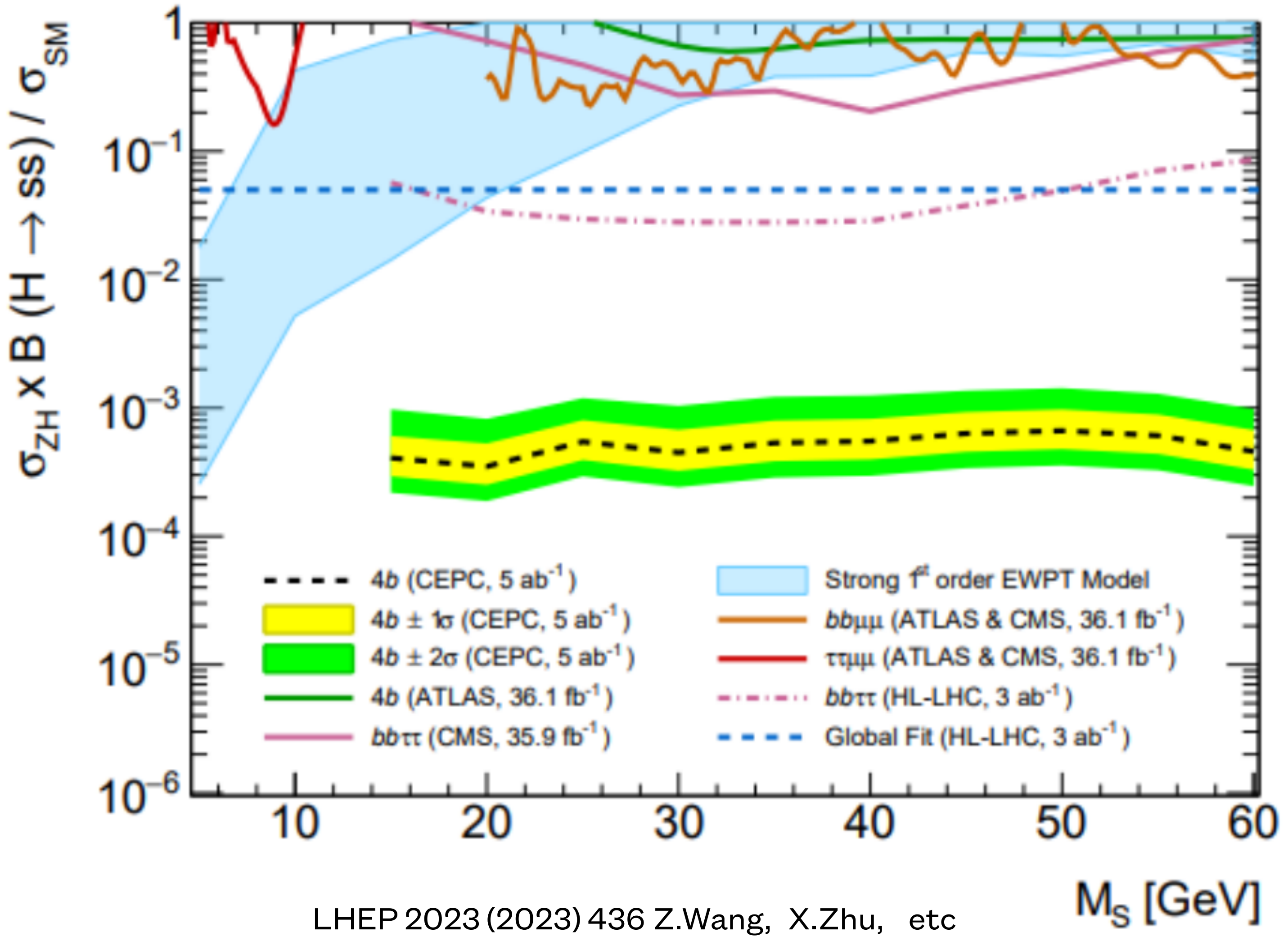

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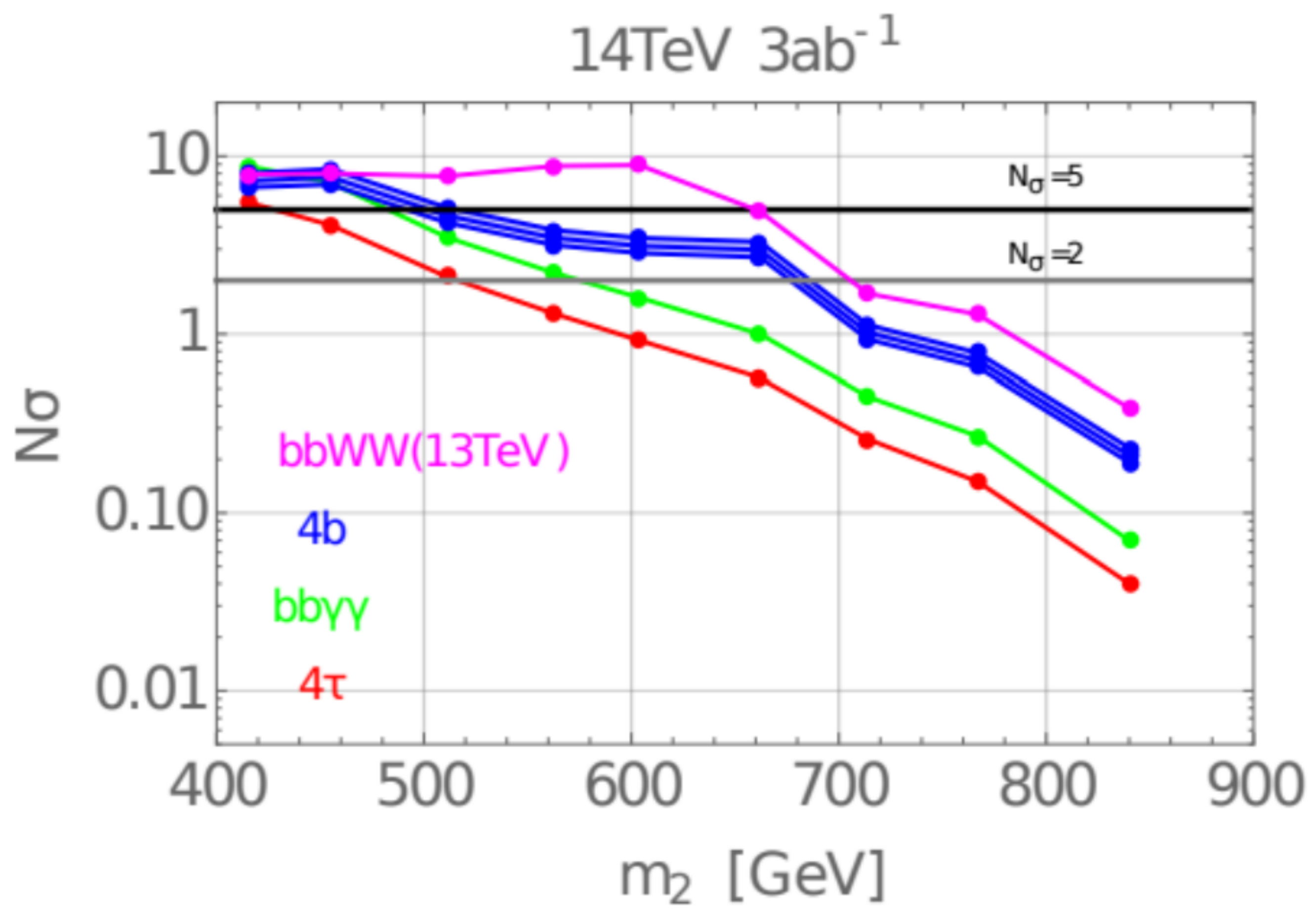

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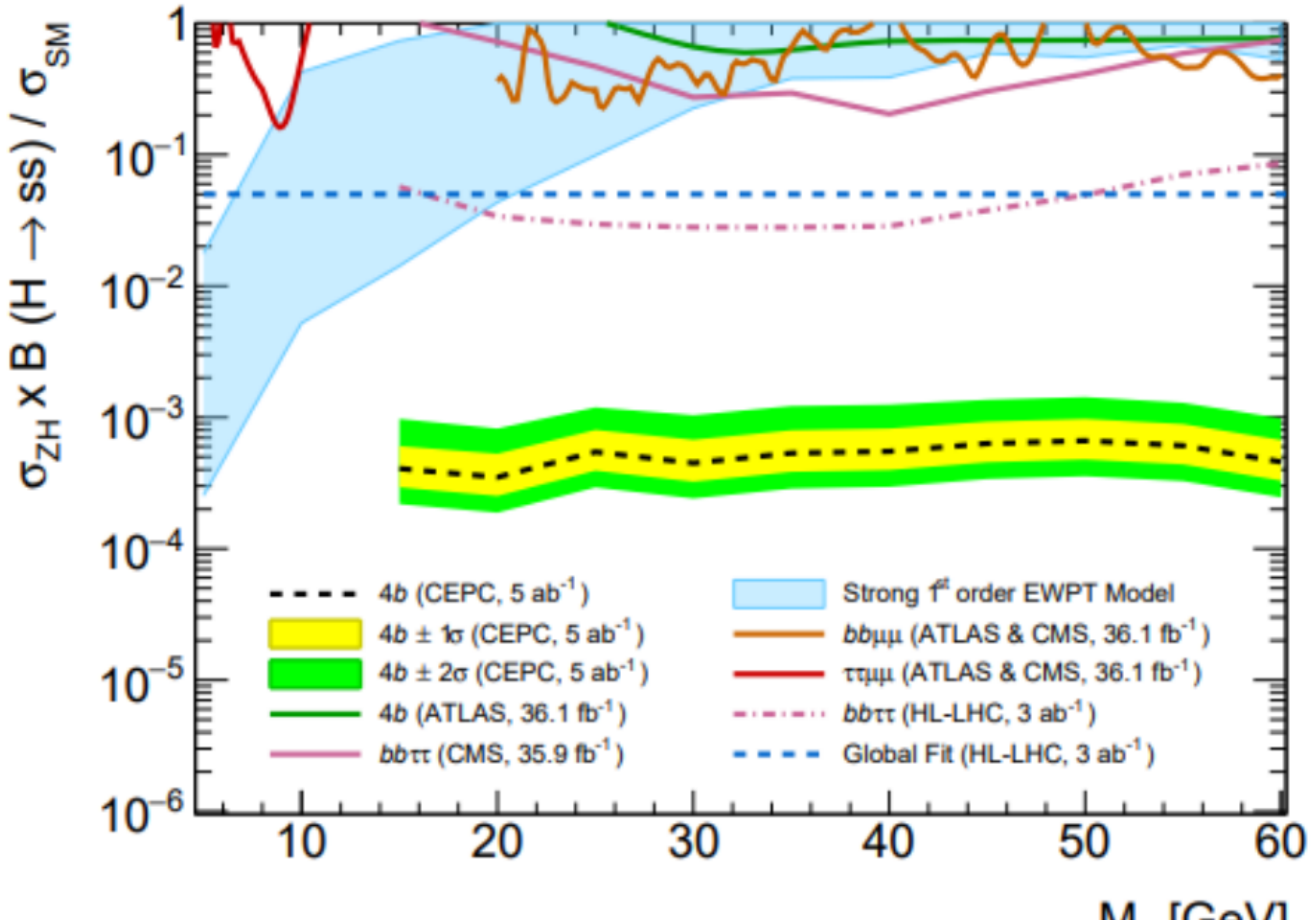

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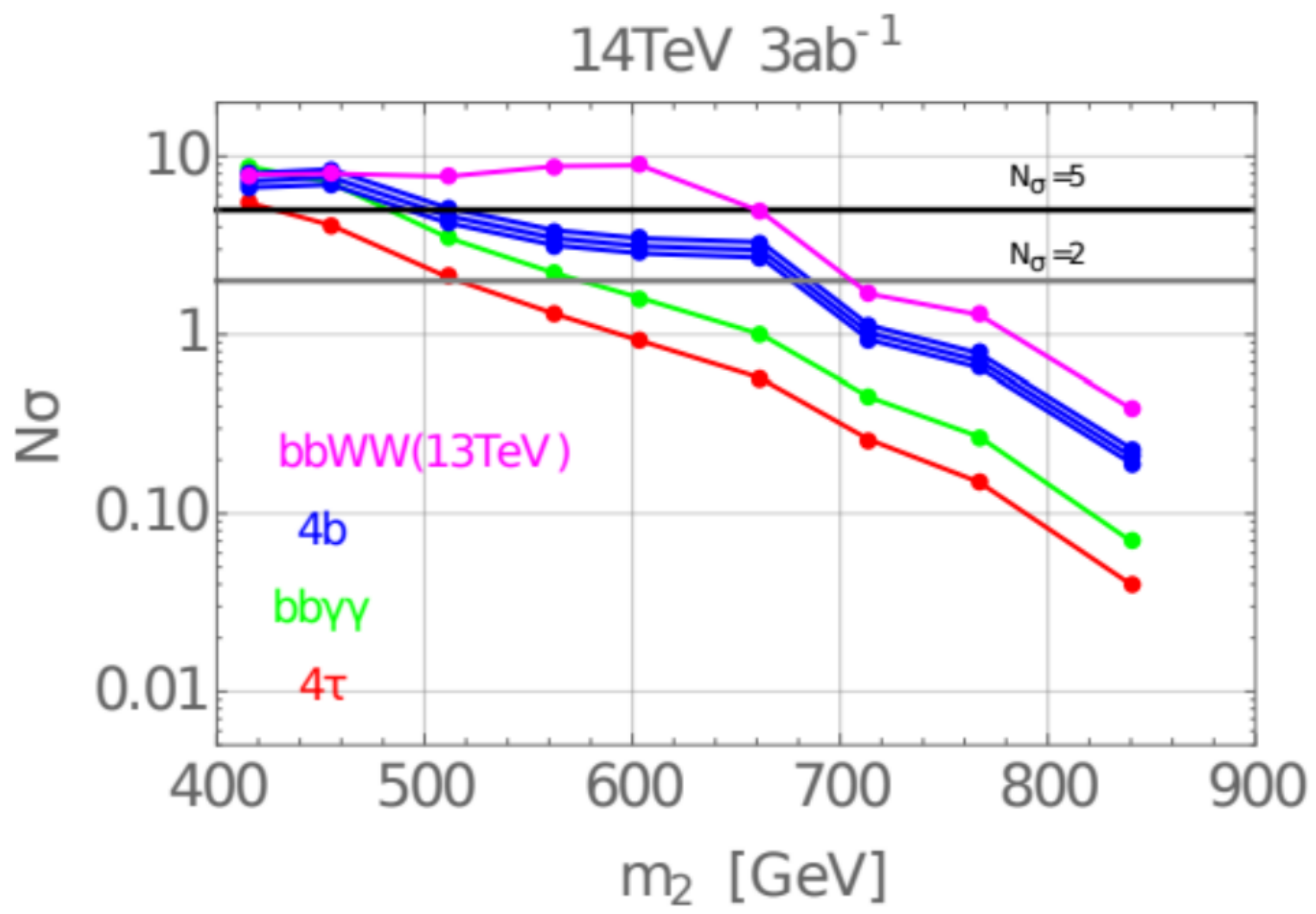

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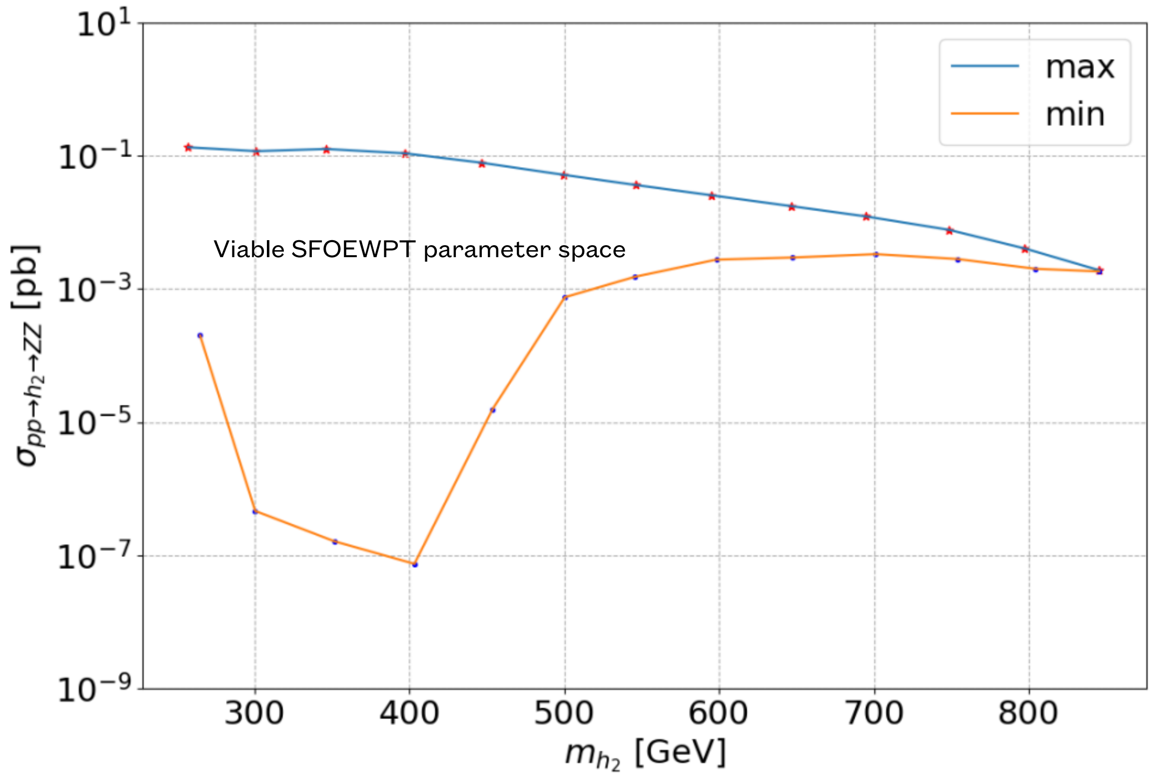
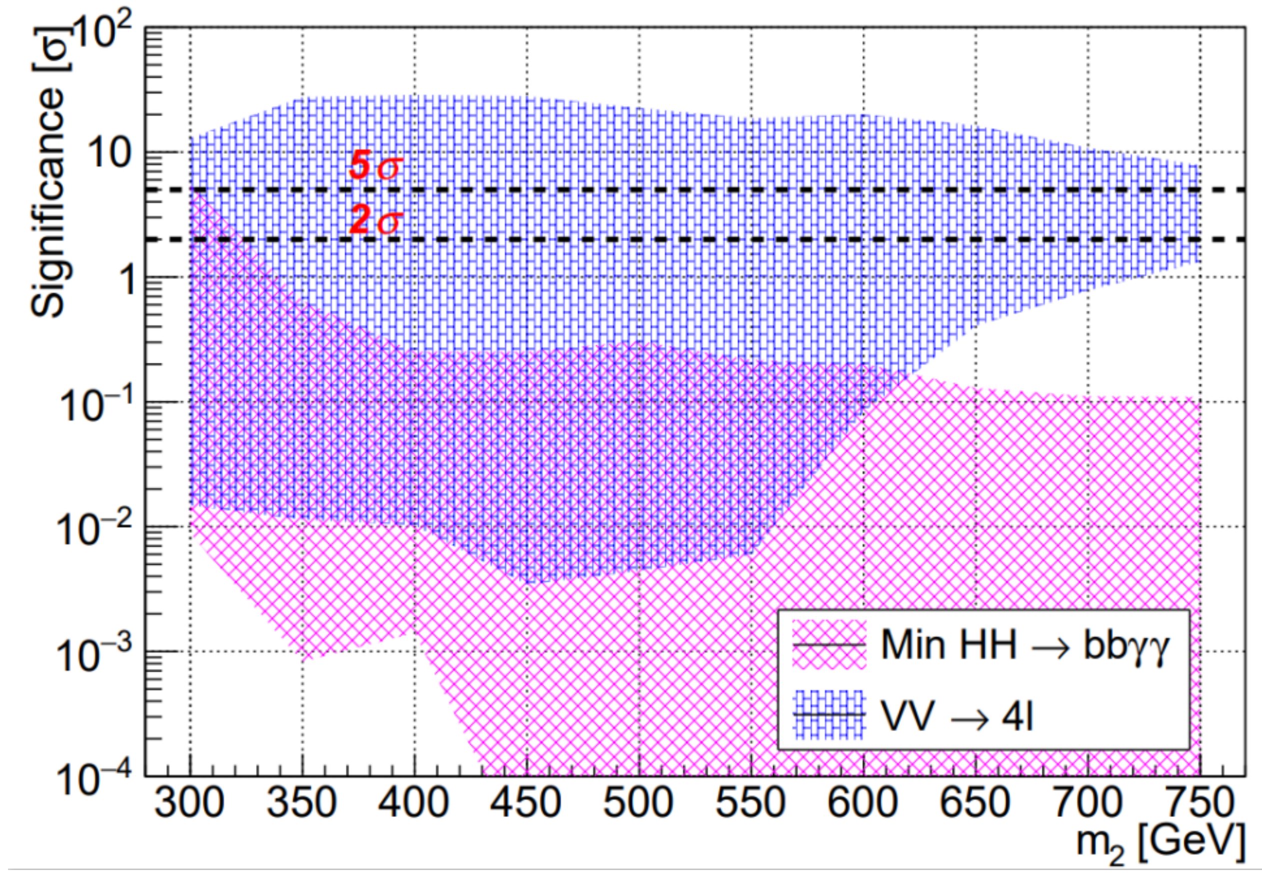
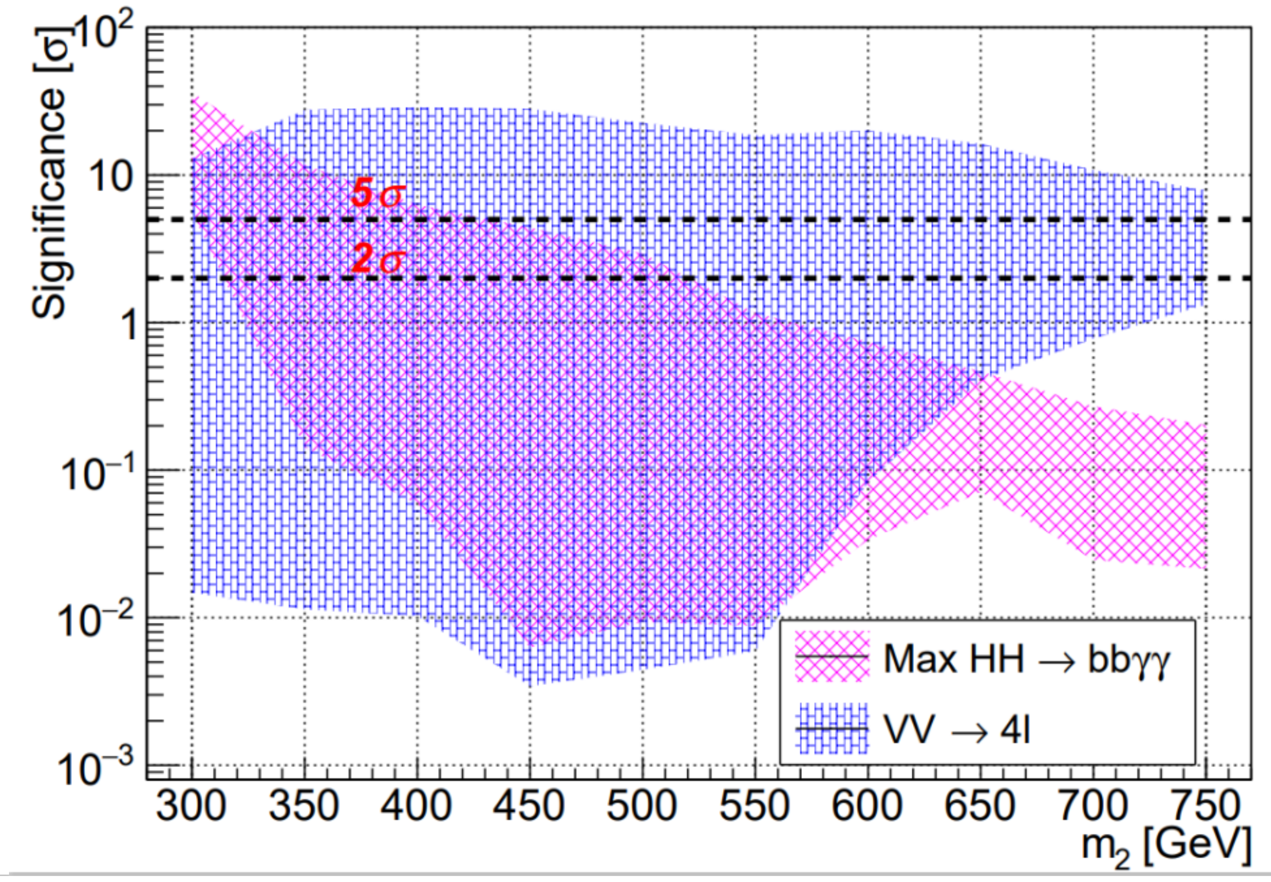
Two answers are included in this talk

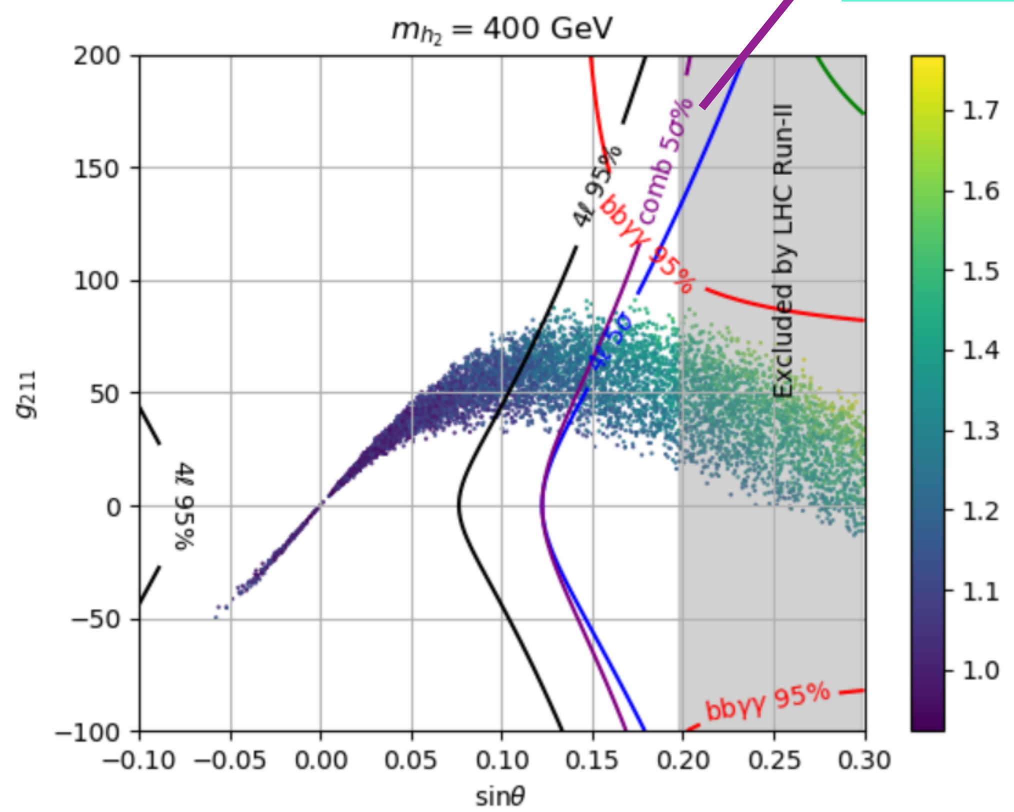
Optimizing detecting PT ability at colliders : Combine $b\bar{b}\gamma\gamma$ and $ZZ \to 4\ell$

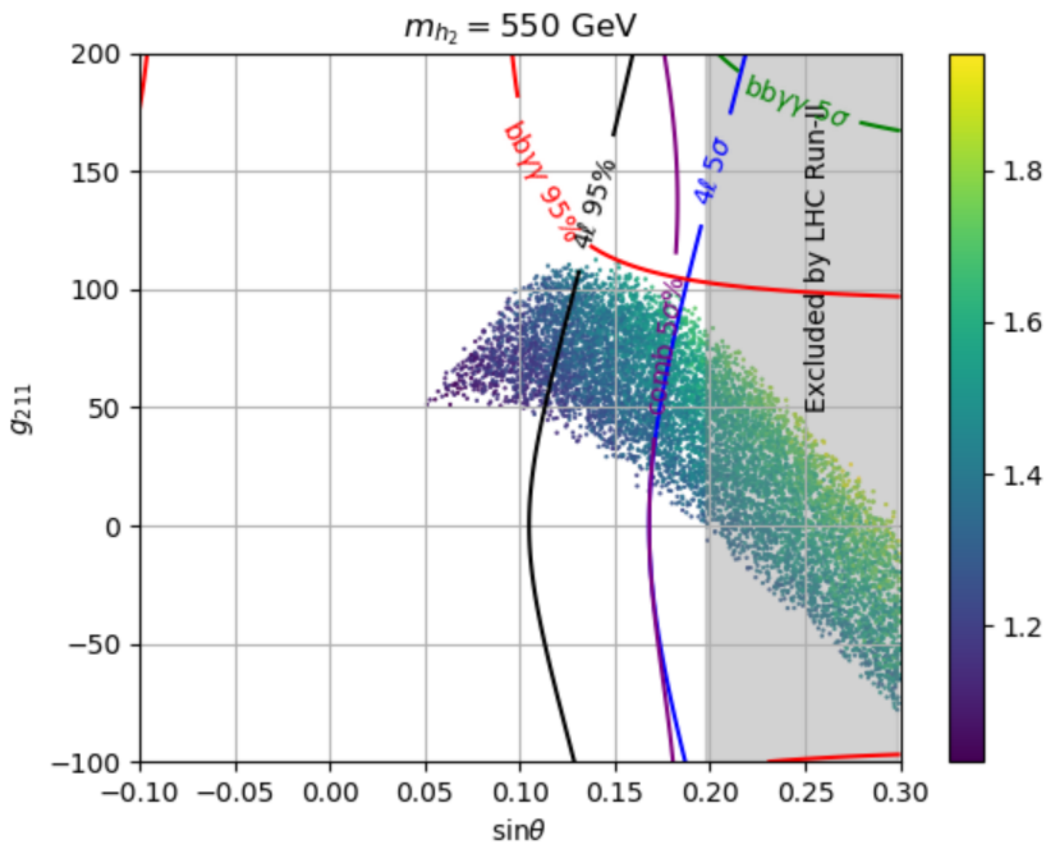


Space between the blue and the purple line can be detected now !









THE DETECTABLE SPACE HAS EXPANDED !!!

Detect the DM phenomenology and SFOEWPT at colliders

$$V_0(H,S) = \frac{\mu^2}{2}(H^\dagger H) + \frac{\lambda}{4}(H^\dagger H)^2 + \frac{\delta_2}{2}H^\dagger H|S|^2 + \frac{b_2}{2}|S|^2 + \frac{d_2}{4}|S|^4$$
$$+ a_1 S + \frac{b_1}{4}S^2 + h.c..$$

Nonzero coupling g_{1AA} would induce Higgs invisible decay if $m_A < \frac{m_{h_1}}{2}$

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$m_A > 62.5$ GeV: Recently-studied case

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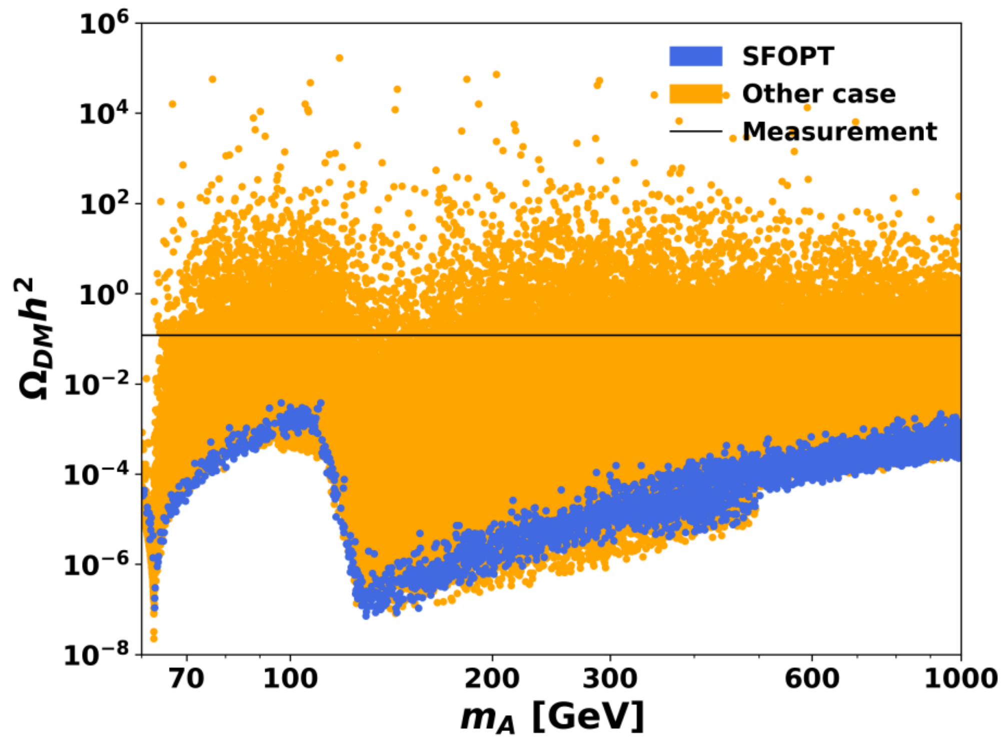

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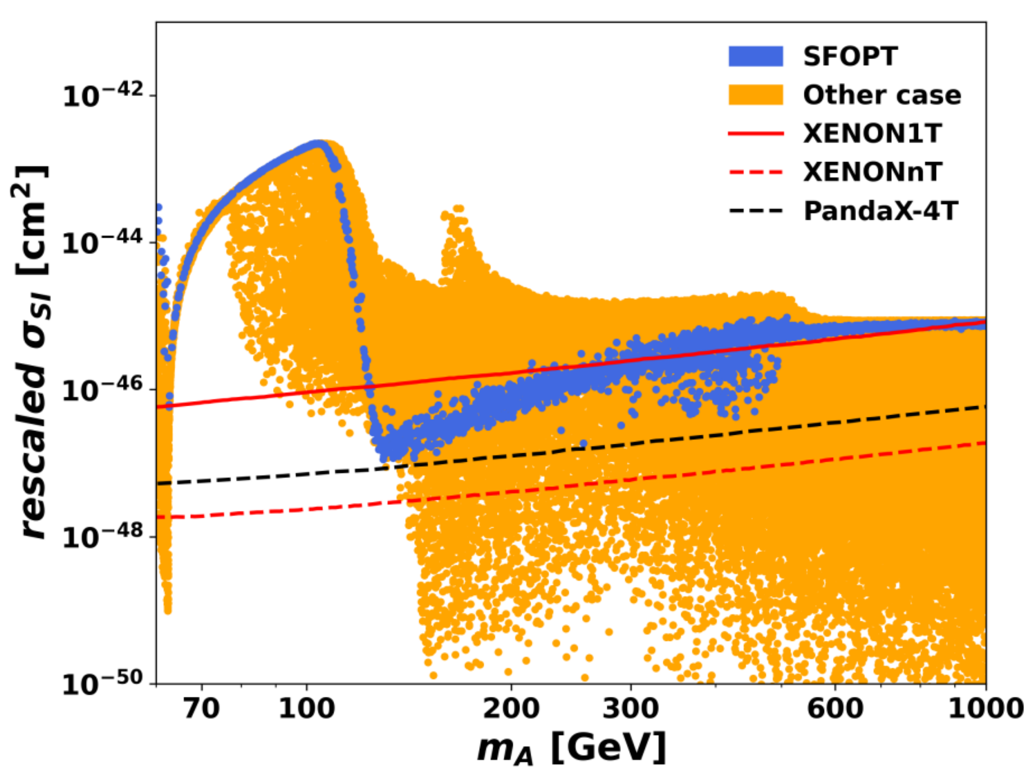

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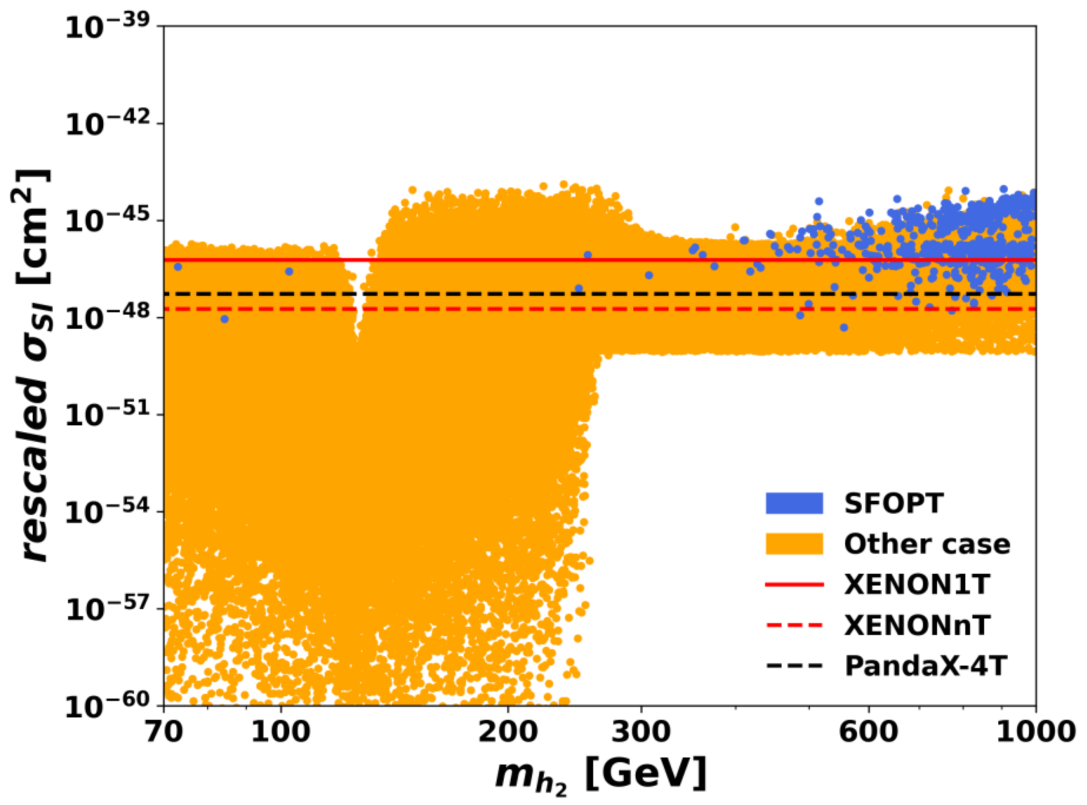
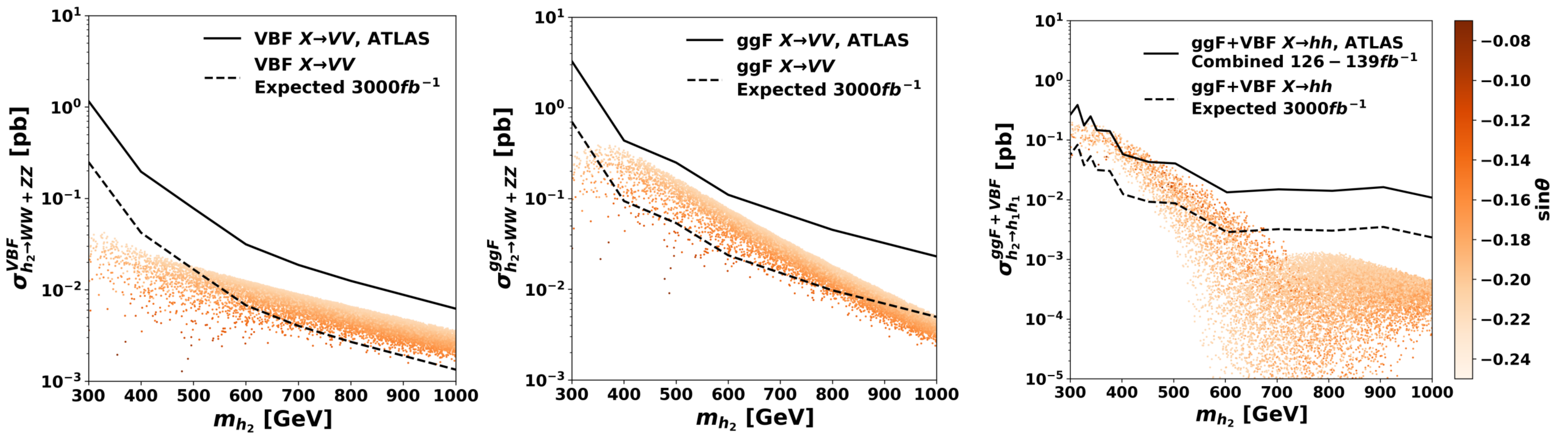


Well-studied case

For $m_A > 62.5$ GeV, most SFOPT points survive XENON1T search and are able to be detected by XENON-nT or PandaX-4T.

For $m_A = 62.5$ GeV, most SFOPT points do not survive XENON1T search.

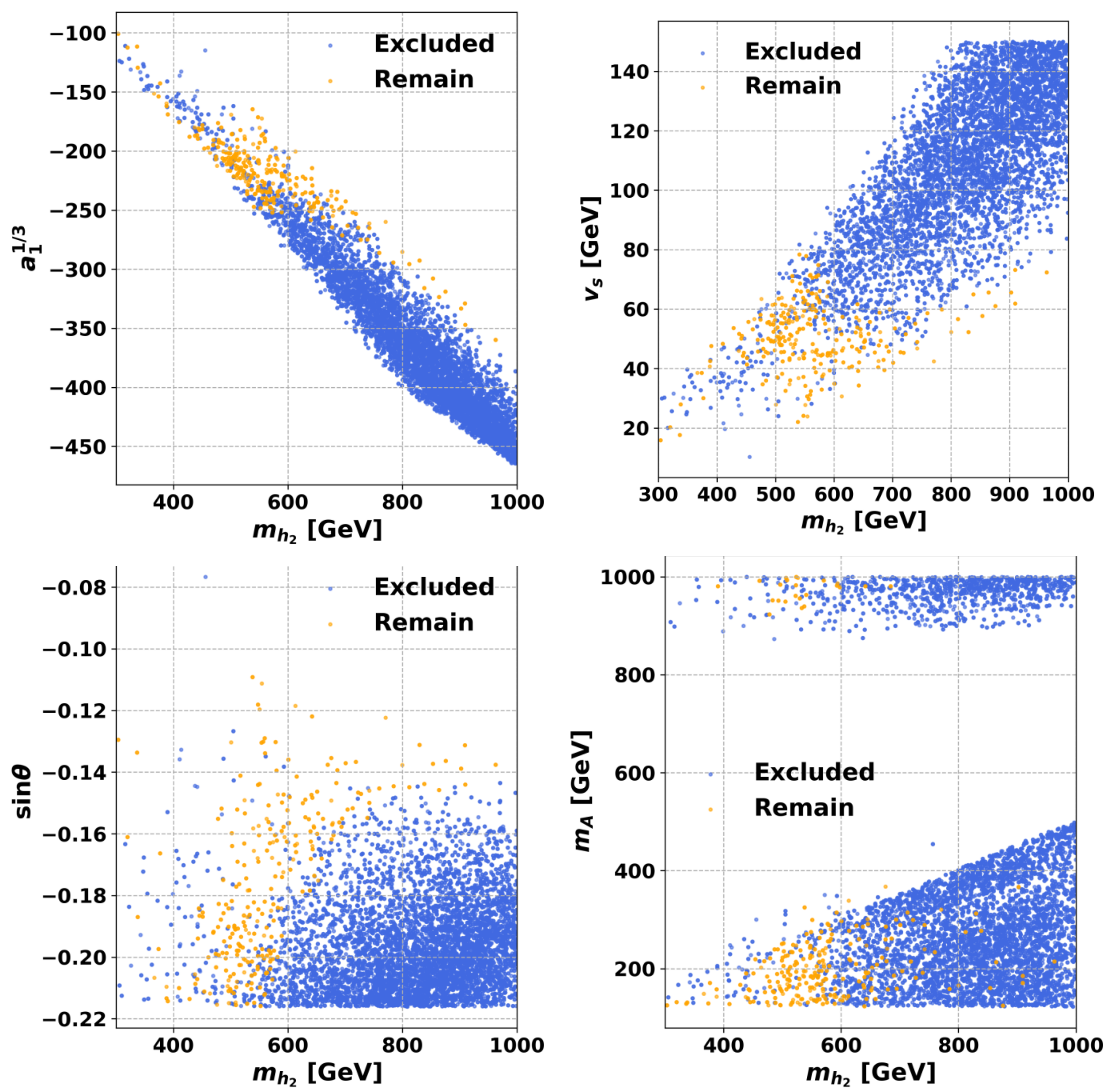
cxSM: search EWPT & DM at the (HL-)LHC

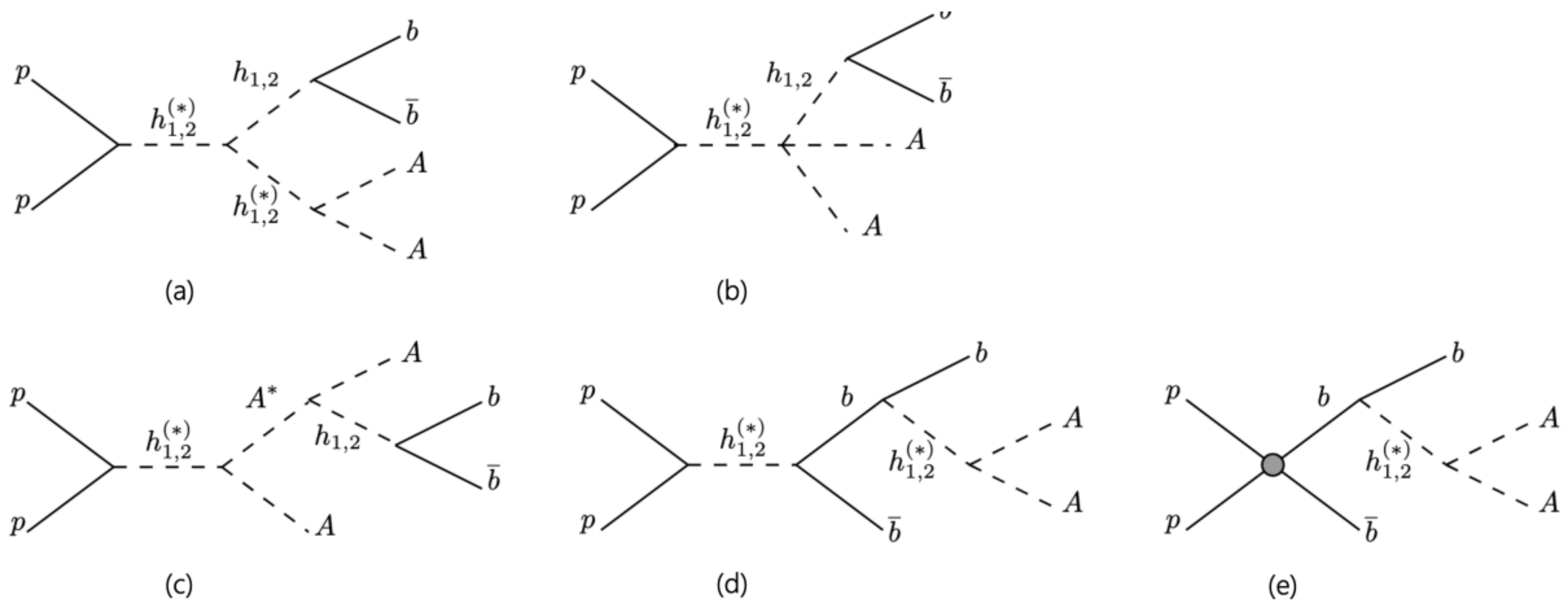


Di-Boson: Cover the whole space in $m_{h_2} > 600$ GeV

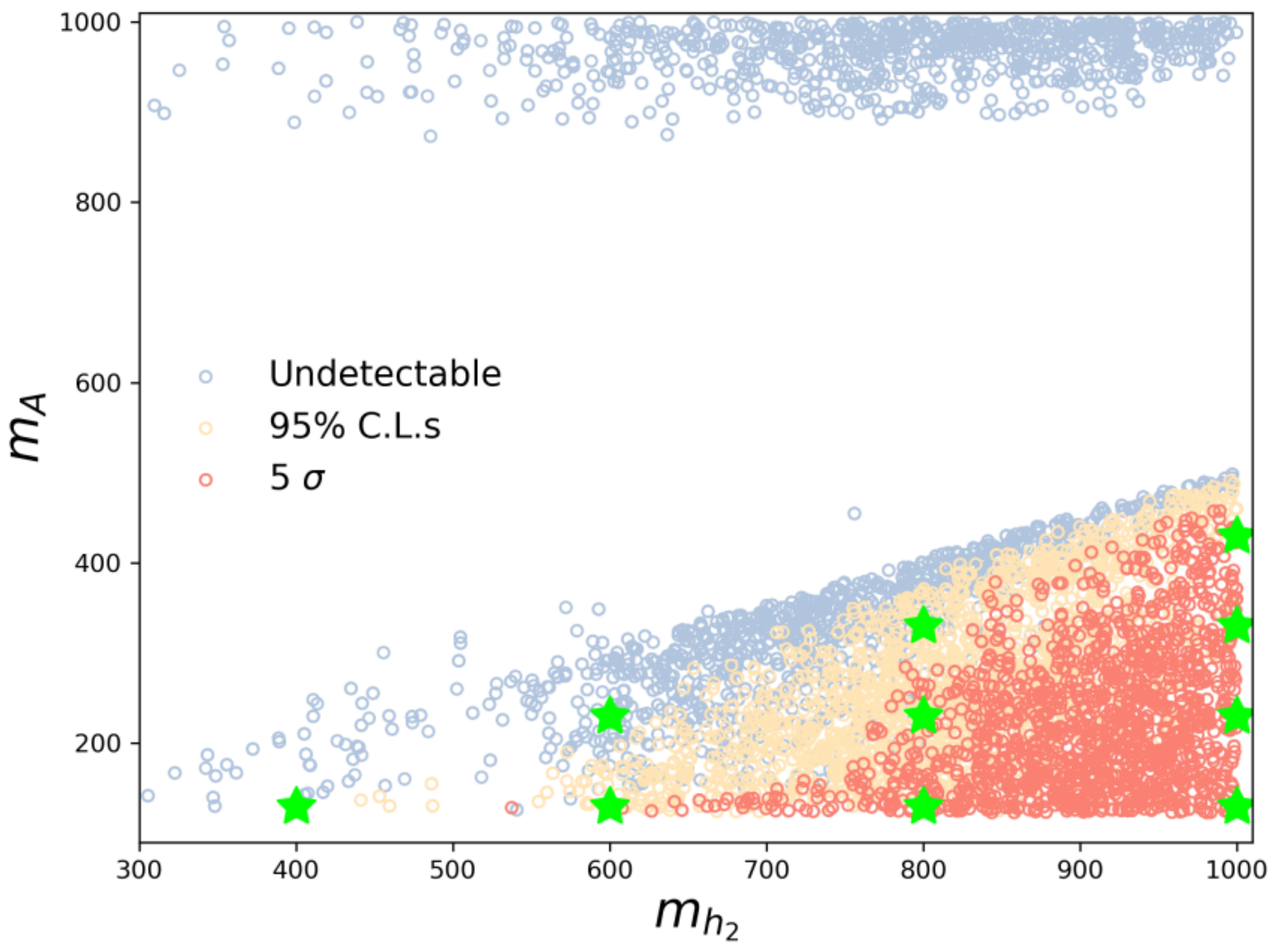
Di-Higgs: Cover significant portion in $m_{h_2} < 400$ GeV

LHC Run-II : Almost no exclusion ability

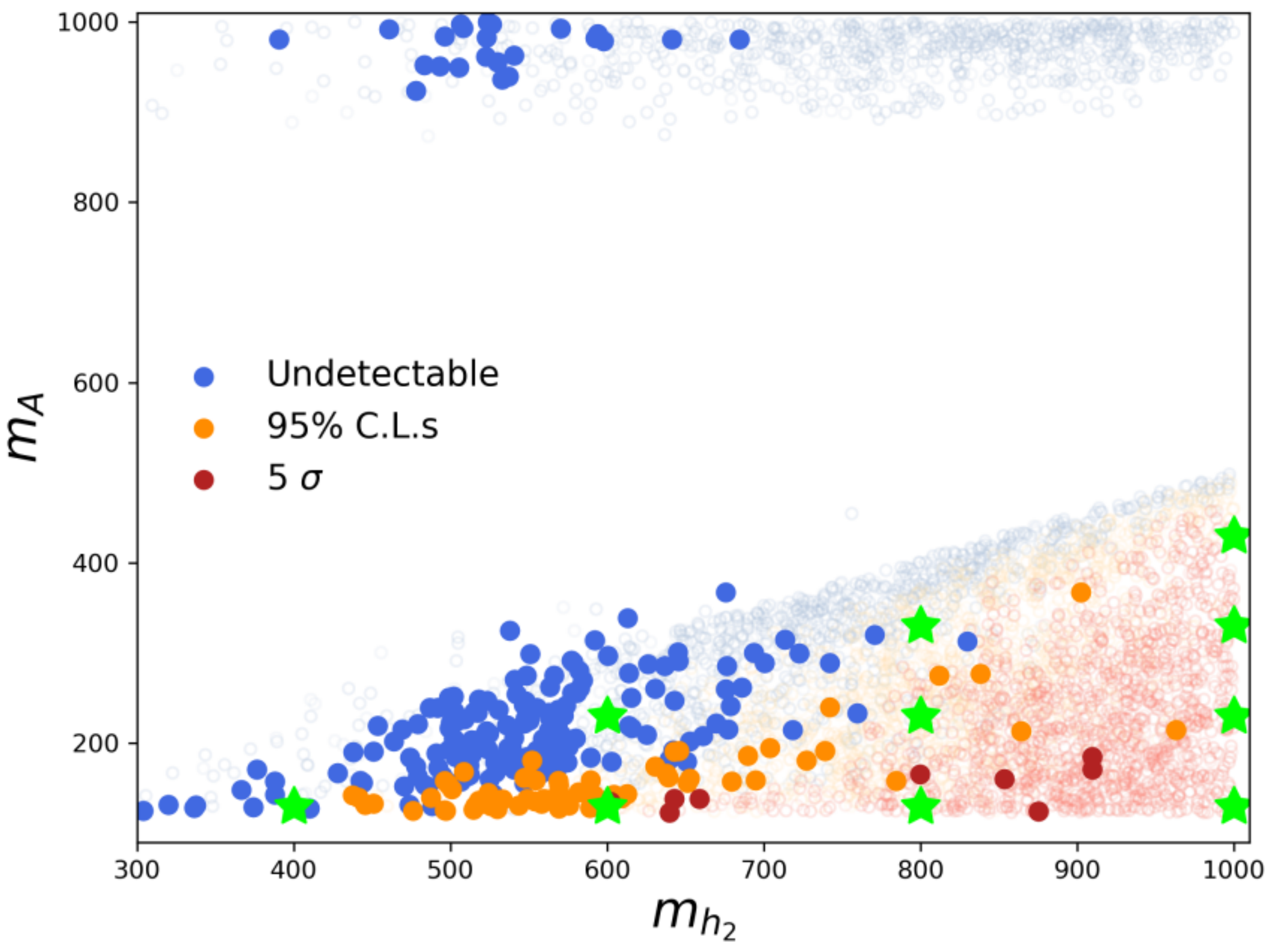




cxSM: search for $b\bar{b}$ + MET at the (HL-)LHC



Detectable region by singlet search only, including di-boson and di-higgs channels



Space that can only be detected by $b\bar{b}$ + MET

Summary

We briefly see how the Higgs measurement impact on the EWPT searches at colliders, which gives an opportunity to the future collider—CEPC. ML method is expected to optimize the preselection step.

Two methods are introduced to optimize the heavy Higgs search for EWPT. One is to combine di-Higgs and di-boson channels, the other is to make use the branching new search channel $b\bar{b}+$ MET.

Without updating LHC hardware, detectable parameter space are extended by the first method. DM is very hopefully to be discovered by the future Xenon-nT or PandaX-4T.