惰性希格斯模型的多手段协同探测

卢致廷 Chih-Ting Lu *ctlu@njnu.edu.cn*

NNU · 南京师范大学
NANJING NORMAL UNIVERSITY

PTNP 中国精确检验与新物理合作组

30th Mini-workshop on the frontier of LHC

- **Confronting dark matter co-annihilation of Inert two Higgs Doublet Model with a compressed mass spectrum**
  Y.L.S. Tsai, **CT Lu** and V.Q. Tran,

  JHEP 06 (2020) 033 • e-Print: 1912.08875 [hep-ph]

- **Current status of inert Higgs dark matter with dark fermions**
  Y.Z. Fan, Y.Y. Li, **CT Lu**, X.Y. Luo, T.P. Tang, V.Q. Tran and Y.L.S. Tsai,

  Phys.Rev.D 111 (2025) 1, 015046 • e-Print: 2410.00638 [hep-ph]

- **LHC Mono-W/Z Signatures as a Probe for Dark Matter Explanations of Astrophysical excesses**
  Y.C. Guo, Y.X. Li and **CT Lu**, (In Progress!)

惰性希格斯二重态模型

- $\boldsymbol{Z_2}$ 离散对称性：$\boldsymbol{H_1 \to H_1}$，　$\boldsymbol{H_2 \to -H_2}$

$$H_1 = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}}(v + h + iG^0) \end{pmatrix}, \quad H_2 = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}(S + iA) \end{pmatrix},$$

- 位能势：

$$V = \mu_1^2|H_1|^2 + \mu_2^2|H_2|^2 + \lambda_1|H_1|^4 + \lambda_2|H_2|^4 + \lambda_3|H_1|^2|H_2|^2 + \lambda_4\left|H_1^\dagger H_2\right|^2 + \frac{\lambda_5}{2}\left\{\left(H_1^\dagger H_2\right)^2 + \text{h.c.}\right\},$$

惰性希格斯二重态模型

- 标量玻色子质量：

$$m_h^2 = -2\mu_1^2 = 2\lambda_1 v^2,$$

$$m_S^2 = \mu_2^2 + \frac{1}{2}(\lambda_3 + \lambda_4 + \lambda_5)v^2 = \mu_2^2 + \lambda_L v^2,$$

$$m_A^2 = \mu_2^2 + \frac{1}{2}(\lambda_3 + \lambda_4 - \lambda_5)v^2 = \mu_2^2 + \lambda_A v^2,$$

$$m_{H^\pm}^2 = \mu_2^2 + \frac{1}{2}\lambda_3 v^2,$$

- 模型参数：

$$m_S,\ m_A,\ m_{H^\pm},\ \lambda_2,\ \lambda_L$$

Y.Z. Fan, T.P. Tang, Y.L.S. Tsai and L. Wu

Phys.Rev.Lett. 129 (2022) 9, 091802

轻暗物质区（55-75 GeV）

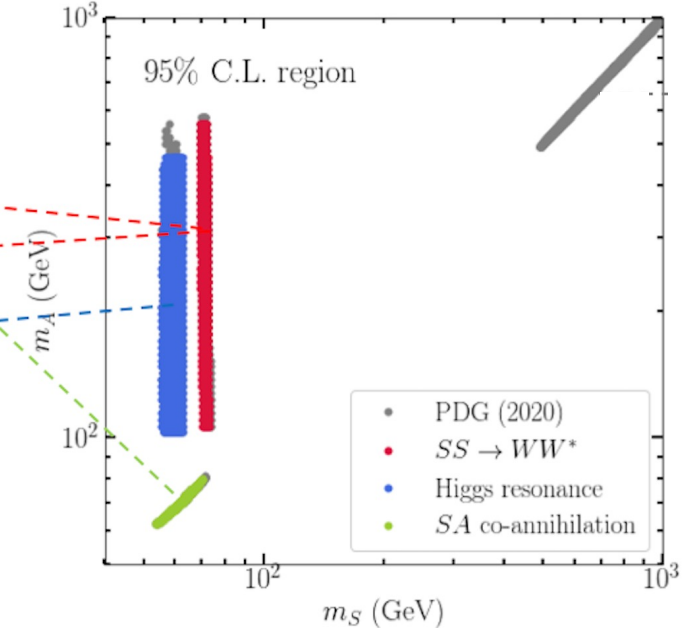
特点：质量谱范围大

对撞机：(1)简并质量谱将被Run-3 LHC验证；(2)检验GCE、反质子超出参数空间超将成为LHC重要目标

间接探测：验证GCE、反质子超非来自天体物理背景

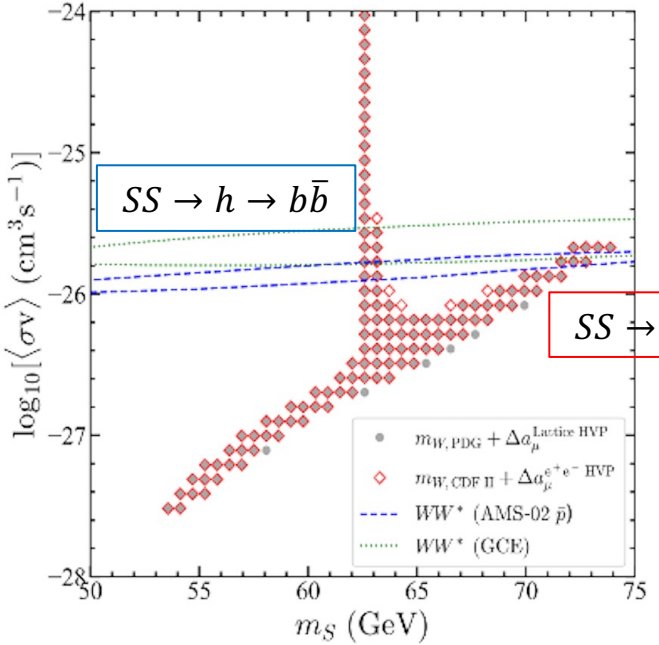
直接探测：暗物质与希格斯耦合参数探索，圈图重要贡献

引力波：填补对势能结构的探测缺乏



Y.Z. Fan, Y.Y. Li, **CT Lu**, X.Y. Luo, T.P. Tang, V.Q. Tran and Y.L.S. Tsai
Y.C. Guo, Y.X. Li and **CT Lu**

间接探测：验证银心光子超、反质子超



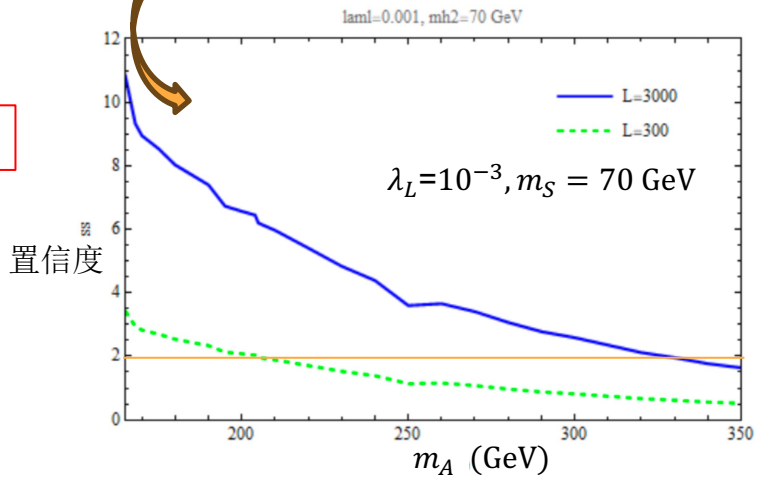
Mono-W,

Mono-Z

$pp \to W^{\pm}SS, \quad W^{\pm} \to l^{\pm}\nu$

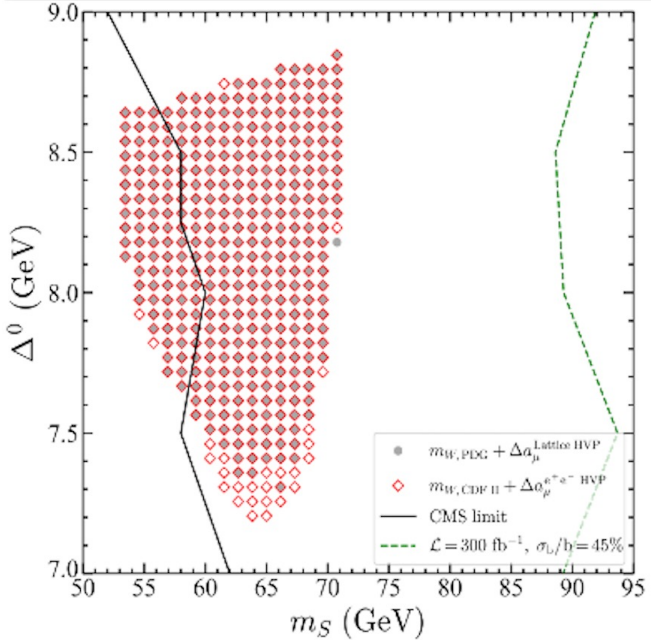
$pp \to W^{\pm}SS, \quad W^{\pm} \to jj'$
$pp \to ZSS, \quad Z \to jj$

$pp \to ZSS, \quad Z \to l^+\, l^-$

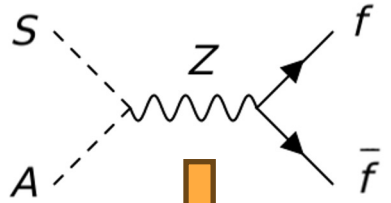


Y.Z. Fan, Y.Y. Li, **CT Lu**, X.Y. Luo, T.P. Tang, V.Q. Tran and Y.L.S. Tsai
Y.L.S. Tsai, **CT Lu** and V.Q. Tran

对撞机：简并质量谱将被Run-3 LHC验证



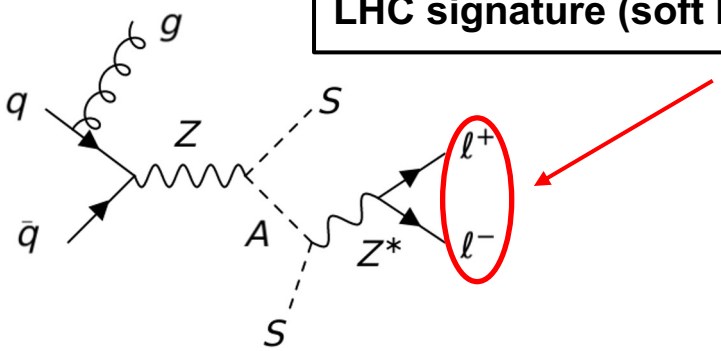
Co-annihilation



$SA \to f\bar{f}$ for a small Δ^0.

$\Delta^0 = m_A - m_S$

LHC signature (soft leptons)

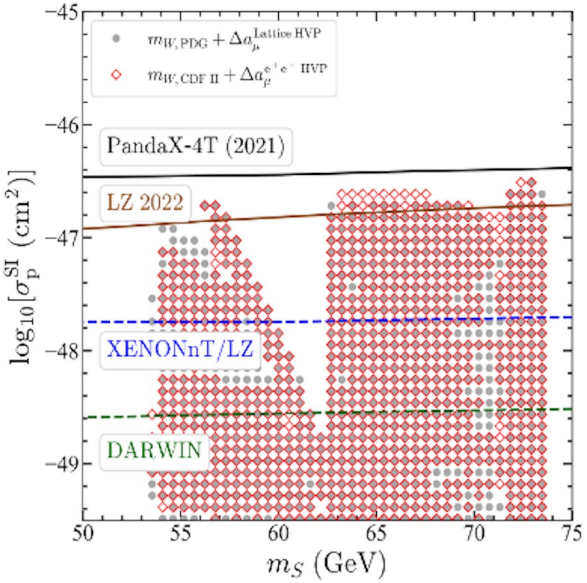


Y.Z. Fan, Y.Y. Li, **CT Lu**, X.Y. Luo, T.P. Tang, V.Q. Tran and Y.L.S. Tsai

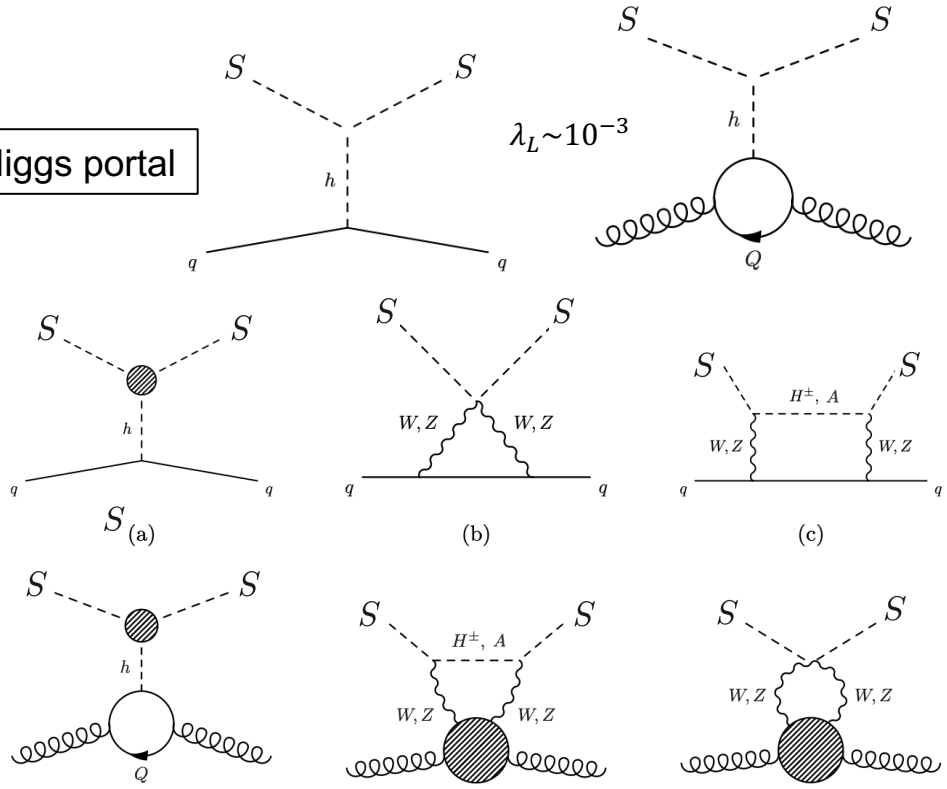
Y.L.S. Tsai, **CT Lu** and V.Q. Tran

T. Abe and R. Sato, *JHEP* 03 (2015) 109

直接探测：暗物质与希格斯耦合参数探索，圈图重要贡献

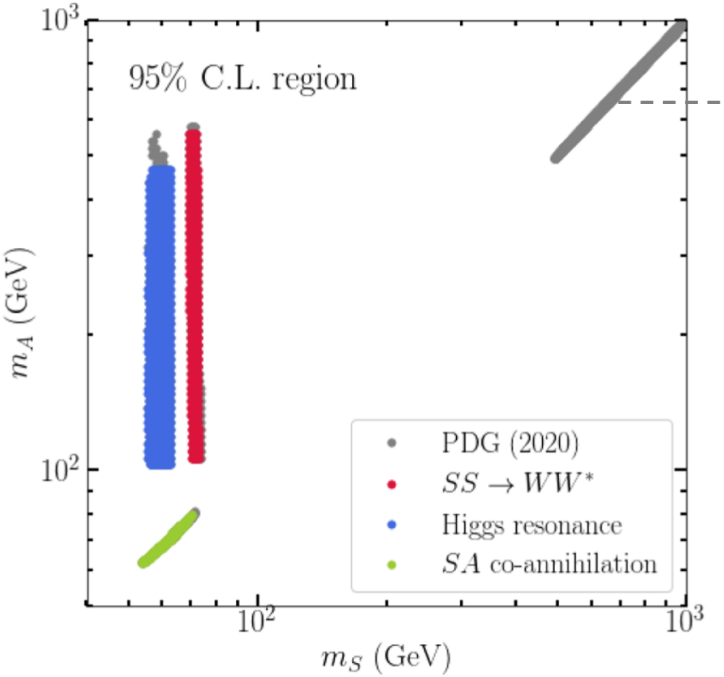


Higgs portal



Y.Z. Fan, T.P. Tang, Y.L.S. Tsai and L. Wu

Phys.Rev.Lett. 129 (2022) 9, 091802



重暗物质区（> 500 GeV）

特点：简并质量谱

对撞机：高能缪子对撞机将克服LHC的局限性

间接探测：电弱规范玻色子末态信号

直接探测：暗物质与希格斯耦合参数探索，圈图重要贡献

引力波：填补对势能结构的探测缺乏

结论与展望

- 惰性希格斯二重态模型是WIMP暗物质的经典代表，模型简单却具有丰富唯象学内容，分为轻暗物质区（55-75 GeV）与重暗物质区（> 500 GeV）。
- 轻暗物质区：

(1) $SS \to WW^*$: 银心光子超、反质子超，HL-LHC mono-W, mono-Z验证；

(2) SA coannihlation: 预期通过Run-3 LHC搜寻soft leptons完全验证该参数空间；

(3) Higgs resonance: 银心光子超、反质子超，暗物质与核子散射过程圈图修正效应的重要性。

- 重暗物质区：TeV质量暗物质探测是未来重要方向， 所有暗区粒子$S, A, H^{\pm}$质量接近，增加探测难度，**高能缪子对撞机**与**契忍可夫望遠鏡陣列**将发挥关键作用。

Thank you
for your attention